



UNITED STATES

EXPLORING EXPEDITION.

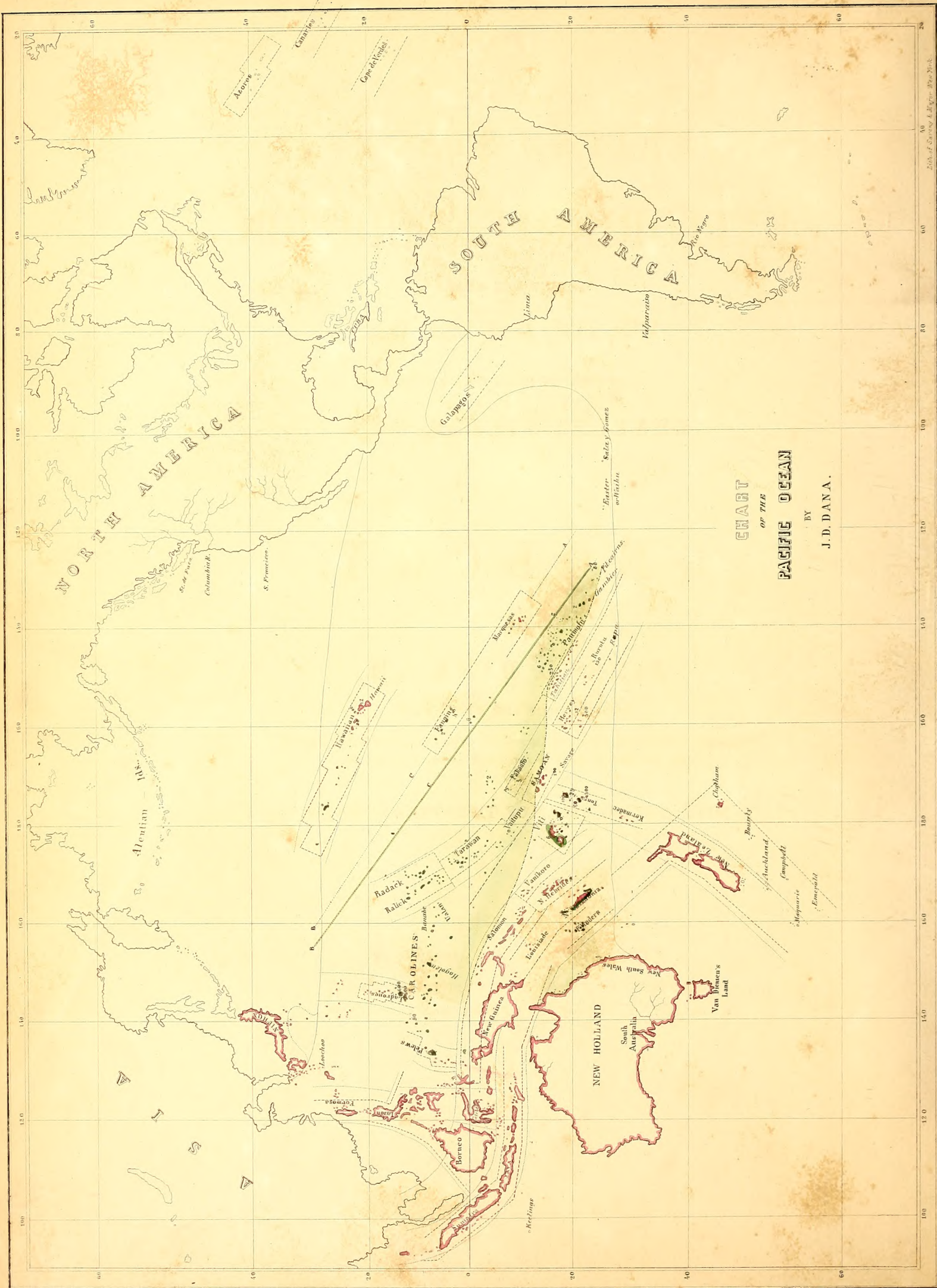


CHART
OF THE
PACIFIC OCEAN
BY
J. D. DANA.

Scale of Survey A. D. 1845. New York.

f DE
350.4
D16g
1840
text
NH

UNITED STATES
EXPLORING EXPEDITION.

DURING THE YEARS

1838, 1839, 1840, 1841, 1842.

V. 10 Text

UNDER THE COMMAND OF

CHARLES WILKES, U. S. N.

G E O L O G Y.

BY

JAMES D. DANA, A. M.,

GEOLOGIST OF THE EXPEDITION,

MEMBER OF THE SOC. CÉS. NAT. CUR. OF MOSCOW, THE SOC. PHILOMATHIQUE OF PARIS,
THE AMERICAN ACADEMY OF ARTS AND SCIENCES AT BOSTON, ETC.

WITH A FOLIO ATLAS OF TWENTY-ONE PLATES.

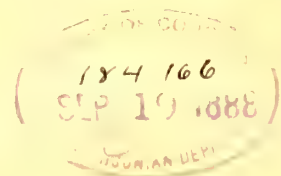
Wanting

NEW YORK:

GEO. P. PUTNAM, 155 BROADWAY.

LONDON: PUTNAM'S AMERICAN AGENCY,

49 BOW LANE, CHEAPSIDE.



250
100
100

TABLE OF CONTENTS.

	PAGE
CHAP. I. General Remarks on the Pacific Ocean, - - - - -	9
Topography, - - - - -	11
General Geological Constitution of Islands, - - - - -	23
Geological agencies, - - - - -	26
 CHAP. II. On Coral Formations, - - - - -	 29
1. Features and Structure, - - - - -	30
General Remarks, - - - - -	30
Fringing and Barrier Reefs, - - - - -	33
Forms, - - - - -	33
Structure, - - - - -	36
Thickness, - - - - -	46
Coral Islands, - - - - -	48
Forms, - - - - -	48
Structure, - - - - -	57
Completed Coral Island, - - - - -	75
2. On Coral Zoophytes, - - - - -	80
Structure and growth, - - - - -	80
Texture and composition of Corals, - - - - -	89
Causes influencing growth, - - - - -	93
Rate of growth, - - - - -	101
3. Formation of Reefs and causes of their features and Geographi- cal Distribution, - - - - -	103
Formation, - - - - -	103
Causes modifying their forms and growth, - - - - -	114
Rate of growth of Reefs, - - - - -	121
Origin of forms of Barrier Reefs and Atolls, - - - - -	123
Geographical Distribution, - - - - -	134
4. Geological Conclusions, - - - - -	147
 CHAP. III. On the Hawaiian Islands, - - - - -	 155
1. Island of Hawaii, - - - - -	158

	PAGE
General Features, - - - - -	158
Volcanoes, - - - - -	168
Mount Loa, - - - - -	168
Kilauea, - - - - -	171
Eruptions, - - - - -	183
General Conclusions, - - - - -	193
Summit Crater of Mount Loa, - - - - -	206
Subordinate Craters of Mount Loa, - - - - -	211
Mount Kea, - - - - -	214
Mount Hualalai, - - - - -	215
General Conclusions on Volcanic Action, - - - - -	216
2. Island of Maui, - - - - -	226
3. Kahoolawe, Lanai, and Molokai, - - - - -	231
4. Island of Oahu, - - - - -	233
General Features, - - - - -	233
Eastern Division, - - - - -	235
Mountains, - - - - -	238
Lateral Craters, - - - - -	240
Western Division, - - - - -	250
Coral Formations, - - - - -	251
General Conclusions, - - - - -	256
5. Island of Kauai, - - - - -	262
General Features, - - - - -	262
Geological Structure, - - - - -	266
Craters of Koloa, - - - - -	271
Coral Formations, - - - - -	275
General Conclusions, - - - - -	278
6. General remarks on the origin of the Hawaiian Group, - - - - -	279
 CHAP. IV. Society Islands, - - - - -	 285
1. Island of Tahiti, - - - - -	286
2. Other Islands of the Group, - - - - -	302
 CHAP. V. Samoan Islands, - - - - -	 307
1. Manua, Ofu, Olosenga, and Rose Islands, - - - - -	309
2. Island of Tutuila, - - - - -	309
3. Island of Upolu, - - - - -	312
General Features, - - - - -	312
Geological Structure, - - - - -	315
Extinct Craters, - - - - -	317
Era of Eruptions and subsequent changes, - - - - -	330
4. Manono, Apolima, Savaii, - - - - -	333
5. Concluding Remarks, - - - - -	335
 CHAP. VI. Viti or Feejee Islands, - - - - -	 337

C O N T E N T S.

vii

	PAGE
CHAP. VII. Pacific Ocean, - - - - -	353
1. General Review of Volcanic Action, - - - - -	353
On Cinder Cones, - - - - -	354
On Tufa Cones, - - - - -	355
On Lava Cones, - - - - -	355
Influence of fluidity of Lavas, - - - - -	358
Influence of Fissure Eruptions, - - - - -	360
Solid Centre of Volcanic Mountains, - - - - -	364
Rapidty of formation, - - - - -	365
Conclusions, with remarks on von Buch's theory of elevation- craters, - - - - -	366
2. Origin of Lithological Characters of Islands, - - - - -	372
3. Origin of Valleys, - - - - -	379
4. Changes of Level, - - - - -	392
Subsidence indicated by Atolls and Barrier Reefs, - - - - -	394
Elevations of modern eras, - - - - -	402
Changes of level preceding Coral Reefs, - - - - -	412
5. General arrangement of lands in the Pacific, - - - - -	414
6. Origin of the general features of the Pacific and of the Globe, - - - - -	424
 CHAP. VIII. On New Zealand, - - - - -	 437
 CHAP. IX. On New South Wales, - - - - -	 449
1. Geological formations, - - - - -	456
2. Sydney Sandstone formation, - - - - -	459
3. Coal formation, - - - - -	469
4. Sandstone strata below the Coal, - - - - -	484
5. Basaltic and allied Rocks, - - - - -	495
6. Circumstances attending the origin of the Deposits, - - - - -	516
7. Degradation and Denudation, - - - - -	526
8. Evidences of Change of Level, - - - - -	533
 CHAP. X. On the Philippine and Sooloo Islands, - - - - -	 539
 CHAP. XI. On Deception Island, - - - - -	 547
 CHAP. XII. On Madeira, - - - - -	 549
 CHAP. XIII. On a part of Chili, - - - - -	 557
1. Granitic Rocks and Veins near Valparaiso, - - - - -	561
2. Greenstone, Basaltic and Porphyritic Rocks, - - - - -	579
3. Sedimentary Rocks, - - - - -	583
 CHAP. XIV. On the vicinity of Lima, Peru, - - - - -	 587
1. Recent deposits of the coast near Callao and on San Lorenzo, - - - - -	588

	PAGE
2. Secondary Rocks of San Lorenzo,	593
3. Rotation by an Earthquake,	599
CHAP. XV. On the vicinity of Nassau Bay, Tierra del Fuego,	601
CHAP. XVI. On the vicinity of Rio Negro,	607
CHAP. XVII. On Oregon and Northern California,	611
1. General Features,	613
2. Geological Structure,	625
Granitic and Associated Rocks,	630
Older Sedimentary Rocks,	638
Basalt and other recent Igneous Rocks,	640
Tertiary Formation,	651
River Terraces and Beach Formations,	659
Causes of Features, and Changes in Elevation,	668
Fiords, evidence of Change of Level,	675
APPENDIX I.—1. Fossils of New South Wales,	681
2. Fossils of Tierra del Fuego and Peru,	720
3. Fossils of Oregon,	722
APPENDIX II.	729
INDEX,	735

ILLUSTRATIONS.*

- Page 31. An island surrounded by coral reefs, barrier and fringing.
33. Clermont Tonnerre, one of the Paumotu Atolls, from a drawing by A. T. Agate.
41. Map of part of the north shore of Tahiti, from Matavai to Papieti, with the reefs of the shore in dotted outline, (spaces included by the dotted lines.) *Point Venus* is the east cape of Matavai Harbour; *One Tree Hill* occupies the west point. Map copied from the chart made by the Expedition.
46. Bluffs of coral sand-rock, north shore of Oahu.
50. Map of the Kingsmill or Tarawan Islands, from the charts of the Expedition.
53. Maps of the Islands Taiara; Henuake, Honden or Dog Island; Swain's Island; Jarvis Island; Fakaafo or Bowditch. From the charts of the Expedition.
58. Section of a coral island reef from the ocean to the lagoon.
61. Figures 1, 2, 3, blocks of coral rock standing on the reefs of coral islands.
91. Figures of crystals of gypsum.
109. View of an island in the Bay of Islands, New Zealand, called "The Old Hat."
115. Harbour of Apia, north side of Upolu, Samoa. From the charts of the Expedition.
117. Harbour of Falifa. Ibid.
118. Whippey Harbour, Viti Lebu; *a*, the entrance through the reef. Ibid.
127. Figure 1.—Section showing the effects of the subsidence of an island surrounded by coral reefs; I, II, III, IV, different water levels; *f, f', f'', f'''*, sections of fringing reefs; *b', b'', b'''*, barrier reefs; *c', c'', c'''*, channels within barrier reefs; *i'''*, islets of coral reef in channel.
- Figure 2. Aiva Island, one of the eastern Feejees, surrounded by a distant barrier.
- Figure 3. Sectional sketch of Aiva Island.
130. Gambier Group, one of the Southern Paumotus.

* From sketches by the author, except when otherwise stated.

- Page 131. Figure 5.—Section showing the effects of subsidence in producing and changing an atoll, a continuation of fig. 1, p. 127; iv, corresponds to iv fig. 1; v, vi, other water levels.
- Figure 6.—Same as figure 5, with the water level at vi; but the emerged reefs widened after a cessation of subsidence.
132. Figure 7.—An island with a barrier reef, in which the reef is widened and surmounted by vegetation, after a cessation of subsidence.
159. Outline view of Mount Loa and Mount Kea, showing angle of slope.
169. Part of Eastern Hawaii.
173. Kilauea, as seen from above; from a sketch in the Narrative of the Expedition, iv. 165.
174. Vertical cross section of Kilauea.
177. Spire of lava seen in Kilauea; height forty feet.
185. View of part of Kilauea, by Lieut. Malden; taken in 1825.
190. Sandhills of Nanawale.
206. Summit crater of Mount Loa, as seen from above; from a sketch in the Narrative of the Expedition, iv. 111.
219. Section of Mount Loa, showing its actual slopes, and an ideal view of the central conduit of the mountain, and that of Kilauea.
220. Diagram, illustrating a probable convergence of the two conduits.
226. Island of Maui, in outline.
228. Crater of Hale-a-kala, from a drawing by Mr. J. Drayton. See Narrative of the Expedition, iv. 254.
229. Part of southeast side of Maui, showing course of last great eruption of the crater.
232. Outlines of Kahoolawe, Molokai and Lanai.
Island of Kahoolawe.
236. Part of the Koolau Precipice, as seen from the north, with the peak Kona-huanui, and the "Pali" or precipice at the head of the valley of Nuuanu to the west of the peak.
240. The Tufa Crater, Diamond Hill, on Southern Oahu.
241. Diamond Hill and the small crater at the foot of the mountains.
242. Koko Head craters; a bird's eye view, a little oblique.
243. Koko Head craters, as seen looking west.
244. Koko Head craters, seen from the east.
245. Map of salt-lake region, Oahu.
246. View of bluffs enclosing salt-lake region, as seen from Honolulu harbour.
248. Map of Kaneohe Point, with its craters.
249. Outline of crater of Kaneohe Point, as seen from the northwest, with a separate view of the large crater on the point.
253. Isolated mass of coral rock rising from the reef of Waialua.
254. Bluffs of drift sand-rock, northern Oahu, near Kahuku Point.
255. Figures 1, 2, 3, sections of drift sand-rock, showing the character of the lamination.
271. Map of craters of Koloa, Kauai. At the projecting point, on the left, is the site of the bluff of drift sand-rock, figured on page 277.

- Page 272. View of craters of Koloa, taken from the bluff of drift sand-rock. There is much less vegetation in the scene than the view presents.
277. Bluff of drift sand-rock.
283. Map, illustrating origin of Hawaiian Group.
285. Outline view of island of Eimeo, Society Group.
297. Curved columnar structure in basalt, on Tahiti.
307. Map of the Samoan or Navigator Islands, from the charts of the Expedition.
318. Crater of Tafua, Upolu, near Fasetootai.
319. Outline of western district of Upolu, as seen at sea, off Apia, north of the island.
325. Figure 1.—Outline of eastern district, as seen from the northwest.
- Figure 2.—Ibid., as seen from the southeast; A, crater of Olomanga; B, Fanga-ganga; C, D, E, summits of other craters.
327. Tufa crater, on island of Nuutele, as seen from the northwest and southeast.
334. Outline of Savaii, as seen from the southeast, with Apolima (*a*), and Manono (*b*), in front of Savaii. Figure 2, north extremity, more enlarged.
354. Outline of Assumption Island, one of the northern Ladrões, showing its actual slopes.
388. Diagram, illustrating the valleys of Tahiti.
442. Island "Old Hat," in the Bay of Islands, New Zealand.
443. "The Black Rocks," Bay of Islands.
444. Extinct crater of Poerua.
459. East and west section through Illawarra, from the sea-port Wollongong.
462. Section, showing structure of Sydney sandstone.
463. Ibid.
464. Ibid.
465. Concentric structure in the Sydney sandstone, in the Illawarra range.
467. View of the North and South Heads of Port Jackson, N. S. W., the former in the distance; taken from the South Head, looking north; shows rectangular fissures of sandstone layer at the water level.
471. View of the island Nobby, and Telegraph Hill at Newcastle, at the mouth of the Hunter; taken from the westward.
477. Diagrams, illustrating faults in the Newcastle coal beds.
480. Sandstone intersected by walls of ironstone.
481. Prismatic calcareous concretions from Glendon.
484. Sketch of a silicified stump, Illawarra.
486. Concentric structure and fissures in sandstone at Wollongong, Illawarra.
487. Ibid.
496. Basaltic columns, near Kiama, Illawarra.
497. Entrance of the Kiama Blow-hole.
500. Figures 1, 2, 3, 4, 5, 6, views of cliffs, showing the relative positions of basaltic layers and sandstone.
502. Figures 7, 8, 9, 10, connexion of basalt and basaltic conglomerate. Figure 9, same as dike No. 17, page 505.
503. Map sketch of jaspery seams in basaltic conglomerate.
506. Dike of basalt, near Wollongong.

- Page 507. Figures 2, 3, 4, 5, basaltic dikes in Illawarra, much faulted.
 Figure 2. Dike in second cliff south of Kiama, (same as No. 18, page 506.)
 Figure 3. Dike near Kiama Blow-hole, (No. 16, page 505.)
 Figure 4, dike in second cliff north of Kiama (No. 10 on page 505); slide two feet.
 Figure 5. Dike in same cliff, (No. 6 on page 505.)
508. View of basaltic rocks, second point north of Kiama.
 Curved columns, as seen looking from above obliquely; from shores south of Kiama.
510. Sketch showing structure of a basaltic dike.
 511. View of part of island of Nobby, intersected by a basaltic dike.
 513. Nodules of chalcedony in the basalt of Kiama, having an ear-drop shape.
 515. From a quarry of basalt, at Prospect Hill, near Paramatta.
 531. Diagram, illustrating the formation of valleys.
 534. Outline of beaches in Illawarra.
 553. Figures 1, 2, 3, basaltic cliffs, intersected by dikes, near Caniçal, island of Madeira.
 562. Sketches of veins and beds of hornblendic rock in granite, near Valparaiso.
 563. Ibid.
 567. Epidotic seams in granite, near Valparaiso.
 568. Figures 6, 7, views of two compound granitic veins in gneissoid granite, with the direction of the micaceous structure of the adjoining or included rock indicated.
 569. Figure 8, another view of same veins.
 570. Figure 9, a striped vein in granite.
 572. Figures 10, 11, 12, 13, faulted veins of granite.
 573. Figures 14, 15, 16, faulted veins of granite.
 574. Figure 17, faulted vein of granite.
 589. Figures 1, 2, crystals of gypsum, from the Callao cliffs, Peru.
 594. Figures 1, 2, sections of San Lorenzo beds.
 599. Entrance of "El Paseo de los Agoas," Lima, showing the upper stones of the obelisk as revolved by an earthquake; sketch by J. Drayton.
644. Mount Swalalahos or Saddle Hill, Oregon.
 649. Figures 1, 2, views of the Sacramento Bute.
 650. Bluff of laminated trachyte, Sacramento Bute.
 655. Dikes of sandstone intersecting tertiary rocks, Oregon.
 657. Figures 1, 2, calcareous crystallizations from concretions, Oregon.
 660. Figure 1, section of the alluvial plain of the Willammet.
 662. Figure 2, section showing terraces on the Umpqua.
 Figures 3, 4, sections illustrating terraces on the Shasty.
 663. Figures 5, 6, 7, 8, sections illustrating terraces on the Sacramento.

G E O L O G Y.

CHAPTER I.

GENERAL REMARKS ON THE ISLANDS OF THE PACIFIC OCEAN.

THE Pacific Ocean, between the coast of America on the one side, and Asia, the East Indies and New Holland on the other; Behring's Straits on the north, and the parallel of 66° south, covers more than sixty-two millions of square miles, and exceeds by ten millions of square miles the area of all the continents and islands of the globe.* About six hundred and seventy-five islands are scattered over this expanse of waters: but though so great their number, the surface of the whole, exclusive of New Zealand, does not exceed eighty thousand square miles, an extent little beyond New Zealand alone. Excepting also from the estimate New Caledonia, the Salomon Group, and other large islands in the southeast part of the ocean, lying between them and New Guinea, there are but forty thousand square miles, (less than the State of New York,) for the six hundred islands remaining.

* The fact above stated is deduced from the calculation of S. P. Rigaud on the "Relative Quantities of Land and Water on the Terraqueous Globe," in the Transactions of the Cambridge Philosophical Society, (England,) vol. vi., 1837, p. 289. From his results we learn that out of a thousand parts, into which he divides the world, there are contained in the Pacific Ocean, in

The North temperate zone,	-	-	-	-	72·3793 parts.
The North torrid zone,	-	-	-	-	70·8383 "
The South torrid zone,	-	-	-	-	77·0000 nearly.
The South temperate zone	-	-	-	-	95·9685 parts.
The whole Pacific Ocean contains	-	-	-	-	316·1861 "
The land of the world amounts to	-	-	-	-	265·9233 "

Yet this small area of land presents us with mountains 14,000 feet in height; volcanoes of unrivalled magnitude; peaks, crags and gorges of Alpine boldness. And amid the wildness and grandeur of these scenes, many of which would well aid our conceptions of a world in ruins, the palm, the tree-fern, and other tropical productions flourish with singular luxuriance. Zoophytes, moreover, spread the sea-bottom near the shores with flowers, and form islands with groves of verdure above, and coral gardens beneath the water. There is no part of the world where rocks, waterfalls and foliage are displayed in greater variety, or where the sublime and picturesque mingle in stranger combinations.

These statements may seem incredible to those who have traversed only the surface of our own land; yet it will be in some degree comprehended when the agencies that have operated to produce the results are considered:—that through every part there has been the volcano to build up mountains, and to shatter again its structures; a vast ocean to surge against exposed shores; rapid declivities to give force to descending torrents; besides a climate to favour the coral shrubbery of the ocean, and bury in foliage the most craggy steps. Under such circumstances, it is not surprising that these ocean lands should be replete with attractions alike to the eye of taste and of science.

The waters abound in fish, mollusks, echini, crabs and other forms of crustacea, asterias or starfish, and the variously coloured actinias or sea-flowers; and the fresh waters, although the islands stand isolated in the ocean, have their own species of fish, reptiles, and even Unionidæ. Yet with all the profuseness of life, animal and vegetable, it is a little remarkable that, besides bats, a native land quadruped is not known in the whole ocean, though rats and mice from shipping are common everywhere. New Zealand, although as large as New England, cannot boast of a single native species, excepting perhaps a mouse of doubtful origin, and bats which have wings to aid them in migration.

It is obvious that the geology of the Pacific Islands embraces topics of the widest importance. There are extensive rock formations in progress, proceeding from the waters through the agency of animal life;—there are other formations, exemplifying on a vast scale the operation of igneous causes in modifying the earth's surface;—there are also examples of denudation and disruption, commensurate with the magnitude of the mountain elevations. These three great sources of change and progress in the earth's history are abundantly illustrated.

In our report on these topics, we may adopt the following order of arrangement:—

Chap. I.—A general review of the topography of the Pacific Ocean, and the constitution of its islands.

Chap. II.—An account of coral reefs and islands, and of their mode of formation.

Chap. III.—General remarks on the basaltic or igneous islands of the Pacific.

Chap. IV—VII.—Geological descriptions of the groups of Pacific Islands, in the following order:—Hawaiian, Tahitian or Society, Samoan or Navigator's, and the Feejee Group.

Chap. VIII.—General considerations respecting the Pacific.

1. General review of volcanic action in the Pacific.
2. Mineral constitution of the basaltic islands.
3. Origin of the valleys of the islands.
4. Changes of level in the Pacific.
5. General arrangement of land in the Pacific.
6. Origin of the general features of the Pacific, and bearing of the facts upon the cause of the prominent features of the globe.

I. TOPOGRAPHY OF THE OCEAN AND CONSTITUTION OF ITS ISLANDS.

1. *Geographical Distribution of the Islands.**

Reviewing the ocean simply with reference to the relative position of land and water, we observe the striking fact that the islands are

* It is important to the reader to be acquainted with the ethnographic distribution of islands in the Pacific; and we here give a brief notice of it, gathered from the Report on Ethnography, by our philologist, Mr. Horatio Hale.

The Pacific is divided into three large regions:—1, Polynesia; 2, Melanesia; and 3, Micronesia.

The *first* division, *Polynesia*, includes all the islands of the middle and eastern parts of the ocean, comprising the Sandwich Islands on the north, New Zealand on the south, and the various clusters intermediate, with all the islands eastward of the same to the farthest limits of the Paumotu Archipelago. The groups included (see the chart) are as follows:—*North of the equator*, the Hawaiian; *south of the equator*, the Nukuhivan or Marquesas, the Paumotu, Tahitian or Society, Atiu or Hervey, Samoan or Navigator,

confined, with few exceptions, to the latitudes within the tropical circles, 23 degrees 28 minutes either side of the equator. New Zealand and a few associates on the south, and some small points northwest of the Hawaiian groups, are almost alone in exceeding these limits.

A second fact, not less worthy of note, is found in the absence of islands, excepting an occasional one of small size, eight or ten in all, from the vicinity of the equator, between the Galapagos and the Carolines. This range of bare waters is more than 6000 miles long, or one-fourth the whole circumference of the globe; and it extends from five degrees south of the equator, to Hawaii, in latitude 19 degrees north.

The large area between the South American coast and the Paumotu, a distance of three thousand miles, is another wide blank in the Pacific, and we may view it as continuing westward with the same width, between the south tropical and antarctic circles. The newly discovered lands of the antarctic, extensively explored by the Expedition, under the direction of its energetic commander, form the southern boundary of this open sea.

These facts are left for the present with this mere mention. They have a bearing on the geological history and dynamics of the ocean, which will be considered in a future chapter.

Arrangement of the groups of islands.—The epithet *scattered*, as applied to the islands of the ocean, conveys a very incorrect idea of their positions. There is a system in their arrangement, as regular as in the mountain heights of a continent; and ranges of elevations are indicated, as grand and extensive as any continent presents. Even a cursory glance at a map is sufficient to discover a general linear course in the groups, (as was long since remarked by Malte Brun and other geographers,) and a parallelism even between those in distant parts of the ocean. Thus the Hawaiian Islands stretch

Fakaafo or Union, Phoenix, Vaitupu or Ellice's, Tongan or Friendly, and New Zealand. The Feejee Group is intermediate, philologically, between Melanesia and Polynesia.

The *second* division, *Melanesia*, embraces the islands within twelve degrees of the northeast coast of New Holland. Starting from New Guinea, to which they are related, the groups are as follows:—Admiralty, New Britain, New Ireland, Salomon, Vanikoro, New Hebrides, New Caledonia, and Flinden's Archipelago, together with many small islands distributed over the included area.

The *third* division, *Micronesia*, comprises the Carolines, extending west and north to embrace the Pelews, the Ladrões, and some scattered islands beyond, and east and south to include the Radack, Ralick, and Tarawan or Kingsmill groups.

along in a direct line to the northwest. The Marquesas also are mostly in a single range. The Tahitian Group, the Samoan, the Tongan, New Hebrides, New Caledonia, Salomon Islands, Radaek and Ralick Islands, the Kingsmills, and the Ladrones are all distinctly linear groups. As this subject is one of both geographical and geological interest, and has been but imperfectly discussed in previous works, we pass in review the principal facts respecting the several groups of islands: and it will appear that its importance is not limited even by the Pacific Ocean, although nearly one-third of the whole surface of the globe; for it has an evident connexion with a system that pervades the world.

The facts and any irregularities will be more correctly appreciated if the reader will first consider, with regard to ranges of mountains, that their courses often vary many degrees, even when a general linear direction is distinct. An exactly straight line is nowhere to be found, not even in a single ridge of a chain. This is apparent in any good map of the world. The peaks advance and retreat all along the line, and occasionally the mountains sweep around into some new direction, and then return again, more or less nearly, to their former course. Again we observe that there are often parallel ranges in the same chain, as is strikingly seen in the Alps, the Andes, and our own Alleghanies.

The characters of fissures, or dikes, afford other hints that should be considered; for they illustrate the operation of those internal forces, by which mountains have been uplifted; and even exemplify, as is generally admitted, the actual origin of many ranges of mountains. Facts illustrating this subject will be found in our descriptions of the Pacific Islands, and the Report on Eastern Australia. They show that fissures are generally a series of linear rents in some main direction, and while they are often parallel, or in continued series, they are also sometimes arranged in a series of overlapping lines, and may be curved or straight in the separate rents, as well as curved or straight in the long composite ranges of rents.* They are often accompanied by transverse rents, at right angles with the general system.

The several groups of islands may be considered in succession.

a. *Hawaiian Islands*.—The Hawaiian Islands proper, extend from Hawaii to Nihau, (see preceding map,) a distance of four hundred

* See American Journal of Science, iii. 2d Ser. p. 390.

statute miles, and have the general trend N. 64° W. But the range of islands does not stop at the last mentioned: it is continued on to 175° east longitude. This western portion appears to consist of two or three parts, each in advance, or a little south, of the preceding, like the interrupted series of many fissures. The directions of the parts scarcely vary from that above given. Viewing the range as a whole, the line is slightly convex northeastward.

We observe, moreover, that between the Island of Hawaii and Oahu, two parallel lines are indicated by the islands intermediate: one including the summits Maui and Molokai, with Mouna Kea on Hawaii; the other the islands Lanai and Kahoolawe, together with Mouna Hualalai and Mouna Loa on Hawaii, and the crater Kilauea.

A *transverse* trend is apparent in the relative situation of Nihau and Kauai, ranging nearly at right angles with the course of the group.

b. *Nukuhivan Group*.—The Nukuhivan or Marquesas Group lies in a parallel line with the Hawaiian. As nearly as can be estimated, the trend is N. 60° W.

Following the line of this range on beyond the equator, we observe four small islands (the Fanning Group), lying in a single series nearly straight, and having the same trend. Although we may not assume any connexion between the Fanning and Nukuhivan Groups, the coincidence of range, as well as trend, is worthy of remark.

c. *Paumotu Archipelago*.—Among the many islands which constitute this archipelago, there is no difficulty in distinguishing a general course from the northward and westward to the southward and eastward, approaching N. 60° W. Even in the separate islands, the prevailing trend is approximately the same as may be seen in the enlarged chart in the Hydrographical Atlas.* From Kruesenstern's and Dean's Islands on the northwest, the atolls stretch along over the sea towards the Gambier or Mangareva Group; and this spot of high land, and Pitcairn's beyond, with some other low islets, lie near its eastern extremity.

d. *Tahitian Group*.—The Tahitian or Society Group, and also the Island of Tahiti itself, conform nearly to the direction of the Paumotus, the trend being about N. 62° W. In the line of the group, to the eastward and southward, there are several islets, lying in a series,

* See also the Narrative of the Exploring Expedition, by C. Wilkes, vol. i.

and others still beyond, which extend the line to longitude 136° W. There is little doubt that the whole should be included in one system or range.

e. *Atiu or Hervey Group*.—South and west of Tahiti lie a number of small islands, the western of which have been called the Hervey Group. Like the preceding groups, they range from the northwestward to the southeastward. They constitute two parallel lines; the northern contains Aitutaki, Atiu, and other Hervey Islands, and extends eastward to Rurutu and Raivavai, with the trend N. 66° W.; the southern embraces Rarotonga, Roxburgh, and Mangaia, and may possibly be continued in Osborn's Reef and Rapa, with the trend N. 65° W.

f. *Samoa or Navigator Group*.—The same linear arrangement is apparent among the Samoas as elsewhere in the ocean. The trend is a little more westerly, or N. 68° W. The easternmost islands give a still more nearly east and west course to that extremity of the line. But examined on an enlarged chart,* it is obvious that Ofu, Manua, and Rose Island constitute properly a parallel line, of like trend with the three western, and in analogy with the interrupted parallel lines of fissures already explained.

g. *Fakaafo or Union Group*.—North of Samoa two hundred and sixty miles, are three small islands, which lie so exactly in a direct line, that they merit separate mention. The trend is N. 58° W.

h. *Vaitupu or Ellice's Group*.—To the west of Fakaafo lie seven or eight small islands, constituting a line of which the general trend is N. 56° W.

i. *Tarawan or Kingsmill Group*.—The Tarawan Islands lie under the equator, just to the north of the last-mentioned group. From Taputeouea, the southernmost, to Maiana (see chart beyond), the trend of the range, as well as of the separate islands, is N. 42° W.; and this line will embrace the two islands Onoutu and Hurd, one hundred to one hundred and fifty miles further to the southeast. The islands Hopper, Knox, Charlotte, lie in a line nearly parallel, a little to the eastward; and Peru and Byron's Islands, one hundred and fifty miles to the southeast, have the same direction and a corresponding position. The Tarawan Group, taken as a whole, trends N. 25° W.

j. *Marshall Islands, or Radaek and Ralick Groups*.—The linear arrangement in the Radaek and Ralick Groups is as distinct as in any

* See the chapter on the Samoan Islands.

part of the ocean. The trend of the former, the easternmost, is N. 30° W.; and that of the latter N. 37° W.

k. *New Hebrides*.—The New Hebrides constitute a long range, trending N. 40° W.

l. *New Caledonia*.—New Caledonia, with its reefs, extends in a similar line, running N. 40° W. There is a distinct line of islands, parallel with New Caledonia, a little to the westward: the Isle of Pines appears to constitute its southeastern termination. On the west of New Caledonia there is another line, the Flinders range, having the same course, or N. 45° W.

m. *Salomon Islands, to New Guinea*.—A linear order and form is nowhere in the ocean more remarkable than in this southwestern part. The Salomon Islands trend N. 57° W. The continuation of the line in New Ireland becomes more westerly, or N. 65° W. The Louisiade Group and the north shores of New Guinea correspond to another range running in the same direction, and also approximating westward, more to an east and west direction.

Just east of the Salomon Islands lies the range of Vanikoro, which trends nearly with the New Hebrides, or N. 44° W.

Thus far in the ocean we have observed only a northwestward and southeastward trend, excepting some subordinate lines. A transverse direction characterizes the following groups.

n. *Tonga or Friendly Group*.—The line of islands from Tongatabu to Vavau trends N. 20° E. to N. 24° E.

o. *Kermadec Isles*.—The Kermadec Isles form a line between Tonga and New Zealand, trending N. 15° E.

p. *New Zealand*.—The northern extremity of New Zealand—the foot of the boot—corresponds in direction with the generality of the Pacific Islands, trending N. 50° W. But the body of the group ranges in a transverse direction, with a course of N. 30° E. Lord Auckland's and Macquarie Island, to the southward, are in the same line. Chatham Island lies in a line with the north part of the island.

q. *Ladrones*.—The southern half of this long series of islands trends N. 22° E.; but to the northward the direction approaches more nearly to north and south. The line, taken as a whole, is slightly curved, with the convexity eastward, and extends in the general direction N. 10° E.

r. *Pelew Group*.—The Pelews seem to connect the Ladrones with the Moluccas; but there is evidence in the positions of the islands that at least two parallel ranges are here included; the Matelotes,

Yap, and Hunter forming one line, having the same trend with the southern extremity of the Ladrões, or about N. 22° E.; and the Pelews, with perhaps the islands to the southward, to Aiou, another line ranging N. 25° E.

s. *Feejee Islands*.—The Feejee Islands constitute a large cluster of scattered islands; but amid the apparent irregularity we observe a fact, which we shall hereafter show to be of much interest, that the easternmost islands range parallel with the Tonga Group, or N. 23° E., while on the west the two large islands constitute a line running N. 40° E.

The linear arrangement thus traced out over the ocean, and marked out by lines on the preceding map of the Pacific, is more distinctly apparent the larger the chart or globe on which it is observed; and any appearance of hypothesis which the reader might suspect from the study of a small map will wholly disappear on the examination of one of sufficient size to exhibit the exact positions and forms of the islands. The enlarged charts of the several groups illustrating this volume, evince clearly this fact. We shall further consider in another place certain particulars to be derived from a more minute study of the positions of islands in particular groups. The facts detailed show certainly a most remarkable uniformity of direction. Running parallel, or nearly so, with the Sandwich Islands, we observe the Fanning Group, the Marquesan, Paumotu, Tahitian, Atiu, Samoan, Salomon, New Hebrides, New Caledonia, Vanikoro, Vaitupu, Kingsmills, Radack and Ralick Groups. Nearly every island of the ocean, over an area whose breadth is five thousand miles from north to south, may be shown to conform to this system, excepting a few groups pointed out as characterized by a transverse trend. The facts brought forward are here presented in a tabular form for the convenience of comparison and future reference.

1. *Northwestward trend.*

Hawaiian Group	-	-	-	trends	-	-	-	N. 64° W.
Nukuhivan	-	-	-	"	-	-	-	N. 60° W.
Fanning's	-	-	-	"	-	-	-	N. 60° W.
Paumotu	-	-	-	"	-	-	-	N. 60° W.
Tahitian	-	-	-	"	-	-	-	N. 62° W.
Atiu—Atiu line	-	-	-	"	-	-	-	N. 66° W.
Rarotonga line	-	-	-	"	-	-	-	N. 65° W.
Samoa	-	-	-	"	-	-	-	N. 68° W.
Fakaafo	-	-	-	"	-	-	-	N. 58° W.

Vaitupu	-	-	-	-	trends	-	-	-	N. 56° W.
Tarawan	-	-	-	-	"	-	-	-	N. 42° W. to N. 25° W.
Marshall—Ralick line	-	-	-	-	"	-	-	-	N. 37° W.
Radack line	-	-	-	-	"	-	-	-	N. 30° W.
Vanikoro	-	-	-	-	"	-	-	-	N. 44° W.
New Hebrides	-	-	-	-	"	-	-	-	N. 40° W.
Britannia	-	-	-	-	"	-	-	-	N. 40° W.
New Caledonia	-	-	-	-	"	-	-	-	N. 40° W.
Flinders	-	-	-	-	"	-	-	-	N. 45° W.
North extremity of New Zealand	-	-	-	-	"	-	-	-	N. 50° W.
Salomon Islands	-	-	-	-	"	-	-	-	N. 57° W.
Louisiade to New Guinea	-	-	-	-	"	-	-	-	N. 56° W.
New Ireland	-	-	-	-	"	-	-	-	N. 65° W.
2. <i>Northeastward trend.</i>									
Tonga Group	-	-	-	-	"	-	-	-	N. 22° E.
Feejees, Eastern side	-	-	-	-	"	-	-	-	N. 23° E.
Western side	-	-	-	-	"	-	-	-	N. 40° E.
Kermadec Group	-	-	-	-	"	-	-	-	N. 15° E.
New Zealand	-	-	-	-	"	-	-	-	N. 30° E.
Ladrones	-	-	-	-	"	-	-	-	N. 22° E. to N. 10° E.
Pelew Group	-	-	-	-	"	-	-	-	N. 22° E. to N. 25° E.

Surveying the Pacific Ocean, we distinguish not only a prevailing northwesterly or southeasterly trend in the separate groups; but the collection of islands, viewed as a whole, stretch off from the Asiatic continent in the same direction. The relation of the New Hebrides and Salomon Islands to New Guinea is scarcely more apparent than that of this vast oceanic archipelago to lands of the northwest. We see further that this grand system of island ranges is bounded on either side by continent ranges having the same direction; for on one side lies the coast of Mexico and California, with mountains trending nearly parallel with the Hawaiian Islands, and on the other the coast of New Holland, trending in the same direction.*

But this view of the topography of the ocean may be much simplified by a closer attention to the relations of the several groups. We may thus refer all the different lines to a few grand chains traversing the ocean. They are as follows:—

* The trend of the south shore of Gulf Carpentaria, and the same line continued along the eastern coast to the east Cape of Australia, is parallel with that of the line by the Salomon Islands and New Hebrides or New Caledonia. The prolongation of the north Cape gives the whole northeast shore a more northerly course than correctly represents the system in Australia.

I. **THE HAWAIIAN CHAIN.**—This chain extends northeastward from Hawaii to 175° east longitude, and has a length of about 2000 statute miles.

II. **NUKUHIVAN CHAIN.**—If the Fanning Group may properly be associated with the Marquesas, the whole length of this chain is 1500 miles.

III. **PAUMOTU CHAIN.**—Reckoning from Lazaroff at the northwest, to Ducie's at the southeast, this chain extends over twenty-five degrees of longitude, and is 1500 miles long. It is of some interest to observe that nearly in the same line, fifteen degrees, or about 1000 miles farther east, lies Waihu, or Easter Island, and four degrees beyond Sala-y-Gomez.

IV. **TAHITIAN CHAIN.**—The Tahitian Islands appear to continue as far eastward as St. Juan Baptista, making a length of 1500 miles.

It would perhaps be more correct to consider the Paumotu and Tahitian Islands as separate and parallel ranges of the same chain.

V. **SAMOAN CHAIN.**—The Samoan chain is prolonged southeastward through the Atiu or Hervey Group to Raivavai and Rapa, and northward and westward by Vaitupu, Tarawa, to the Marshall Groups. It is therefore the great back-bone or central chain of the Pacific, and is about 3800 miles long. Nearly the same extent is given the chain by Malte Brun. The Atiu and Raratonga lines appear as parallel spurs or subdivisions at the eastern extremity, and the Radack and Ralick Groups similar parallel lines at the northwest extremity.

VI. **SALOMON CHAIN.**—The Salomon Islands and New Hebrides form a single line, which is continued southeastward to Matthew's Rock, in latitude $23^{\circ} 3'$, and westward to the Admiralty Islands, a distance of about 2000 miles.

VII. **NEW CALEDONIA CHAIN.**—New Caledonia, and the Louisiade Group, make a line 1200 miles in length; and this is continued westward by the north side of New Guinea. The Britannia line, northeast of New Caledonia, is a parallel range.

Malte Brun unites New Guinea with the north of New Zealand, through the Salomon Islands and New Caledonia, as one grand compound range. We may, however, with much appearance of propriety, consider this part of New Zealand as ranging, through Middleton and Lord Howe's Island, with the north of Australia or south of New Guinea. The island of New Guinea, it should be remembered, is four hundred miles in breadth. But New Zealand is

so far distant, with only a few intermediate points, that we barely suggest this idea, without laying any stress upon it.

VIII. TONGA RANGE.—The Tonga Group is continuous with New Zealand through the Kermadec Islands, and may be considered as extending to Macquarie Island, which lies in the same course. The whole length is therefore about 2900 statute miles.

It is worthy of remark, that the Samoan, Fakaafo, Fanning, and Hawaiian Groups range in a single line. While, therefore, the Samoan chain is the back-bone of the Pacific, the group Samoa is situated also in the course of the great transverse chain of the ocean.

IX. LADRONE RANGE.—This range includes some islands to the north of the Ladrone, and may be about 1000 miles in length.

The idea of mountain chains in an ocean may to some appear hypothetical. Yet on reflection, it must be apparent that we should find this to be simple truth, were the ocean's bottom laid bare. The islands would be found to be but the summit peaks of the great ranges that rib this watered portion of our globe. Could we in such a case take a bird's eye view over the six thousand miles between New Holland and Mexico, we should see some of the most extensive mountain chains of the world: the Samoan stretching over its 3800 miles, the Hawaiian its 2000, and others no less remarkable, all preserving a systematic regularity, which seems even to exceed the regularity of continental chains. The height of summits in these chains, measured from the bottom of the ocean, would exceed the most majestic peaks of the Himmaleh range. Even allowing but three miles for the depth of the sea near Hawaii, and Mount Loa will stand 30,000 feet above its base.

We cannot fully understand the bearing and importance of the foregoing facts, without considering their correspondence with the general topography of the earth. We thus learn that no new principles in physical geography have been indicated, but simply a conformity to a system marked in the very structure of the globe. We might follow the subject farther by pointing to the examples of similar trends in the Atlantic Islands, and in the mountain ranges and coast-lines of the continents. But it would lead us too far from the topic immediately before us, and we defer it to a future chapter.

Without entering into any speculations, we may continue our statement of facts respecting the Pacific ranges, by mentioning certain

characteristics of the great chains, bearing upon their courses, and the relations of the two systems of ranges.

I. *The ranges, when viewed as a whole, are generally more or less curved.*

a. The Hawaiian chain has a slight curve, with the convexity northward, the western extremity of the range becoming a little more westerly in its course.

b. The Samoan chain is a striking example of a curved course. The trend becomes more and more northerly on going westward, as the following measured courses show:—Atiu range extends N. 66° W.; Samoa, N. 68° W.; Vaitupu, N. 56° W.; Tarawan, N. 42° W.; Marshall Groups, N. 35° W.

c. The *Ladrones* have a slight curve, the northern islands becoming more northerly, as already stated.

d. The *Salomon* range curves very decidedly, the northwest course changing gradually, and approaching east and west; the New Hebrides trending N. 40° W.; Vanikoro, N. 44° W.; the Salomon Islands, N. 57° W.; New Ireland, N. 65° W.; Admiralty Islands, N. 85° W.

e. The New Caledonia range curves nearly parallel with the preceding, New Caledonia trending N. 40° W.; Louisiade, N. 56° W.; New Guinea, (north coast,) N. 65° W.; and the west extremity becoming still more westerly, or N. 82° W., as nearly as can be estimated.

The line of Java and Flores, we thus perceive, is part of the same system; for the northwest course falls imperceptibly into the east and west, through the Salomon and New Caledonia ranges. Again, farther west, the line rises as gradually to a northwest course, through Java and Sumatra.

The courses of all the ranges are marked upon the chart. The anomaly of an east-and-west trend in the southern part of the East Indies appears, therefore, to be but an example of a modification in direction, which the northwest system may undergo. A thorough examination of the relative positions of the groups in the Southwest Pacific only confirms this conclusion, as will appear from the following facts.

II. *The transverse trend varies in its direction with the northwest trend, so as to be in each case nearly at right angles with the latter.*

a. In the East Indies, the Sumatra range, which is continued, as we have suggested, by Java and the south of New Guinea, (and possibly by Flinders Island, North New Zealand to Chatham Island,)

has an east-and-west course by Flores and Sumbawa, west-northwest in Java, northwest-by-west between Sumatra and Java, and northwest in Sumatra. The transverse trend varies in direction with the varying course of this range. The east coast of Borneo, the main line of Celebes and Luzon,* and Formosa beyond, constitute one of the most remarkable of the *north-and-south* ranges anywhere to be met with; for it extends over thirty-four degrees of latitude, a distance of nearly 2400 miles: and we may with much reason consider the coast of Northern China, and perhaps also of Southwestern New Holland, as a continuation of it. This range, considering only the limit first laid down, has the course N. 3° E. It crosses the other range near the west extremity of Sumbawa, where its direction is about three degrees north of west, (N. 87° W.) The exact rectangularity of the crossing lines seems a little too surprising; yet the facts cannot be set aside. Moreover, in the line of Celebes, which is farther east than the first line, and north of Flores, the two directions are quite north-and-south, and east-and-west.

Again, the west coast of Borneo and the long island of Palawan constitute another line, very regular and nearly straight. Its direction is N. 40° E. It meets the transverse range in the southern extremity of Sumatra, where a tangent to the curve representing its direction would have a course 40 degrees north of west, (N. 50° W.) This is another coincidence, so exact as to excite surprise, yet a matter of direct measurement and true, whatever be its cause. Still, were the two cases just cited alone, the connexion between the two systems of ranges might notwithstanding be doubted.

The form of the island of Borneo, (narrowing northward, and widest south,) is a consequence of the difference of trend here pointed out.

b. Another instance of the same kind we observe in New Zealand, for the position of the foot on the leg of the boot varies but little from a right angle. The same fact literally is also seen in the island of Luzon.

c. The Tongan Group is one of the most perfectly linear in the ocean, and one of the finest examples of the northeasterly ranges. It runs nearly at right angles with Samoa, the course of the former being N. 22° E., and that of the latter N. 68° W. From Samoa

* The southern extremity of Luzon, which is mostly recent volcanic, belongs to the northwest system, and extends in a line towards the Pelews. The curved directions and the overlapping of the several lines is well shown in the Philippines.

westward the line becomes more northwest; and concurrently, if not consequently, the *east* side of the Feejee Group, lying near the Tongan, trends nearly the same with it, or N. 23° E.; while the *west* side, which is from 150 to 200 miles distant, trends N. 40° E., or nearly at right angles with the Vaitupu range on the north and New Hebrides on the south. The Feejee Group is therefore wedge-shape, like Borneo, with the narrow side of the wedge, however, in the opposite direction.

d. The Ladrões, in their northern part, are parallel with Formosa and Luzon; but the southern portion trends westerly, so as to be nearly at right angles with the Salomon range, or the southern east-and-west portion of Luzon, which line, we have stated, may possibly be continued in the Pelews.

e. It is of course impossible that the curving ranges should be uniformly at right angles: the system exhibited is actually inconsistent with it. Thus the bending northward of the Samoan chain at the Marshall Islands, approximates it to a rectangularity with the western part of the Hawaiian range, but at the same time to a parallelism with the Ladrões. Yet we observe in this same region that the Carolines branch off westward, at right angles with the Ladrone range. The same convergings and cross-courses are apparent in the East Indies.

III. The parts of the ocean where the two systems correspond most nearly with the equatorial and meridional directions respectively, are those which abound most in lands. The Tongan, Samoan and Feejees constitute one of these regions. The East Indies another. The West Indies and Mexican mountains are an example of a similar kind.

With regard to the causes of the system of things pointed out, we offer nothing in this place, as our object has been simply to present the facts in illustration of the physical geography of the Pacific.

II. GENERAL CONSTITUTION OF THE PACIFIC ISLANDS.

An area of the extent of the Pacific might be expected to present some considerable variety in the geological constitution of its lands, at least as much as is observed among the loftier summits of the continents. This is, however, far from the fact. Igneous rocks, volcanic or basaltic, and occasionally porphyritic, constitute all the islands of

the ocean, not of coral origin, until we approach the East Indies and Asia, where granites and sedimentary rocks make their appearance. New Zealand has its granites, schists, and coal formation. New Caledonia presents ridges of talcose rock, mica schist, and probably others of a sedimentary character; and many of the larger islands of Melanesia approximate in geological character to Australia and New Guinea. But according to present knowledge, through all Polynesia exclusive of New Zealand, throughout Micronesia, and a considerable portion of Melanesia, the six hundred islands are either basaltic or coral. Under the term basaltic we include the *volcanic*, as the latter differ only in having had the igneous action which originated them continued to a later period.

The islands of the Pacific belong, then, to three divisions: the *coral*, the *basaltic* or igneous, and the *continental*,—designating by the last term those which have the mixed geological character of the continents.

The coral islands of the ocean amount to 290, the basaltic to about 350. The number of the third kind is doubtful, as the character of the various islands of the Salomon Group, and those adjoining, is not fully known. The large number of coral islands is an interesting fact, as we see from it how much the ocean and the world are indebted to the coral zoophytes. Were we to count, also, the many green spots, large enough for a village site, or a grove of palms, that occur on the reefs around the high islands, the number would be greatly augmented. The sea has lost some of its wonders by late observations on corals; for they were believed by early travellers to build up their structures from the deep bottom of the ocean: and in view of the supposed rapidity of the work, it was thought that navigation might soon be everywhere obstructed. Although these opinions have proved groundless, yet the facts may well surprise: for it is still true that these islands stand in an unfathomable ocean; and attempts to explain the congruity of this fact with the growth of corals only in shallow waters not exceeding a depth of 20 fathoms, called forth much speculation, before the truth was finally ascertained.

The whole area covered by the coral islands of the ocean, is not far from 19,000 square miles. Yet the area of dry land in the whole, as we shall hereafter explain, is little more than one eighth of this amount.

These islands constitute a large archipelago, northeast and east of the Society Islands, called the Paumotus; the whole number is eighty-two, and all are of coral origin, excepting the Gambier Group and

Pitcairn's. The Carolines constitute another archipelago of like extent and character; and if we include with these the Marshall Islands, the Tarawan Islands and Depeyster's, the number is ninety-four; the only high islands in the area are Ualan, Banabe or Ascension, and Hogoleu. Between these large coral archipelagos various islands are scattered over the ocean, all of which, north of a line from the Society Islands to Samoa and Rotuma, are of coral formation. There is a third archipelago, Flinders, between New Caledonia and New Holland, in which the islands north of the parallel of 25°, are believed to be solely of coral. Coral reefs are also extensive about most of the high islands.

The basaltic islands, excluding any among the Salomon Group and others adjoining, which are still of unascertained character, cover an area of 16,000 square miles. They are of all shapes, from the simple volcanic cone, to broken mountain heights with deep gorges and lofty peaks. These islands indicate that this ocean has been the scene of a vast number of volcanoes, subaerial or submarine. And if the coral islands have a basaltic basement, as is probable in those parts of the ocean where all the other islands are basaltic, the number would be still larger. We may count for each island one, and for many two or more, so that the number, not reckoning subordinate vents, could not have been less than a thousand. Yet, at the present time, there are few in action. In Polynesia, which embraces three-fourths of the ocean, they are confined to *four* islands, Hawaii in the Hawaiian Group, Tafoa and Amargura in the Tongan Group,* and the north island of New Zealand. In Micronesia there are none excepting on two or three of the Northern Ladrões, Assumption, Pagon and Guguan, which are barely smoking. In Melanesia the active volcanic islands are Tanna and Ambrym in the New Hebrides, Matthew's Rock west of the south extremity of New Caledonia, Tinakoro in the Santa Cruz or Vanikoro Group, and Sesarga and perhaps others in the Salomon Group, besides one or two on the east coast of New Britain. These alone remain of the fires that have burned over this wide area.

* Information has been recently received of an eruption, and extensive flow of lavas on the island of Amargura, one of the Friendly Group. This eruption took place on the 9th of July, 1847.

III. GEOLOGICAL AGENCIES IN THE PACIFIC.

The following brief statement of the several sources of geological changes and effects in the Pacific, is here introduced, to aid the reader in apprehending more clearly the particular facts presented by the different groups of islands.

a. As the islands are situated within or near the tropics, the mountains are free from the rending and degrading action of frosts or ice. At the same time, a luxuriant vegetation throws a protection even over the steepest declivities. Bluffs, with a talus or slope of fallen fragments at foot, are therefore rarely met with.

b. Volcanic or igneous action having been rife in this ocean, the results of eruption and of earthquakes, with the usual attendant circumstances, are common.

c. The growth of coral not only forms islands, but produces barriers around basaltic islands, which act as breakwaters, or confine the sediment flowing from the hills.

d. The action of the waves and swell of the sea, are agents of great force in insular lands, where so large a line of coast compared with the area, is exposed to their action.

e. The currents of the ocean are but little appreciable at the surface, and have left few traces of their influence, except in the transport of seeds, and floating logs carrying occasionally an attached stone and some sea-shore animals.

f. Around many islands, other more active currents exist, owing in part to the reefs and the configuration of the land, which currents have an important influence on the growth and distribution of coral, and the characters of shores.

g. The tides in the Pacific are comparatively feeble in their effects. Through the eastern part of Polynesia they are but two or three feet in height; about Samoa, they are four feet; at the Feejee Islands, six feet; at New Zealand, eight feet. They have a decided influence on the height of growing reefs, and upon the forms of the shores of coral islands.

h. The winds in connexion with the swell of the sea exert much influence on the features of a coast, drifting the beach-sands into hills on the parts of the islands exposed; and this effect is strikingly apparent on coral reefs and islands. Through the greater part of

the year, the trade-winds prevail, blowing quite uniformly from the eastward, (between northeast and southeast,) except for five to seven degrees either side of the equator, which region is subject to calms and variables. During the winter months, westerly winds displace the regular trades, and blow over the part of the ocean included within fifteen or twenty degrees of the equator, extending as far east as the Paumotus. Gales often appear in the course of these winds, and occasional hurricanes prove destructive to the forests and native villages, and give great height and force to the waves.

i. Rains fall almost exclusively on the windward sides of the higher islands; for the moisture brought in with the winds is condensed by the first slopes which they encounter. In consequence of this, one side of an island is comparatively dry, with few if any streams, while the other is well watered; and denudation is correspondingly apparent on the opposite slopes.

j. The usual steepness of the declivities of basaltic islands gives great rending and transporting force to the torrents.

k. Slow decomposition from moisture and atmospheric agents is constantly in progress, and this is hastened by the luxuriance of vegetation.

l. The solution of lime by the sea acting upon the corals and shells of the reefs, leads to its deposition again along the sea-shores, forming a cement to a consolidating limestone, sand-rock, or conglomerate.

m. As another agent, we mention the great waves of translation, which sometimes drive along over the whole extent of an ocean, with a rending power far beyond the ordinary oscillations of the sea. The earthquake of Valdivia in 1837 gave origin to a series of these waves of translation, which moved on and made themselves felt with serious results at the Sandwich Islands, a distance of more than five thousand miles.

n. The geology of the Pacific islands might be expected to derive other peculiarities from the absence of all native mammals excepting bats. While at the same time their insular condition does not preclude the possibility of fresh-water formations containing fossil animals of land and fresh-water origin, and even in some cases the fresh-water clam (*Unionidæ*), as at the Feejee Islands.

CHAPTER II.

ON CORAL FORMATIONS.

CORAL reefs and islands partake sufficiently of the mysterious, both from their magnitude, position, and fancied origin, to have excited much curious inquiry. The question is often heard, How have these island structures been raised from the ocean's depths; through what means have the reefs, like bulwarks of rock, risen to the surface, to serve as a barrier to the shores of the basaltic islands, and a break-water for their harbours? Moreover, with greater earnestness, the navigator asks whether new reefs are not yearly adding to the intricacies of tropical seas, obstructing old channels, and rendering useless former charts. Curiosity as well as interest thus prompts to a thorough study of this subject, in order that we may trace out the modes of growth and accumulation from the first development of the zoophyte, and discover those laws which preside over the forms and distribution of coral formations.

Coral islands also merit special attention, on account of their productions, their extent and number, the various forms and beauty of the coral zoophytes, and the singular features of the emerging land. The submarine garden grows slowly towards the surface, and as it increases, the waves contribute towards forming and consolidating the structure, and finally aid in covering the new islet with soil, and supplying it with vegetation. Such is the brief history. In this way, as we shall more particularly explain, vast seas have been studded with islands; two hundred may now be counted over an area of ten millions of square miles in the Pacific, where otherwise there would have been less than twenty.

Reef formations are exciting much attention for the part they have taken in forming many of the rock strata of our globe. They have not always been confined as now to the equatorial regions; but early in the earth's history, extended far towards either pole. Reef-rocks

much resembling those of the Pacific are to be found throughout the interior of our own country, constituting some of the beds of limestone that underlie the Western States; and over other parts of the world there are extensive strata of similar character and origin. Many interesting points in geology are consequently illustrated by the forming reef. The polyp though among the lowest animals in organization, may therefore claim a place with the most efficient agents of change and progress in the geological history of the earth.

In view of these considerations,—the simplicity of the means, the grandeur of the results, and the important bearing of the facts on science and commerce,—we shall be justified in much minuteness of detail in the following pages. In another volume, we have dwelt at length upon the structure and habits of coral animals, and endeavoured to illustrate the manner in which coral is secreted, its relation to the polyp, and the source of the various forms which it assumes, besides giving full descriptions of species. In the following pages we present the subject with reference to the formation of reefs and islands.

In treating of coral formations, we may first consider their actual condition and characters, as presented in existing seas; and next, the several causes, arising from the habitudes of polyps and different external agencies, by which their features have been produced, and their growth and distribution regulated.

I. FEATURES AND STRUCTURE OF REEFS AND ISLANDS.

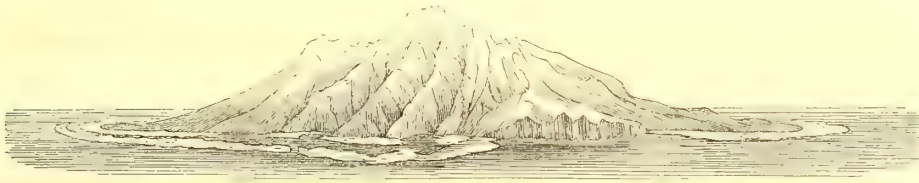
I. GENERAL VIEW OF CORAL REEFS AND ISLANDS.

The general features of reefs and coral islands have often been delineated by travellers, and are probably almost as familiar to the reader as the scenes of the land around us. Yet a few brief remarks on this point form a necessary introduction to the more minute descriptions of structure which follow.*

* The features of coral islands and reefs were first particularly detailed by J. R. Forster, who accompanied Captain Cook in his second voyage. They have since been described by Kotzebue, Chamisso, Beechey, Quoy and Gaymard, Lutke, Stutchbury, Ehrenberg, Darwin, and Jukes. The opportunities for investigation which the Expedition afforded were of the most extended kind, and enabled us to make personal examinations

Coral reefs.—A wide platform of rock, covered with the sea except at low tide, borders most of the high islands of the Pacific. It is a vast accumulation of coral, based upon the bottom in the shallow waters of the shores. This bank or table of coral rock, is of varying width, from a few hundred feet to a mile or more; and, although the surface is usually nearly flat, it is often intersected by irregular boat-channels, or occasionally incloses large bays, affording harbour protection to scores of ships. In very many instances the reef stands at a distance from the shores like an artificial mole, leaving a wide and deep channel between it and the land; and within this channel are other coral reefs, some in scattered patches and others attached close to the shore. The inner reef in these cases is distinguished, as the *fringing* reef, and the outer, as the *barrier* reef. The sea rolls in heavy surges against the outer margin of the barrier; but the still waters of a lake prevail within, affording safe navigation for the tottling canoe, sometimes through the whole circuit of an island: and not unfrequently ships may pass, as by an internal canal, from harbour to harbour around the island. The reef is covered by the sea at high tide, yet the smoother waters indicate its extent, and a line of breakers its outline. Occasionally a green islet rises from the reef, and in some instances, a grove of palms stretches along the barrier for miles, where the action of the sea has raised the coral structure above the waves.

The sketch annexed conveys some idea of the peculiar features



presented by a Pacific island and its encircling reefs, though, in order to fill out the scene, the jagged heights and deep gorges of the island

into all the peculiarities of coral formations. The author has deemed it therefore incumbent upon him to present a full account from his own observations, without special reference to the writings of others, excepting a faithful acknowledgment wherever any facts or views have been cited from them. The Report is therefore complete in itself, and has the advantage, where it agrees with previous observers, of being independent testimony to the facts.

should be covered with forests, and the shores with groves and native villages. The coral platform which borders the shore is represented with its usual uneven outline,—its broad harbours with a narrow entrance,—and to the left, an irregular ship channel running between the inner or fringing reef, and the outer or barrier. At a single place, the sea is faced by a cliff; and here, owing to the boldness of the shores and depth of waters, the reef is wanting. To the right there is only a fringing reef.

Coral islands.—Coral islands resemble the reefs just described, except that a lake or lagoon is encircled instead of a mountainous island. A narrow rim of coral reef, generally but a few hundred yards wide, stretches around the enclosed waters. In some parts it is so low that the waves are still dashing over it into the lagoon; and in others, it is verdant with the rich foliage of the tropics. The coral-made land when highest is seldom over eight or ten feet in height.

When first seen from the deck of a vessel, only a series of dark points is descried just above the horizon. Shortly after, the points enlarge into the plumed tops of cocoanut trees, and a line of green, interrupted at intervals, is traced along the water's surface. Approaching still nearer, the lake and its belt of verdure are spread out before the eye, and a scene of more interest can scarcely be imagined. The surf beating loud and heavy along the margin of the reef, presents a strange contrast to the prospect beyond—the white coral beach, the massy foliage of the grove, and the embosomed lake with its tiny islets. The colour of the lagoon waters is often as blue as the ocean, although but fifteen or twenty fathoms deep; yet shades of green and yellow are intermingled, where patches of sand or coral-knolls are near the surface; and the green is a delicate apple-shade, quite unlike the usual muddy tint of shallow waters.

The belt of verdure, though sometimes continuous around the lagoon is usually broken in some parts into islets which are separated by varying intervals of bare reef; and through one or more of these intervals, a ship-channel occasionally opens into the lagoon, the larger coral islands are thus a string of islands arranged along a line of coral reef. The King of the Maldives bears the high-sounding title of "Ibrahim Sultan King of the Thirteen Atollons and Twelve Thousand Isles;" which Captain W. F. W. Owen, R. N., remarks is no exaggeration.*

* See Journal of the Geographical Society, ii. 72.—According to Captain Owen, who

The usual features of these islands are presented in the following sketch. The narrow belt is seen to consist of several patches of



vegetation; and within are the quiet waters which offer a retreat for vessels whenever there is an opening through the reef.

A few small coral islands are simple reefs without lagoons. In some cases they are bare banks of coral; but generally the usual vegetation of these islands has obtained a foothold, and affords some protection against the glare of the coral sand.

With these general remarks we may enter upon the more particular consideration of the characters of reefs and islands.

2. CHARACTERS OF FRINGING AND BARRIER REEFS.

a. *General Features.*

Fringing reefs have been described as those that directly adjoin the shores of an island; and the *barrier*, as the exterior reefs, separated from the fringing reef, or from the shores when there is no inner reef, by an open channel.

While there are only narrow shore reefs to many islands, around others a distant barrier extends like an artificial mole, sometimes ten or even fifteen miles from the land, and enclosing not only one, but at times several islands. Between the narrow fringing platform and these remote barriers, there is every possible variation as to extent and relative position. The inner channel is sometimes barely deep enough at low tide for canoes, or for long distances may be wanting entirely. Then again it is a narrow intricate passage, obstructed by knolls or patches of coral, rendering the navigation quite

quotes from John de Barros, "Maldive is derived from *mal*, signifying a thousand or uncountable number, and *diva*, an island." The title of the Sultan, given in the text, is cited from a geographical description of the Maldives by François Pyrard; and Captain Owen adds, "I believe the actual number to be more than treble or fourfold this number." (Ibid, p. 81.)

The Maldivic word Atoll, or Atollon, commonly used to signify the groups into which the Maldives are divided, and now applied to lagoon islands generally, means in strictness only the chaplet or circle on which the islands rest, and which encloses them. (Ibid, p. 88.)

dangerous. Again, it is for miles in breadth an open sea, in which ships find room to beat against a head wind with a depth of twenty, thirty, or even fifty fathoms. Yet hidden reefs make caution necessary. Patches from a few square feet to many square miles in extent are met with over the broad area enclosed by these distant barriers.

These varieties of form and position are well exemplified in a single group of islands—the Feejees; and we would refer the reader to a reduced copy of the excellent chart of the Expedition, in this volume, preceding the chapter on that group.

Near the middle of the chart is the island *Goro*; its shores, excepting the western, are bordered by a fringing reef. The island *Angau*, south of *Goro*, is encircled by a coral breakwater, which on the southern and western sides runs far from the shores, and is a proper barrier reef, while on the eastern side, the same reef is attached to the coast and is a fringing reef. From these examples it is perceived that there is no proper distinction as regards mode of formation between barrier and fringing reefs. It is also apparent that while a reef is sometimes quite encircling, in other instances it is interrupted along certain shores, or may be wanting along a large part of a line of coast: occasionally the reef may be confined to a single point of an island.

Above *Angau* lies *Nairai*; though a smaller island than *Angau* the barrier reef is of greater extent, and stretches off far from the shores. To the eastward of *Nairai* are *Vatu Rera*, *Chichia*, and *Naiiau*, other examples of islands fringed around with narrow reefs. *Lakemba*, a little more to the southward, is also encircled with coral: but on the east side the reef is a distant barrier. In *Aiva*, immediately south of *Lakemba*, the same structure is exemplified; but the coral ring is singularly large for the little spots of land it encloses. The *Argo Reef*, east of *Lakemba*, is a still larger barrier, encircling two points of rock called Bacon's Isles. It is actually a large lagoon island, twenty miles long, with some coral islets in the lagoon and two of basaltic constitution, the largest of which is only a mile in diameter. *Aiva* and *Lakemba* are in fact other lagoon islands, in which the rocky islands of the interior bear a larger proportion to the whole area. The same view is farther illustrated by comparing the *Argo Reef* with *Nairai*, *Angau*, or *Moala*: the only difference in these cases consists in the greater distance of the reef from the shores which it encircles, and the smaller extent of the enclosed land.

Passing to the large islands *Vanua Levu* and *Viti Levu*, we observe the same peculiarities illustrated on a much grander scale. Along the southern shores of *Viti Levu*, the coral reef lies close against the coast; and the same is seen on the east side and north extremity of *Vanua Levu*. But on the west side of these islands, this reef stretches far off from the land, and in some parts is even twenty-five miles distant, with a broad sea within. This sea, however, is obstructed by reefs, and besides, along the shores there are proper fringing reefs.

The forms of encircling reefs depend evidently to a great extent on that of the land they enclose. That this is the case even in the Argo Reef and such other examples as offer now but a single rock above the surface of the enclosed lagoon, we shall endeavour to make apparent, if not already so, when the cause of the forms of coral islands is under discussion. Yet it is also evident that this correspondence is not exact, for many parts of the shores, or even more than half the coast, may be exposed to the sea, while other portions are protected by a wide barrier.

In recapitulation, we remark, that reefs around islands may be (1) entirely encircling; or they may be (2) confined to a larger or a smaller portion of the coast, either continuous or interrupted: they may (3) constitute throughout a distant barrier; or (4) the reef may be fringing in one part and a barrier in another; or (5) it may be fringing alone: the barrier may be (6) at great distances from the shores, with a wide sea within, or (7) it may so unite to the fringing reef that the channel between will hardly float a canoe. These several points are fully sustained by all reef regions.

A wide difference in the extent of reefs would be inferred from these facts. There is the mere point of coral rock; and again, as for example, west of the two large Feejee islands, there may be three thousand square miles of continuous reef-ground, occupied with coral patches and intermediate channels or seas. The enclosing barrier off *Vanua Levu* alone is more than one hundred miles long. The Exploring Isles, in the eastern part of the Feejee Group, have a barrier eighty miles in circuit. New Caledonia, as often cited, has a reef along its whole western shores, a distance of two hundred and fifty miles, and it extends one hundred and fifty miles farther north, adding this much to the length of the island. The great Australian barrier forms a broken line, a thousand miles in length, lying off the coast from the Northern Cape to the tropical circle; and the

channel within is in some parts sixty miles from the coast, with a depth of thirty to sixty fathoms.

The seas outside of the lines of coral reef are often unfathomable within a short distance of the line of breakers.

b. *Structure of Reef Formations.*

In the description of reef-grounds or reef formations there are several distinct subjects for consideration, as is obvious from the preceding remarks. These are

1. *Outer reefs*, or reefs formed from the growth of corals exposed to the open seas. Of this character are all proper barrier reefs, and such fringing reefs as are unprotected by a barrier.

2. *Inner reefs*, or reefs formed in quiet water between a barrier and the shores of an island.

3. *Channels or seas within barriers*, which may receive detritus either from the reefs, or the shores, or from both of these sources combined.

4. *Beaches and beach formations*, produced by coral accumulations on the shores through the action of the sea and winds.

The outer and inner reefs, channels, and beaches, act each their part in producing the coral formations in progress about islands.

Outer reefs.—The outer reefs or flats of coral rock receive the waves along their margin; and the outline exposed to this action is very much cut up with deep channels, which give passage to the advancing waters and to the currents that flow back, in preparation for the next breaker. This margin, which we have said rises but little above low tide level, usually slopes beneath the water at an angle of forty to seventy degrees to a depth of three to eight fathoms; thence, the waters deepen very gradually for one to five hundred yards out, and from this there is finally an abrupt descent, generally by an angle of at least forty degrees, to depths beyond the reach of a sounding lead. There is a great difference in the rapidity with which the water deepens, as might be inferred from the varied character of submarine slopes; in some cases the shallow waters may extend for two or three miles beyond the reef, but it is far more common to meet with the opposite extreme—unfathomable depths within a few hundred feet.

The growing corals are mostly confined to the shallow waters and to the sloping margin of the reef, up which they extend to within

a foot or less of the surface. In these shallow waters the various zoophytes at times are crowded over extensive areas; yet very often they occur only in patches scattered throughout large fields of coral debris. The top of the reef is mostly destitute of life, and consists of the naked coral rock, more or less covered with coral sand. Yet there are some shallow pools, especially towards the outer limits, which abound in corals.

The exposed edge of the reef is commonly raised a few inches above the general surface, and is, therefore, the first part laid bare by the retreating tide, although a dangerous place for a ramble, on account of the heavy breakers. Though very uneven, the surface has generally a smooth, water-worn appearance, and is spotted with various shades of pink and purple. These colours, as observed by Chamisso, are due to incrusting Nullipores, that grow like lichens over the rock: they are vegetable in nature, though composed mostly of lime. Other nodular and branching Nullipores, some sprigs of Madreporæ, and a few *Astræas* grow in the more sheltered cavities, where they are not easily dislodged by the waves; and among them, despite the breakers, cling numerous echini, asterias, and actiniæ. The gradual wear of the reefs by the wash of the sea is prevented, to a great extent, by these Nullipore incrustations, as was pointed out by Darwin.* He states that on Keeling's Island they constitute a layer two or three feet in thickness, with a breadth of twenty feet. They are abundant on the Paumotu reefs.

The outer reefs are distinguished in many parts from the inner by becoming covered with accumulations of coral fragments and sand, which are thrown up by the waves: finding a lodgment some distance back from the margin of the reef, they gradually increase, till in many instances they form dry land, and thus commence the foundation of islands. Such effects are mostly confined, however, to the sides open to the prevailing wind, and are generally of limited extent. Occasionally, as at Bolabola, the reef for miles in length is changed from the submerged coral bank into a habitable islet—a green belt to the island of rocks and forests within. The causes and the result are much the same as in the case of the lagoon island, and the steps in the process will be more particularly described when treating of the coral atoll.

The rock of the reef, wherever broken, exhibits a compact texture. In some parts it consists of coral fragments of quite large size, firmly

* Op. cit. page 9, and elsewhere.

cemented: other portions are a finer coral breccia, or conglomerate: and still others, more common, are solid white limestone, as impalpable and homogeneous in texture as the secondary limestones of our continents, and usually much harder. It is rare to meet with any corals in this reef-rock retaining the original position of growth. It is at once apparent that the rock consists of the debris of the coral fields, consolidated by a calcareous cement; and the great abundance of the finer variety of rock indicates that much of it has originated from coral sand or mud. Wherever broken, it is found to present the same character as here described, a texture indicating a detritus origin. This reef-rock is formed in the midst of the waves; and we shall hereafter show that to this fact it owes many of its peculiarities. Besides corals, the shells of the seas contribute to it, and it sometimes contains them as fossils, along with bones of fish, exuviae of crabs, spines and fragments of echini, and other remains of organic life inhabiting reef-grounds.

Inner reefs.—In the still waters of the inner channels or lagoons, when of large extent, we find corals growing in their greatest perfection, and the richest views are presented to the explorer of coral scenery. There are many regions—in the Feejees, examples are common—where a remote barrier encloses as pure a sea as the ocean beyond; and the greatest agitation is only such as the wind may excite on a narrow lake or channel. This condition gives rise to some important peculiarities of structure in the inner reefs.

In the general appearance of the surface, however, they much resemble the outer reefs. They are nearly flat, and though mostly bare of life, and much covered with coral sand, there are seldom any large accumulations of coral debris. The margin is generally less abrupt; yet there is every variety, from the gradually sloping bed of corals to the bluff declivity with its clinging clumps. Over the surface there are many portions still under water at the lowest tides; and here, (as well as upon the outer banks,) fine fishing sport is afforded the natives, who wade out at the ebb tide with spears, pronged sticks, and nets, to supply themselves with food. The lover of the marvellous may find abundant gratification by joining in such a ramble; among coral plants and flowers, with fishes of fantastic colours, starfish, echini, and myriads of other beings which science alone has named, fit inhabitants of a coral world, there is on every side occasion for surprise and admiration.

Between the larger reefs, which spread a broad surface at the water's

edge of lifeless coral rock, sometimes of great extent, there are other patches, still submerged, which are covered with growing corals throughout. They are of different elevations; and though at times but a few yards in breadth, there is often alongside of them a depth of many fathoms. They sometimes seem to grow up from a narrow base, like a mushroom; and a ship striking one with her keel may crush it and glide on. More frequently, they are below like the solid reef above described, and the contest is more likely to be fatal to the vessel than to the coral patch. Corals grow over them, as in the shallow waters about other reefs; and, as elsewhere, there are deep cavities among the congregated corals, in which a lead will sometimes sink to a depth of several feet, or even fathoms. These holes about growing reefs often give much annoyance to the boat which may venture to anchor upon them; and in many an instance in the course of the surveys, diving was the only resource left for freeing the foul anchor.

The rock of the inner reefs is peculiar in being but sparingly fragmentary. The corals composing it stand to a great extent as they grew; yet it is not less compact or firm in its texture than the rock of the outer reefs. The cavities among the branches and growing masses gradually become filled with coral sand, and the whole is finally cemented and thoroughly compacted. At Tongatabu and among the Feejee Islands, reefs thus made of corals standing in their growing positions are common. Though now mere dead rock, the limits of the several constituent coral masses may be distinctly made out. Some individual specimens of *Porites* in the rock of the inner reef of Tongatabu were twenty-five feet in diameter; and *Astræas* and *Meandrinæ*, both there and in the Feejees, measured twelve to fifteen feet. These corals, when growing beneath the water, form solid hemispheres, or rounded hillocks; but on reaching the surface, the top dies, and enlargement takes place only on the sides. In this manner the hemisphere is finally changed to a broad cylinder with a flat top. This was the condition of the *Astræas* and *Porites* in the reef-rock referred to. The platform looks like a Cyclopean pavement, except that the cementing material, filling in between the huge masses, is more solid than any work of art: it even exceeds in compactness the corals themselves. Other portions of these reefs consist of *branching* corals, with the intervals filled in by sand and small fragments; for even in the more still waters fragments are to some extent produced.* There is also

* A rock of this kind is often used for buildings and for walls on the island of Oahu. It consists mainly of *Porites*, and in many parts is still cavernous, or but imperfectly cemented. It is the material of the large church at Honolulu.

to be found here, and frequently over large areas, the solid white limestone already described, showing internally no evidence of its coral origin, and containing only a few shells or imbedded fossils.

The formation of inner reefs goes on at a less rapid rate than that of the outer, as the process depends on growth unaided, except in a comparatively small degree, by the action of the waves. Moreover, as we shall explain more particularly in another place, impure or fresh waters and currents often operate to retard their growth.

Owing to the last-mentioned cause, the inner reefs are not usually joined close to the beach. They stand off a little, separated by an interval of shallow water. At Mathuata, in the Feejees, however, the reef extends quite up; and it is the more remarkable as the country is a plain, the site of a Feejee village, and a mile or two back stands a high bluff. On an island off this part of Vanua Lebu is another example of this fact, and many more might be cited. In such cases, however, there is evidence that the shores upon which the corals grew were bare rocks, instead of moving beach-sands.

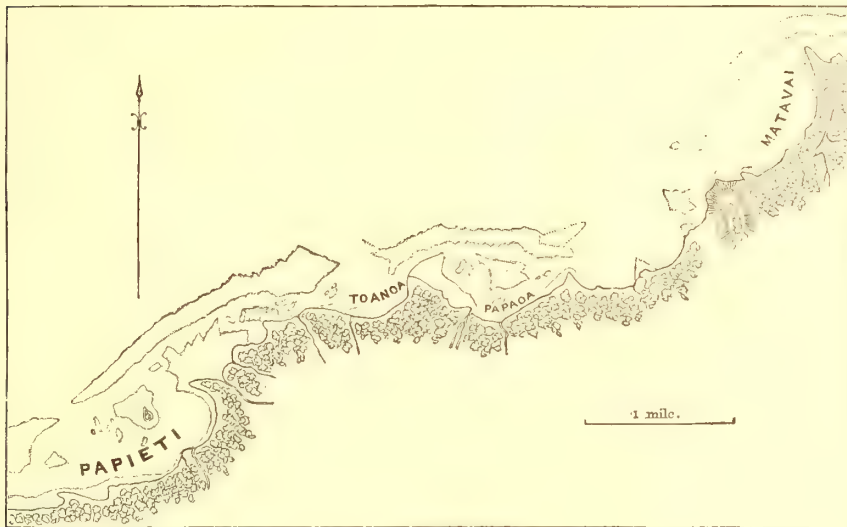
From these descriptions it appears that the main distinction between the inner and outer reefs consists in the less fragmentary character of the rock in the former case, the less frequent accumulations of debris on their upper surface, and the more varied features and slopes of the margin. Moreover, the Nullipores, which seem to flourish best in the breakers, are of less extent, or but sparingly met with.

The inner margin of a barrier reef, it should be observed, is entitled to rank with inner reefs, as its corals grow in the same quiet waters, and under like circumstances. The variety of coral zoophytes is also greater in the stiller waters, and there are species peculiar to the different regions, as explained on a following page.

Channels among reefs.—To complete this review of the general appearance and constitution of reef formations, it remains to add some particulars respecting the channels which intervene between coral patches, or separate them from the shores of an island, and also to describe the coral accumulations forming beaches.

The reef of New Holland has been instanced as affording an example of one of the larger reef-channels, varying from thirty to sixty miles in width, and as many fathoms in depth. The reefs west of the large Feejee Islands offer another remarkable example, the reef-grounds being in some parts twenty-five miles wide, and the waters within the barrier, where sounded, twelve to forty fathoms in depth. The barrier in this instance may be from a few hundred yards to a half a mile in

width; and some of the inner patches are of the same extent; but by far the larger part of the reef-ground is covered with deep waters, mostly blue like the ocean, and as clear and pure. The sloop of war Peacock sailed along the west coast of both Viti Lebu and Vanua Lebu, within the inner reefs, a distance exceeding 200 miles. The island of Tahiti on its northern side presents us with a good illustration



PART OF NORTH SHORE OF TAHITI.

of a *narrow* channel, and at the same time exhibits the usual broken or interrupted character of reefs. The outer reef extends half to two-thirds of a mile from the shore. Within it, between Papieti and Matavai, there is an irregular ship channel, varying from three to twenty fathoms in depth. Occasionally it enlarges into harbours; and in other parts it is very intricate, though throughout navigable by large vessels. The island of Upolu, of the Samoan Group, is bordered by a reef nearly a mile wide on part of its northern shore; but the waters within are too shallow for a canoe at low tide; and therefore, notwithstanding its extent, the reef is rather a fringing than a barrier reef.

The bottom of these channels or lagoons will take its character, as regards the material constituting it, either from the reefs, a source of calcareous sand and fragment, or from the earthy detritus of the island streams. At Upolu the white coral sands of the reefs, (or in more general terms the reef debris,) form the bottom; in some places

it had the consistence of mud, and was seldom observed to be covered with coarse material. There were some small patches of coral over it, and here and there a growing mass of *Porites*. The fresh waters of the shores do not flow over these wide reefs, as there is no proper inner channel, and there is consequently no shore detritus mingled with the reef debris. At Tahiti, the sounding lead usually brought up sand, shells, and fragments of coral. At Tongatabu, the bottom, where the Peacock anchored, was a grayish blue mud, appearing as plastic as common clay; it consisted solely of comminuted coral and shells, with colouring matter probably from vegetable decomposition. To the west of the larger Feejee islands, soundings commonly indicated a bottom of basaltic mud, and this material was frequently brought up with our dredges. On the north side of Vanua Lebu, a stream has so filled with its detritus the wide channel into which it empties, that for a mile our ship dragged its keel in the mud, although elsewhere the water had been from twelve to twenty fathoms deep; and at least half a dozen square miles of land had been added to the shores from this source. Though due principally to shore material, the reefs have probably added somewhat to these accumulations; yet little coral sand can be detected in the mud by the eye, and the proportion is certainly very small. In many places where we anchored, having the reef not more than five hundred yards from the ship, we might have judged, from the character of the bottom, that there were no corals nor shells within many miles. When the materials from both sources, the shore and the reef, are mingled, the proportion will necessarily depend on the proximity to the mouths of streams, the breadth of the inner water or channels, and the direction and force of the currents. These tidal currents often have great strength, and are much modified and increased in force at certain places, or diminished in others, by the position of the reef with reference to the land. Sweeping on, they carry off the coral debris from some regions to others distant; and again they bear along only the shore detritus, and distribute it. It is thus seen that the same region may differ widely in its adjacent parts, and seemingly afford evidence in one place that there is no coral near, and in another no basaltic island, although either is within a few rods, or even close alongside. The extent of the land in proportion to the reef will have an obvious effect upon the character of the channel or lagoon depositions. When the island stands like Bacon's Isles, as a mere point of rock in a wide sea

enclosed by a distant barrier, the streams of the land are small and their detritus quite limited in amount. In such a case the reef and the growing patches scattered over the lagoon, are the sources of nearly all the material that is accumulating upon the bottom.

Shore accumulations.—The wide coral banks and the enclosed channels greatly enlarge the limits tributary to the islands they encircle. They afford extensive fishing grounds for the natives, and internal waters which enable them to practise and improve their skill in navigation, and communicate without danger between distant settlements: and the effect is evident in the spirit of maritime enterprise which has characterized the Polynesians; for these circumstances have favoured the construction of large sail-canoes, in which they venture beyond their own land, and often undertake voyages hundreds of miles in length. Instead of a rock-bound coast, harbourless and thinly habitable, like most extratropical islands, the shores are blooming to the very edge, and wide plains are spread out with breadfruit and other tropical productions. Ports, safe for scores of vessels, are also opened by the same means, and some islands number a dozen, when the unprotected shores would have hardly offered a single good anchorage. Coral reefs are sometimes viewed as only traps to surprise and wreck the unwary mariner. But one who has visited the dreary prison-house, St. Helena, can have some appreciation of the benefits derived from the growth of the zoophyte.

The area of level shores, alluded to as added to many of the high islands by this means, is one of the most striking of these benefits. These plains are sometimes of large extent. The reefs stop the detritus from the hills, and are thus the means of its being added again to the land: they prevent, therefore, that waste which is constantly going on about islands without such barriers; for the ocean not only encroaches upon the unguarded shores of the smaller islands, but carries off whatever the streams may empty into it. The delta of Rewa, on Viti Lebu, resulting from the detritus accumulations of a large river, covers nearly sixty square miles. This is an extreme case in the Pacific, as few islands are so large, and consequently rivers of such magnitude are not common. But there is rarely an island which has not at least some narrow plains from this source; and upon them the villages of the natives are usually situated. Around Tahiti these plains are from half a mile to two or three miles in width, and the cocoanut and breadfruit groves are mostly confined to them.

Beach sandrock.—Besides the accumulations from a shore source,

there are also beach formations derived from the reefs. The tides and the attending currents carry to the shores more or less coral sand with shells and other reef-relics, and these sometimes form large deposits. The material is mostly like common sand in fineness, but often somewhat coarser, or even like a bank of pebbles. When the barrier is distant, only the sand and smaller pebbles are met with; but if the reef is quite narrow, there may be larger fragments and masses of coral rock.

These deposits become cemented by being alternately moistened and dried, through the action of the recurring tides, and the wash of the sea on the shores. The waters take up some carbonate of lime which is deposited and hardens among the particles on the evaporation of the moisture at the retreat of the tides. In some places the grains are loosely coherent, and seem to be united only by the few points in contact; and with a little care, the calcareous coating which caused the union may be distinctly traced out. In other cases, the sand has been changed to a solid rock, the interstices having been filled till a compact mass was formed. Generally, even the most solid varieties show evidence of a sand origin, and in this they differ from the reef-rock. The pebbly beds produce a pudding-stone of coral.

In all instances observed, these calcareous sandrocks or conglomerates, form a number of parallel layers along the coast, which dip regularly at an angle of five to eight degrees towards the water. The layers are from a few inches to a foot in thickness. They appear as if they had been tilted by some force below, and are seen to outcrop successively, on receding from the water. Tutuila and Upolu in the Navigator Group, and Oahu in the Hawaiian, afforded us many examples of these beach formations. They seldom rise more than a few inches above high tide. At certain localities they appear to have been washed away after they were formed; and occasionally large masses or slabs have been uplifted by the sea, and thrown back on the beach.

The same kind of deposits sometimes includes detritus from the hills. Black basaltic pebbles are thus cemented by the white calcareous material, producing a rock of very singular appearance. Near Diamond Hill on Oahu, is a good locality for observing the steps in its formation. Many of the pebbles of the beach are covered with a thin incrustation of carbonate of lime, appearing as if they had been dipped in milk, and others are actually cemented, yet so weakly that the fingers easily break them apart.

The lime in solution in waters washing over these coral shores, is also at times deposited in the cavities or seams of the basaltic rocks; the cavities of the lava or basalt become filled with white calcareous kernels, and the cellular lava is changed into an amygdaloid. In large cavities or caverns, it often forms stalactites or stalagmitic incrustations.*

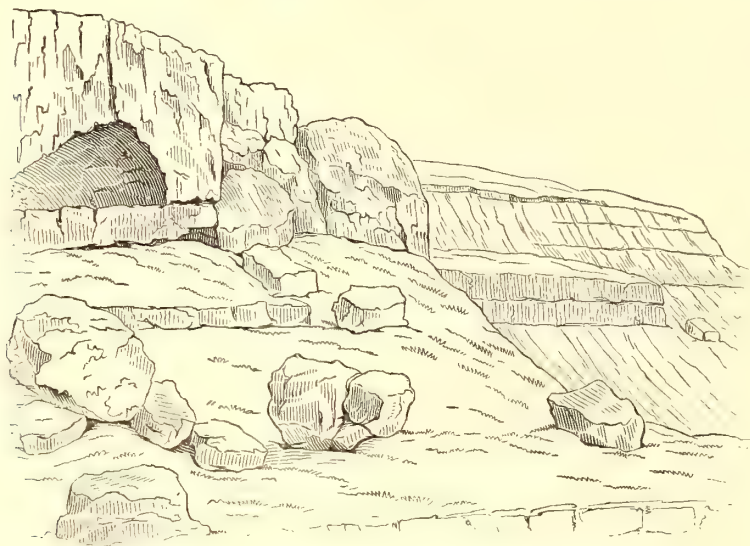
Drift sandrock.—Still another kind of beach formation is going on in some regions through the agency of the winds in connexion with the sea. It occurs only on the windward side of islands when the reefs are narrow, and proceeds from the drift sands.

The drifts resemble ordinary sand-drifts, and are often quite extensive. On Oahu, they occur at intervals around the eastern shores, from the *northern* cape, to Diamond Point which forms the *south* cape of the island,—the part exposed to the trades; and they are in some places twenty to forty feet in height. They are most remarkable on the north cape, a prominent point exposed to the winds that blow occasionally from the westward, as well as the regular trades. They also occur on Kauai, another of the Hawaiian Islands. But at Upolu, (Samoa,) where the protecting reefs are broad, I met with no instance worthy of mention.

These sand-banks, through the agency of infiltrating waters, fresh or salt, become cemented into a sandrock, more or less friable. The rock consists of thin layers or laminae, which are very distinct, and indicate, generally, every successive drift of sand which puffs of wind had added in the course of its formation: and where a heavier gale had blown off the top of a drift, and new accumulations again completed it, the whole history is distinctly displayed in the rock. Several catastrophes of this kind may be made out from the character of the lamination in one of the sand-bluffs on the north side of Oahu. This island, since their formation, has undergone an elevation of twenty-five or thirty feet; these hills, once on the shores, are now seventy feet above the level of the sea, and they face the water with a bluff front (due to degradation), in which the lamination is finely exposed to view. The structure is best seen in a transverse section, presented on the west side. The layers are but a fraction of an inch

* Similar facts are stated by Mr. Darwin as observed on the shores of Ascension, and many interesting particulars are given respecting calcareous incrustations on coasts.— See Volc. Islands, p. 49. They were observed by us upon Madeira, in St. Jago, one of the Cape Verds, as well as among the basaltic islands of the Pacific.

thick. At one of the hills large slate-like slabs may be obtained ; they have a sanded surface, but are so hard within as to clink under



BLUFFS OF CORAL SANDROCK, NORTH SHORE OF OAHU.

the hammer. We reserve a particular description of these bluffs for the remarks on the geology of the Hawaiian Islands.

One of the most interesting facts, observed in connexion with these drift hills, is the absence of shells, and even of fragments of shells or corals, sufficiently large to be referred definitely to either of these sources. The material is a fine sand, without organic remains, although situated on shores, off which, within a hundred yards, there are shells and corals innumerable.

c. Thickness of reefs.

We have considered in the preceding pages the peculiarities of form and structure characterizing the reef formations bordering islands and continents, and their influence upon the enclosed land. Could we raise one of these coral-bound islands from the waves, we should find that the reefs stand upon the submarine slopes like massy structures of artificial masonry ; some forming a broad flat platform ranging around the land, and others encircling it like vast ramparts, perhaps a hundred miles or more in circuit. The reefs that were near the water line of the coast would be seen to have stood in the shallowest water, while the outer ramparts rested on the more deeply submerged slopes. Indeed, it is obvious that with a given slope to

the declivity of the land, the thickness of the reef resting upon it may be directly determined, as it would be twice as great two hundred feet from the shore as at one hundred feet. The only difficulty, therefore, in correctly determining the depth or thickness of any given reef, arises from the uncertainty with regard to the submarine slope of the land. It is, however, admitted as the result of extensive observation, that in general, these slopes correspond nearly with those of the land above water. Mr. Darwin has thus estimated the thickness of the reefs of the Gambier Group and some other Pacific islands, and he arrives at the conclusion, as his figures indicate, that some coral reefs, at their outer limits, are at least *two thousand feet* in thickness.

It will be shown in another part of this volume, that the mountain declivities of the islands of the Pacific, except when increased by degrading agents, cannot be assumed as above twelve or fourteen degrees, and they are often but half this amount. The slopes of Mauna Kea and Mauna Loa, island of Hawaii, do not average over eight degrees. On the north side of Upolu, where the reefs are wide, the inclination is from three to six degrees. Throughout the Pacific, the *steeper* slopes of the mountains are due to agencies which cannot be shown to have affected the submarine slopes, excepting in cases of disruption of islands by forces below.

Assuming *eight* degrees as the mean inclination, we should have for the depth of reef, (or water,) one mile from the shore, 740 feet; or assuming *five* degrees, 460 feet. Adopting the first estimate, the Gambier Group would give for the outer reef a thickness of at least 1750 feet; or with the second, 1150 feet. The island of Tahiti, (taking the north side for data,) would give in the same manner 250 feet by the last estimate, which we judge to be most correct; Upolu, by the same estimate, 440 feet. The deduction for Upolu may be too large: taking three degrees as the inclination, it gives 260 for the thickness at the outer margin. The results are sufficiently accurate to satisfy us of the great thickness of many barrier reefs.

These calculations, however, are liable to error from many sources. Very different results might generally be obtained from different sides of the same island; and the same group often contains islands without reefs, and others with reefs one or even several miles from the shores. But since we may show that the absence of a reef or its limited extent may be traced to some causes restricting or modifying its formation, it is obvious that the errors would be probably on the side of too low

an estimate. Adjacent to the larger islands, such as those of Vanua Levu and New Holland, the error might be of the opposite kind; for the slopes of the land are of a more complex or irregular character than on the smaller islands. In the latter they may be shown to belong generally to a single elevation of igneous origin, or at the most to two or three combined; while in the former they may pertain to different ranges of hills or mountains. For correct results in any instance, the land and its declivities should be carefully studied beforehand, and the system in its inclinations determined by observation. With regard to Tahiti and Upolu, information bearing upon this point was obtained, and the above conclusions may be received with much confidence. Many of the Feejee reefs, on the same principle, cannot be less than 2000 feet in thickness.

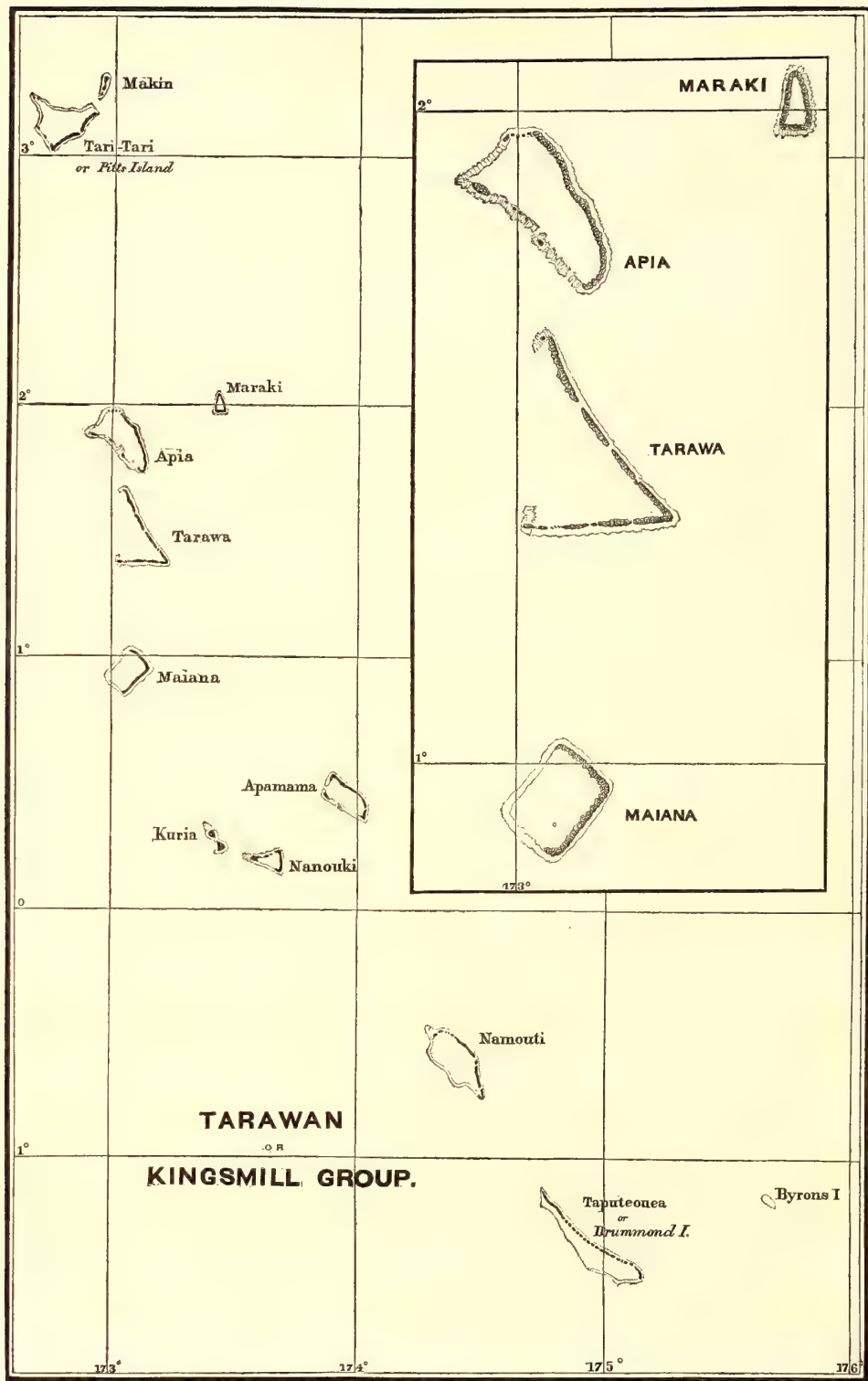
Such accumulations of calcareous rock may appear to be an incredible work for the coral polyp, but only because we are not accustomed to contemplate the results which may proceed from the smallest agencies long continued. The operatives in the inorganic world are invisible molecules; and so among living organisms, it is the lowest grade, the minims of existence, that have accomplished the grandest results in the earth's history.

3. CORAL ISLANDS.

a. *Forms and general features of coral islands.*

A barrier reef, and a lagoon enclosed by it, are the prominent features of a coral island, though there are a few of small size in which the lagoon is wanting. In the larger islands, the waters within look like the ocean, and are similarly roughened by the wind, though not to the same extent. Standing on the north shore of the Raraka lagoon, (in the Paumotus,) the eye scanning over it descries nothing but blue waters. Far in the distance, to the right or left, a few faint dots are distinguished; these gradually enlarge into lines of palms and other verdure, which sweep around into distinct groves as they near the observer. At Dean's Island, another of the Paumotus, and at many of the Carolines, the resemblance to the ocean is still more striking. The lagoon is in fact but a fragment of the ocean cut off by more or less perfect walls of coral reef-rock; and the reef is here and there surmounted by verdure, forming a series of islets.

In many of the smaller coral islands, the lagoon has lost its ocean



character, and become a shallow lake, and the green islets of the margin have coalesced in many instances into a continuous line of foliage. Traces may perhaps be still detected of the passage or passages over which the sea once communicated with the internal waters, though mostly concealed by the trees and shrubbery which have spread around and completed the belt of verdure. The coral island is now in its most finished state: the lake rests quietly in its bed of palms, scarce ruffled by the storms that madden the surrounding ocean.

From the islands with small lagoons, there is every variety in the gradation down to those in which there is scarcely a trace of a lagoon. These simple banks of coral are the smallest of coral islands.

These remarks, in connexion with the general view given on a preceding page (p. 32), will prepare the reader to appreciate the following descriptions of various coral islands, illustrating their forms, actual size, and condition.

A single group of islands, the Tarawan or Kingsmills, (see annexed plate,) affords good examples of the principal varieties.* The irregularity of shape and size is at once apparent to the eye. In the southernmost, *Taputeouea*, the form is very narrow, the length being thirty-three miles, with the width of the southern portion scarcely exceeding six miles, and that of the northern more than one-half less. The emerged land is confined to one side, and consists of a series of islets, upon the eastern line of coral reef. The western side is for the most part some feet under water, and there is hardly a proper lagoon. Sailing by the island to windward, the patches of verdure thus strung together seem to rise out of a long white line of breakers, the sea surging violently against the unseen coral reef upon which they rest.

Namouti, the next island north, is about twenty miles long by eight broad. The rim of land, though in fewer islets, is similar to that of *Taputeouea* in being confined to the reef fronting northeast. The reef of the opposite side, though bare of vegetation, stands near low tide level, and the whole encloses a large lagoon.

Nanouki and *Apamama*, though smaller than *Namouti*, have the same general character. *Nanouki* is triangular in shape, and has an islet on the western point or cape, which is quite prominent. *Apamama* differs from either of the preceding in having two narrow ship-

* The plate is a reduced copy of the chart of these islands, as surveyed by the Exploring Expedition.

entrances to the lagoon, one through the northwestern reef, and another through the southwestern.

Kuria is a remarkable double island, without a proper lagoon. It consists of two neighbouring groves, each about a square mile in extent, on adjacent patches of reef.

Maiana is quite regularly quadrangular, with an uninterrupted range of land on two of the four sides, and an exposed reef constituting the other two.

Tarava consists of two sides of a triangle. The western reef is wanting, and the sea and lagoon have unbroken communication. In place of it, there are two to ten fathoms water, and a bottom of coral sand. Small vessels may sail in almost anywhere on this side to a good anchorage, and there is a passage for ships of the largest size. The depth within is greater than on the bar, and these inner waters obviously correspond to the lagoon of other islands.

Apia has much resemblance to Apamama in its forest border and lagoon. Moreover, there is a ship-entrance through the southwestern reef.

Maraki is one of the prettiest coral islands of the Pacific. The line of vegetation is unbroken; and from the mast-head it lies like a garland thrown upon the waters. The unpractised eye scarcely perceives in such a view the variation from a circular form, however great it may be. The grove is partially interrupted at one point, where there are indications of a former passage through the reef.

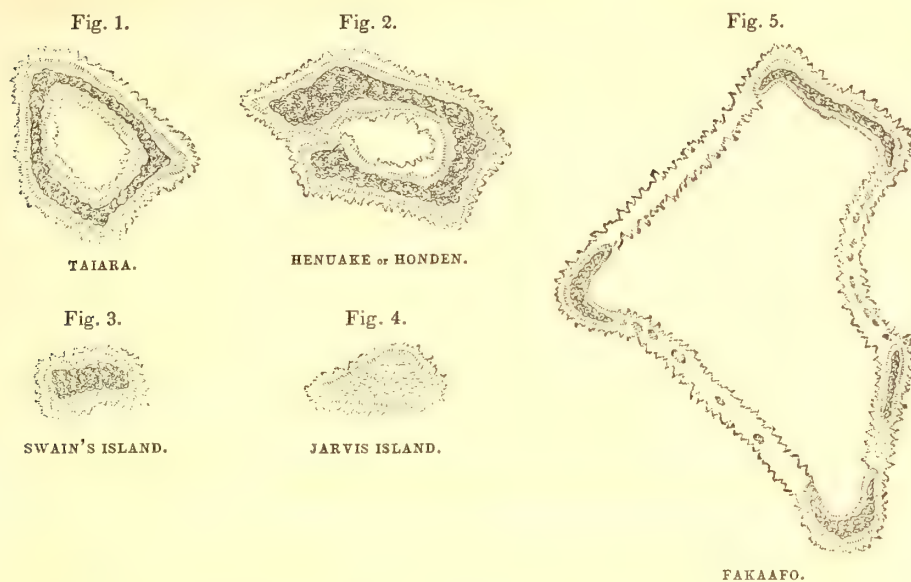
Tari-tari is a large triangular atoll. It is wooded almost continuously on the reef facing southeast, and has a few spots of verdure on the southwest, with three entrances to the extensive lagoon. The northern side is a naked reef throughout, scarcely apparent from a ship's deck, except by the long line of white breakers. *Makin*, just north of *Tari-tari*, is a mere patch of coral reef without a lagoon.

We add a few more descriptions of Pacific islands, with figures reduced from the maps of the Expedition to a scale of four-tenths of an inch to a mile.

Taiara and *Henuake*, (figs. 1 and 2,) are two small belts of foliage, somewhat similar to *Maraki*. *Henuake* possessed an additional charm in being tenanted only by birds; and they were so tame that we took them from the trees as if they had been their flowers.

Swain's and *Jarvis* Islands, (figs. 3 and 4,) are of still smaller size, and have no lagoon. The former is densely covered with foliage, while the surface of the latter is sandy. *Swain's* Island is a little

depressed about the centre, a fact indicating that there was formerly a lagoon.



Fakaafu, or Bowditch, (fig. 5,) 200 miles north of Samoa, is the type of a large part of coral islands. The bank of reef has only here and there emerged from the waves and become verdant; in other portions the reef is of the usual height,—that is, near low tide level,—excepting a few spots elevated a little by the accumulation of sand.

The Paumotu Archipelago, the crowded cluster of coral islands just northeast of Tahiti, is a most instructive study for the reader; and a map of these islands by the Expedition, inserted in the Narrative of the Expedition, and also in the Hydrographical Atlas, will well repay close study. It is called the Low or Dangerous Archipelago. Sailing among these islands, but four of which are over twelve feet high, exclusive of the vegetation, two or three are almost constantly in sight from the mast-head.

The small amount of habitable land on these reef-islands is one of their most peculiar features. Nearly the whole surface is water; the land around the lagoon is but a narrow rim, the greater part of which is usually under water at high tide. This fact will be rendered more apparent from the following table, containing a statement of the sizes and areas of several islands, with the amount of habitable land. The measures are given in geographical miles.

	Length.	Greatest breadth.	Area in square miles.	Habitable part in square miles.
Carlshoff, Paumotus, .	27	13	200	10
Wolchonsky, " .	15	3	40	3
Raraka, " .	15	10	90	8
Manhii, " .	14	6½	50	9
Nairsa or Deans, " .	50	19	1000	16
Fakaafu, Union Group,	7½	4½	20	2½
Clarence, " .	8½	5½	27	2
Taputeouea, Kingsmills,	33	6	60	6
Tarawa, " .	20	10	130	8
Namouti, " .	22	9	125	7
Tari-tari, " .	18	11	110	4

The *ten* islands here enumerated have an aggregate area of 1952 square miles, while the amount of actual dry habitable land is but 76 miles, or less than one twenty-fourth. In the Caroline Archipelago the proportion of land is still smaller. Menchikoff atoll covers an area of 500 square miles, and includes hardly 6 square miles of wooded land. In the Marshall Islands, the dry land is not over one-hundredth of the whole surface; while in the Pescadores the proportion of land to the whole area is about as 1 to 200.

The distribution of the land upon the reef is obvious from the sketches already given. It was long since remarked that the windward side was in general the highest. It is also apparent that there are not only great irregularities of form, but the reef may at times be wholly wanting or deeply submerged on one side.

In many islands there is a ship-entrance, sometimes six or eight fathoms deep, through the reef to the lagoons, where good anchorage may be had; but the larger part have only shallow passages, or none at all. In the Paumotus, of the twenty-eight visited by the Expedition, not one half were found to have navigable entrances. In the Carolines, where the islands are large and not so much wooded, entrances are of more common occurrence. About half of the Kingsmill Islands afford a good entrance and safe anchorage. Through these openings in the reefs there is usually a rapid outward current, especially during the

ebbing tide. At Depeyster Island, it was found to run at the rate of two and a half miles an hour. It was as rapid at Raraka, in the Paumotus, and as Captain Wilkes remarks, it was difficult to pull a boat against it, into the lagoon.

Soundings about Coral Islands.—The water around coral islands deepens as rapidly and in much the same way as off the reefs about high islands. The atoll usually seems to stand as if stilted up in a fathomless sea. The soundings of the Expedition afford some interesting results.

Seven miles east of Clermont Tonnerre, the lead ran out to 1145 fathoms (6870 feet), without reaching bottom. Within three quarters of a mile of the southern point of this island, the lead, at another throw, after running out for a while, brought up an instant at 350 fathoms, and then dropped off again and descended to 600 fathoms without reaching bottom. On the lead, which appeared bruised, a small piece of white coral was found, and another of red; but no evidence of *living* zoophytes. On the east side of the island, three hundred feet from the reef, a bottom of coral sand was found in 90 fathoms; at one hundred and eighty feet, the same kind of bottom in 85 fathoms; at one hundred and thirty feet, a coral bottom in 7 fathoms;—and from this it decreased irregularly to the edge of the shore reef.

Off the southeast side of Ahii (another of the Paumotus), about a cable's length from the shore, the lead after descending 150 fathoms, struck a ledge of rock, and then fell off and finally brought up at a depth of 300 fathoms.

Two miles east of Serle's Island, no bottom was found at 600 fathoms.

A mile and a half south of the larger Disappointment Island, there was no bottom at 550 fathoms.

Near the eastern end of Metia, no bottom was found with a line of 150 fathoms; and a mile distant, no bottom was reached at 600 fathoms.* In general, for one to five hundred yards from the margin

* Beechey, whose observations on soundings are the fullest hitherto published, states many facts of great interest. At Carysfort Island, he found the depth sixty yards from the surf line, 5 fathoms;—80 yards, 13 fathoms;—120 yards, 18 fathoms;—200 yards, 24 fathoms; and immediately beyond, no bottom with 35 fathoms. At Henderson's Island, soundings continued out 250 yards, where the depth was 25 fathoms, and then terminated abruptly. Off Whitsunday Island, 500 feet out there was no bottom at 1500 feet.

Darwin states many facts bearing upon this subject, of which we may cite the follow-

of the shore reef, the water slowly deepens, and then there is an abrupt descent, at an angle of 40 or 50 degrees. The results of earlier voyagers, among whom Beechey stands pre-eminent, correspond with this statement. At considerable depths, as would appear from the above facts, the sides of the coral structure may be vertical or even may overhang the bottom below.

There are examples also of less abrupt slopes. Northwest of the Sandwich Group, Lisiansky, at the island bearing his name, found shallow water for a distance of six or seven miles; the water deepened to ten or eleven fathoms the first mile, fifteen the second, and at the last throw of the lead there were still but twenty-five fathoms.* Christmas Island affords on its western side another example of gradually deepening waters. Yet these shallow waters terminate finally in a rapid declivity of forty or fifty degrees. Off the prominent angles of an atoll, soundings generally continue much beyond the distance elsewhere, as was first observed by Beechey. At Washington Island, mostly abrupt in its shores, there is a bank, according to the surveys of the Expedition, extending from the east point to a distance of half a mile, and another on the west extending to a distance of nearly two miles. At Kuria, one of the Kingsmills, soundings continue for three miles from the north extremity, along a bank stretching off from this point to the north-northwest. Many other instances might be cited, but they are seldom as remarkable; yet nearly all islands, especially if the points are much prominent, afford similar facts. It has been said that the reef to leeward is generally less abrupt than that to windward, but no facts were obtained by the Expedition sufficiently definite or extensive to settle this question. It is probably true, yet the difference if any must be slight.

ing.—At Heawandoo Pholo (one of the Maldives) Lieutenant Powell found 50 or 60 fathoms close to the edge of the reef. One hundred fathoms from the mouth of the lagoon of Diego Garcia, Captain Moresby found no bottom with 150 fathoms. At Egmont Island, 50 fathoms from the reef, soundings were struck in 150 fathoms. At Cardoo Atoll, only 60 yards from the reef, no bottom was obtained with a line of 200 fathoms. Off Keeling Island, 2200 yards from the breakers, Captain Fitzroy found no bottom at 1200 fathoms. Mr. Darwin also states that at a depth between five and six hundred fathoms, the line was partly cut, as if it had rubbed against a projecting ledge of rock; and deduces from the fact "the probable existence of submarine cliffs."

* Voyage round the world, in the years 1803-6, in the ship *Neva*, by N. Lisiansky, Captain in the Russian Navy, 4to, London; pp. 254-257.

b. *Structure of Coral Islands.*

The descriptions of reefs and their islets apply with equal force to coral islands. By transferring here the statements respecting the former, we should have a nearly complete account of the latter. The same causes, with scarcely an exception, are at work:—the growing of coral-zoophytes, the action of the waves, oceanic currents, and the winds. This resemblance will be rendered more apparent by a review of their characters; the description will be found to be a simple recapitulation of a former paragraph.

The reef or the coral atoll, as it lies at the surface still uncovered with vegetation, is a platform of coral rock, usually two to four hundred yards wide, and situated so low as to be swept by the waves at high tide. The outer edge, directly exposed to the surf, is generally broken into channels and jagged indentations, along which the waters of the resurging wave drive with great force. Though in the midst of the breakers, the edge stands a few inches, and sometimes a foot, above other parts of the platform; the incrusting *Nullipores* cover it with varied tints, and afford protection from the abrading action of the waves. There are usually three to five fathoms water near the margin; and below over the bottom, which gradually deepens outward, beds of corals are growing profusely among lifeless patches of coral sand and fragments: often the dead areas much exceed those flourishing with zoophytes, and not unfrequently the clusters are scattered like tufts of vegetation in a sandy plain. The growing corals extend up the sloping edge of the reef, nearly to low tide level. For ten to twenty yards from the margin, the reef is usually very cavernous or pierced with holes or sinuous recesses, a hiding-place for various crabs, or a retreat for the echini, asterias, the sea-anemones, and many a pretty mollusc; and over this portion, the gigantic *Chama* or *Tridacna* is generally found lying more than half buried in the solid rock, with barely room to gape a little its ponderous shell, and expose to the waters a gorgeously coloured mantle. Farther in are occasional pools and basins, alive with all that lives in these strange coral seas.

The reef-rock, wherever broken, shows a detritus origin. Parts are of compact homogeneous texture, a solid white limestone, without a piece of coral distinguishable, and rarely an imbedded shell. But

generally the rock is a breccia or conglomerate, made up of all kinds of corals cemented together into a compact mass, and the fragments of which it consists are sometimes many cubic feet in size.

It is apparent that we are describing a second time an *outer* reef. Without dwelling farther upon its characters, we may pass to the features of the reef when raised above the waters and covered with vegetation.

Sections of coral islands and their lagoons have been given by Captain Beechey and Mr. Darwin. We add another, by way of illustration, although little may be presented that is novel after the excellent descriptions of these authors. Sketches of several of these islands, showing the general relation of the rim of land to the reef and the lagoon within, are given on the preceding plate. The following sketch represents a section of the rim of land from the sea on one



SECTION OF A CORAL ISLAND REEF.

side, (the left,) to the lagoon on the other. In the view, the part *m a*, represents the shallow sea bordering an island, and abruptly deepening one to six hundred feet from the line of breakers. In these shallow waters are the growing corals; yet, as before stated, a large part is barren sand or coral rock.

From *a* to *b* is the shore platform of reef-rock, nearly at low tide level, with the margin (*a*) slightly elevated, and much incrustated at the top with Nullipores. From the platform there is a rise by a steep beach (*b c*), of six or eight feet, to the wooded part of the coral belt represented between *c* and *d*. From *d* to *e* there is a gently sloping beach bordering the lagoon. Beyond *e*, the waters of the lagoon at first deepen gradually, and then fall off more or less abruptly.

In the Paumotus, the shore platform, the steep beach, and the more gently sloping shore of the lagoon are almost constant characteristics.

The width of the whole rim of land, when the island gives no evidence of late elevation, varies from three hundred yards to one-third of a mile, excepting certain prominent points, more exposed to the

united action of winds and waves, and from opposite directions, which occasionally exceed half a mile.*

Shore platform and emerged land.—The shore platform is from one to three hundred feet in width, and has the general features of a half-submerged outer reef. Its peculiarities arise solely from the accumulations which have changed the reef into an island. Much of it is commonly bare at low tide, though there are places where it is always covered with a few inches or a foot of water; and the elevated edge, the only part exposed, often seems like an embankment preventing the water from running off. The tides, as they rise, cover it with water throughout, and bear over it coral fragments and sand, comminuted shells and other animal remains, to add them to the beach. The heavier seas transport larger fragments; and at the foot of the beach there is often a deposit of blocks of coral or coral rock, a cubic foot or so in size, which low tide leaves standing commonly in a few inches of water.†

Besides the deep channels cutting into the margin of the reef and giving it a broken outline, there are long fissures in some instances intersecting its surface. On Aratica, (Carlshoff,) and Ahii, (Peacock Island,) they extended along for a fourth to half a mile, generally running nearly parallel with the shore, and at top were from a fourth to half an inch wide. These fissures are not essential features of the reef, and will come up for consideration on a future page of this volume.

The *beach* usually slopes at an angle of 35 to 45 degrees, and consists of coral pebbles or sand, with some worn shells, and occasionally the exuviae of crabs and bones of fishes. Owing to its whiteness, and the contrast it affords to the massy verdure above, it is a remarkable feature in the distant view of these islands. It often seemed like an artificial wall or embankment, running parallel with the shores. On Clermont Tonnerre, the first of these islands visited by us, the natives

* Beechey states that the rim is generally three to four hundred yards in width, and never exceeds half a mile.—*Voyage*, Amer. ed., p. 160.

† On moving these masses, which generally rest on a few points, and have an open space beneath, the waters at once become alive with fish, shrimps, and crabs, escaping from their disturbed shelter; and beneath appear various living flowers, the spiny echini and sluggish biche-la-mar, while swarms of shells, having a soldier crab for their tenant, walk off with unusual life and stateliness. Moreover, delicate corallines, ascidiæ and sponges tint with lively shades of red, green, and pink, the under surface of the block of coral which had formed the roof of the little grotto.

seen from shipboard, standing spear in hand along the top of the beach, were believed by some to be keeping patrol on the ramparts of a kind of fortification. This deception arose from the dazzling whiteness of the coral sand, in consequence of which the slope of the beach was not distinguished in so distant a view.

The *emerged land* beyond the beach, in its earliest stage when barely raised above the tides, appears like a vast field of ruins. Angular masses of coral rock, varying in dimensions from one to a hundred cubic feet, lie piled together in the utmost confusion; and they are so blackened by exposure, or from incrusting lichens, as to resemble the clinkers of Mauna Loa; moreover, they ring like metal under the hammer. Such regions may be travelled over by leaping along from block to block, with the risk of falling into the many recesses among the huge masses. On breaking an edge from the black masses, the usual white colour of coral is at once apparent. Some of the blocks, measuring five or six feet in each of their dimensions, were found to be portions of individual corals, while others have the usual conglomerate character of the reef-rock.

In the next stage, coral sand has found lodgment among the blocks; and though so scantily supplied as hardly to be detected without close attention, some seeds have taken root, and vines, purslane, and a few shrubs begin to grow, relieving the scene, by their green leaves, of much of its desolate aspect.

Both of these stages are illustrated on the greater part of coral islands.

In the last stage, the island stands six to ten feet out of water. The surface consists of coral sand, more or less discoloured by vegetable or animal decomposition. There is but little depth of coral soil, although the land may appear buried in the richest foliage: and scattered among the trees, stand still uncovered many of the larger blocks of coral, with their usual rough angular features, and blackened surface. The soil is seldom discoloured beyond four or five inches, and but little of it to this depth; there is no proper vegetable mould, but a simple mixture of darker particles with the white grains of coral sand. It is often rather a coral gravel, and below a foot or two, it is often cemented together into a more or less compact coral rock.

One singular feature of the shore platform, occasionally observed, remains to be mentioned. Huge masses of reef-rock are sometimes found upon it, some of which lie loose upon the reef, while others

are firmly imbedded in it below, and so cemented to it as to appear to be actually a part of the platform rock. Sketches of some of these masses are here given.

Fig. 1.

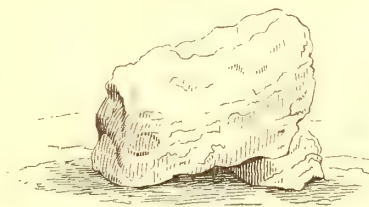


Fig. 2.



Figure 1 represents a mass on the island of Waterland, (one of the Paumotus,) six feet high, and about five in diameter; it was solid with the reef rock below, as though a part of it, and about two feet above its base, it had been so nearly worn off by the waters as to have become irregularly top-shape. Figure 2 is another mass, similarly attached to the reef at base, observed on Kawehe, (Vincennes Island.) It was six feet high above low water level, and seven feet in its longest diameter. Below, it had been worn like the one just described, though to a less extent. Another similar mass was eight feet high. Figure 3 represents a block six feet high and ten feet in its longest diameter, seen on Waterland; it was unattached below, and lay with one end raised on a smaller block. On Aratica, (Carlshoff,) the same were observed. One loose mass like the last was eight feet high and fifteen feet in diameter, and contained at least a *thousand cubic feet*. Raraka also afforded examples of these attached and unattached blocks, some standing with their tops six feet above high water mark.

Fig. 3.



These masses are similar in character to others met with among the fields of blocks just described, and only differ in having been left on the platform instead of being transported over it. Some of them are near the margin of the reef, while others are quite at its inner limit. The third mass figured above was a solid conglomerate, consisting of large fragments of *Astræas* and *Madrepores*, and contained some imbedded shells, among which an *Ostræa* and a *Cypræa* were noticed. This is their general character. The other two were parts of large individual corals (*Porites*); but there was evidence in

the direction of the cells that they did not stand as they grew; on the contrary, they had been upthrown and were afterwards cemented with the material of the rock beneath them, probably at the time this rock itself was consolidated. Below some of the loose masses like figure 3, (as on Aratica,) the platform was at times six inches higher than on either side of the mass, owing to the protection from wear given to the surface beneath it. These blocks are always extremely rough and uneven, like those of the emerging land beyond; and the angular features are partly owing in both cases to solution from rains or from the sea-water that may be dashed over them.

It should be distinctly understood that these masses here described were found isolated, and only at considerable intervals. In no instance were they observed clustered. The loose blocks and those cemented below had the same general character, and must have been placed where they were by the same cause, though it may have been at different periods.

The shore of the lagoon is generally low and gently inclined, yet in the larger islands, in which the waters of the lagoon are much disturbed by the winds, there is usually a beach resembling that on the seaward side, though of less extent. A platform of reef-rock at the same elevation as the shore platform sometimes extends out into the lagoon; but it is more common to find it a little submerged and covered for the most part with growing corals: and in either case, the bank terminates outward in an abrupt descent of a few yards or fathoms, to a lower area of growing corals, or a bottom of sand. Still more commonly, we meet with a sandy bottom gradually deepening from the shores without growing coral. These three varieties of condition are generally found in the same lagoon, characterizing its different parts. The lower area of growing corals slopes outward, and usually ceases where the depth is 10 to 12 fathoms; from this there is another descent to the depth which prevails over the lagoon.

On some small lagoons the shore is a thick plastic mud, either white or like clay, and forms a low flat which is very gently sloping. On Henuake, these mud deposits are quite extensive, and of a white colour. At Enderby's Island, another having a shallow lagoon, the mud was so deep and thick that there was some difficulty in reaching the waters of the lagoon; the foot sunk in 8 or 10 inches and was not extricated without some difficulty. The colour at this island was a dirty brownish clay. This mud is nothing but comminuted coral, so fine as to be almost impalpable.

The *lagoons* of the smaller islands are usually very shallow; and in some, merely a dry bed remains, indicating the former existence of water. Instances of the latter kind are met with only in islands less than three miles in diameter; and those with shallow lagoons are seldom much larger. These shallow waters, when direct communication with the sea is cut off, become, in some instances, very salt by evaporation, and contain no growing coral, with few signs of life of any kind: and in other cases, they are made too fresh for marine life, through the rains. At Enderby's Island the water was not only extremely saline, but the shores of the lagoon were in some places incrustated with salt. But when there is an open channel, or the tides gain access over a bare reef, corals continue to grow, and a considerable portion of the lagoon may be obstructed by them. At Henuake, the sea is shut out except at high water, and there were consequently but few species of corals, and those of small size. At Ahii (Peacock's Island) there was a small entrance to the lagoon, and though comparatively shallow, corals were growing over a large part of it.

In the larger islands, the lagoons contain but small reefs compared with their whole extent; the greater part is an open sea, with deep waters and a sandy bottom. There are instances, as at the southern Maldives, of a depth of 50 and 60 fathoms. Twenty to thirty-five fathoms is the usual depth in the Paumotus. This was the result of Captain Beechey's investigations; and those of the Expedition, though few, correspond. It is however probable that deeper soundings would be found in the large island of Nairisa (Dean's). In the Tarawan Group, southeast of the Carolines, the depth, where examined by the Expedition, varied from 2 to 35 fathoms. Mr. Darwin found the latter depth at Keeling's Island. Chamisso found 25 to 35 fathoms at the Marshall Islands.

The bottom of these large lagoons is very nearly uniform, varying but little, except from the occasional abrupt shallowings produced by growing patches of reef. Soundings bring up sand, pebbles, shells, and coral mud; and the last-mentioned material appears to be quite common, even in lagoons of considerable size. It has the same character as above described. The bluish clay-like mud of the harbour of Tongatabu may be classed with these deposits.* It appears, therefore, that the finer coral material of the shores prevails throughout

* Darwin describes this mud as occurring at the Maldives, and at Keeling Island, (op. cit. p. 26;) Kotzebue mentions it as common at the Marshall Atolls, and Lieutenant Nelson observed it at the Bermudas.

the depths of the lagoon. The growing reefs within lagoons, are in the condition of the *inner* reefs about high islands. The corals grow but little disturbed by the waves, and the reef-rock often contains them in the position of growth. At Taputeouea (Tarawan Group), reefs very similar to those of the Feejees occur; they present the same large *Astræas*, 10 to 12 feet in diameter, which once were growing where they stand, but are now a part of the solid lifeless rock.

Beach formations of coral sandrock are common on the coral islands, and they present the same features in every respect, as those described. They were observed among the Paumotus, on Raraka, Honden, Kawehe, and other islands. The stratified character is always distinct and the layers slope toward the water at the usual small angle, amounting to 5—7 degrees bordering the lagoon, and 7—8 degrees on the seashore side of the land. They often occupy a breadth of 30 to 50 yards, appearing like a series of outcrops, yet not unfrequently they are mostly concealed by the sands of the beach.* The rock is a fine or coarse sandrock, or a coral pudding-stone, and consists of beach materials. Occasionally it is quite compact, and resembles common limestone, excepting in its white colour; but generally its sand origin is very apparent.

The *drift sandrock* was not met with by the writer on any coral islands visited, and probably for the reason that opportunities were not favourable for a thorough exploration. It has been stated that the more exposed points towards the trades, especially the northeast and southwest, are commonly a little higher than other parts; and it is altogether probable that some of the sand-heaps, there formed, will prove on examination to afford examples of this variety of coral-rock. Such situations are exactly identical with those on Oahu, where they occur on so remarkable a scale. Mr. R. H. Schomburgh states that on the island of Anegada in the West Indies, the drift banks on the windward shores are forty feet in height.†

Although in these descriptions of atolls, we have dwelt on some points more at length than when describing barrier reefs, still it will be observed that the former have no essential peculiarities of structure apart from such as necessarily arise from the absence of high rocky

* On the northern atolls of the Maldives, the beach sandrock is said to be quarried out in square blocks and used for building.—*Journ. Geog. Soc.* v. 400.

† *Journal of the Royal Geographical Society*, ii. 152. Mr. Schomburgh describes the sandhills as 40 feet in height, and behind the first range, a second, and even a third.

lands. The encircling atoll-reef, corresponds with the outer reefs that enclose high islands; and the green islets with the beach formations, in the two cases, originate in the same manner.

The lagoons, moreover, are similar in character and position to the inner channels within barrier reefs; they receive only coral material from the action of degrading agents, because no other source of detritus but the reefs is at hand. The accumulations going on within them are, therefore, wholly of coral. The reefs within the lagoons, correspond very exactly in mode of growth and other characters to the *inner* reefs under the lee of a barrier. The corals grow but little disturbed by the waves, and the reef-rock thus formed, often contains them in their natural positions.

The preceding descriptions, represent the general character of atolls, but are more especially drawn from the Paumotus. There are some peculiarities in other seas, to which we may briefly allude.

Among the scattered coral islands north of the Samoan Group, the shore platform is seldom as extensive as at the Paumotus. It rarely exceeds fifty yards in width, and is cut up by passages often reaching almost to the beach. It was not unusual for our boats to obtain a landing by watching for a favourable opportunity at the entrance of one of these channels to mount a wave and ride in on its top. In some places the platform is broken into islets. Enderby's Island is one of the number to which this description applies: the beach is eleven or twelve feet high. For the first eight feet, it slopes very regularly at an angle of 30 to 35 degrees, and consists of sand, coarse pebbles, or rounded stones of coral, with some shells; and there is the usual beach conglomerate near the water's edge. After this first slope, it is horizontal for eighty to two hundred feet, and then there is a gradual rise of three to four feet. Over this portion there are large slabs of the beach conglomerate, along with masses from the reef-rock, and some thick plates of a huge foliaceous *Madrepora*; and these slabs, many of which are six feet square, lie inclining quite regularly against one another, as if they had been taken up and laid there by hand. They incline in the same direction with the slope of the beach. The large *Madrepora* alluded to has the mode of growth of the *Madrepora palmata*; and probably the entire zoophyte extended over an area twelve or fifteen feet in diameter. The fragments are three to four inches thick, and thirty square feet in surface.

As a key to the explanation of the peculiarities here observed, it

may be remarked that the tides in the Paumotus are two to three feet, and about Enderby's Island five to six feet in height.

Maldives.—Chagos Bank.—The Maldives have been often appealed to in illustration of coral structures. They are particularly described by Mr. Darwin, from information communicated to him by Captain Moresby, and from the charts of this officer and Lieutenant Powell.* The point of special interest in their structure is the occurrence of atolls or rings within the larger atolls. The islets of the lagoon, and those of the encircling reef, are in many instances annular reefs, each with its own little lake. Gems within gems are here clustered together.

The annular islets of the main encircling reef are oblong, and lie with the longest diameter, which is sometimes three miles long, in the line of the reef. Those of the lagoon are generally less than two miles across. The lagoons they contain vary from five fathoms or less to twelve fathoms in depth.

The Maldives are among the largest atoll-reefs known; and they are intersected by many large open channels; and Mr. Darwin observes, that the interior atolls occur only near these channels, where the sea has free access. We may view each large island in the archipelago as a sub-archipelago of itself. Although thus singular in their features, they illustrate no new principles with regard to reef-formations.†

* Darwin on Coral Reefs, p. 32. See also Journal of the Royal Geographical Society, on the Geography of the Maldives, by J. J. Horsburgh, ii. p. 72; and by Captain W. F. W. Owen, *ibid.*, p. 81; also vol. v., p. 398, on the Northern Atolls of the Maldives, by Captain Moresby.

† Mr. Darwin thus remarks, (*Op. cit.* pp. 33, 34,)—"I can in fact point out no essential difference between these little ring-formed reefs, (which, however, are larger, and contain deeper lagoons than many true atolls that stand in the open sea,) and the most perfectly characterized atolls, excepting that the ring-formed reefs are based on a shallow foundation instead of the floor of the open sea, and that instead of being scattered irregularly, they are grouped closely together."—"It appears from the charts on a large scale, that the ring-like structure is contingent on the marginal channels or branches being wide, and consequently on the whole interior of the atoll being freely exposed to the waters of the open sea. When the channels are narrow, or few in number, although the lagoon be of great size and depth, (as in Suadiva,) there are no ring-formed reefs; where the channels are somewhat broader, the marginal portions of reef, and especially those close to the larger channels, are ring-formed, but the central ones are not so: where they are broadest, almost every reef throughout the atoll is more or less perfectly ring-formed. Although their presence is thus contingent on the openness of the marginal channels, the

The *Chagos Bank* lies about ten degrees south of the Maldives, and is ninety miles long and seventy broad. The rim is mostly submerged from five to ten fathoms.

Mr. Darwin confirms the opinion of Captain Moresby, that this bank has the character of a lagoon reef, resembling one of the Maldives; and he states on the evidence of extensive soundings, that, if raised to the surface, it would actually become a coral island, with a lagoon forty fathoms deep. In the words of Captain Moresby, it is in truth nothing more than a half-drowned atoll.*

Metia, and other elevated coral islands.—In the Chagos Group we have an example of a *sunken* coral atoll. Metia affords an instance of one that has been *elevated* by some force; and several such are met with in the Pacific. Metia, or Aurora Island, is one of the western Paumotus. It is a small island, about four miles by two and a half in width, and two hundred and fifty feet in height; and it consists throughout of coral limestone. As we approached it from the northeast, its high vertical cliffs were supposed to be basaltic, and had much resemblance to the Palisades of the Hudson.† This appearance of a vertical structure was afterwards traced to vertical furrowings by the waters dripping down its front, in connexion with stalagmitic incrustations. Deep caverns were also seen.

The cliff, though vertical in some parts, is roughly sloping in others, and on the west side the surface of the island gradually declines to the sea.

The rock was found to be a white and solid limestone, seldom presenting any traces of its coral origin. In some layers there were disseminated corals, looking like imbedded fossils, along with some beautiful casts of shells; but for the most part it was as compact as any secondary marble, and as uniform in texture. Occasionally there were disseminated spots of crystallized calc spar.

The caverns presented us with coarse stalactites, some of which were six feet in diameter; and handsome specimens were obtained, containing recent land shells, which had been enclosed while hibernating.‡

theory of their formation, as we shall hereafter see, is included in that of the parent atolls, of which they form the separate portions.”

* Darwin, op. cit. p. 39.

† For a sketch of this island, see Narrative Exp. Exp., vol. i., p. 338.

‡ It is probable that more extensive caverns would have been found, had there been more than a few hours for the examination of the island. The Rev. Mr. Williams, in

The surface of the island is singularly rough, owing to erosion by rains. The paths that cross it wind through narrow passages among ragged needles and ridges of rock as high as the head, the peaks and narrow defiles forming a miniature model of the grandest Alpine scenery. There is but little soil, yet the island is covered with trees and shrubbery.

The shores, at the first elevation of the island, must have been worn away to a large extent by the sea; and the cliff and some isolated pinnacles of coral rock still standing on the shores are evidence of the degradation. But at present there is a shore platform of coral reef, two hundred or two hundred and fifty feet wide, resembling those of the low coral islands, and having growing coral as usual about its margin, and in the shallow depths beyond.

In the face of the cliff there are two horizontal lines, along which cavities or caverns are most frequent, which consequently give an appearance of stratification to the rock, dividing it into three nearly equal layers.

We might continue our account of coral reefs and islands, by particular descriptions of those visited by the Expedition. But the similarity among them is so great, and their peculiarities are already so fully detailed, that this would amount only to a succession of repetitions. And moreover the facts will be found in the geographical report by Captain Wilkes, and are to a great extent well exhibited on the map of the Paumotus and on the other valuable charts of the Expedition. The characters of a few briefly stated will suffice in this place. We commence with the smallest.

Jarvis's Island. (Fig. 4, page 53.) Lat. $0^{\circ} 22'$ S. Long. $159^{\circ} 31'$ W. Length $1\frac{3}{4}$ miles, trending east and west. No lagoon. Shape triangular. A low sandy flat, eighteen or twenty feet high, without

his work on Missionary Enterprises in the Pacific, gives very interesting descriptions of caverns in the *elevated* coral rock of Atiu, one of the Hervey Group.^a In one, he wandered two hours without finding a termination to its windings, passing through chambers with "fretwork ceilings of stalagmite and stalactite columns, which, 'mid the darkness, sparkled brilliantly with the reflected torch-light." This author remarks, "that while the madrepores, the brain, and every other species of coral are full of little cells, these islands, (including those resembling Atiu,) appear to be *solid masses of compact limestone, in which nothing like a cell can be detected.*"

Beechey, in his description of Henderson Island, another of this character, speaks of the rock as *compact, and having the fracture of a secondary limestone.*

* Wateoo of Cook.

trees, and partly covered with small shrubs. A high sloping beach continuous around. Trends east and west. Did not land.

Birnie's. Lat. $3^{\circ} 35'$ S. Long. $171^{\circ} 39'$ W. $\frac{1}{2}$ of a mile by $\frac{1}{3}$, trending northwest. No lagoon. A sandy flat about ten feet high, except near the north-northeast extremity, where it is about twelve feet. To the south-southwest the submerged reef extends out nearly a mile, over which the sea breaks. Distinguished no vegetation except some low trailing plants. Did not land.

Swain's. (Fig. 3, page 53.) Lat. $11^{\circ} 10'$ S. Long. $170^{\circ} 52'$ W. $1\frac{1}{4}$ miles by $\frac{2}{3}$; shape nearly rectangular, and trend east and west. No lagoon, but the centre a little lower than the sides. Surface covered with large trees and shrubbery, among which are many cocoanuts; the centre more sparsely wooded. The height fifteen to eighteen feet, excepting on the middle of western side, where the surface is covered with loose fragments of coral of small size; there appears to have been a former entrance to the lagoon at this place. Shore reef or platform, one hundred yards in average width, and one hundred and fifty yards at the place where we landed. Beach high, ten to twelve feet. At lower part of beach, for a height of two to three feet, the coral reef-rock was exposed, indicating an elevation of the island. For three or four feet above this, layers of the beach sandrock were often in view, consisting of coral pebbles firmly cemented, and having the usual dip of seven or eight degrees seaward; in many places it was concealed by the beach sands and pebbles. There was no growing coral on the platform excepting some Nullipores. The outer margin of this platform was very uneven, and much intersected by channels, though less so than at Enderby's Island.* Great numbers of Birgi, (large Crustacea,) were burrowing over the island, some of which were six inches in breadth.

* The sea was quite heavy when we attempted to land at low tide upon the edge of the shore platform. As we pulled towards the reef, an anchor was dropped, as usual, some distance out, to hold on and save the boat from being carried by the surges against the rocks. After some heavy seas had passed, a partial lull seemed to favour, and the boat was pulled in. Taking advantage of the favourable moment, I jumped out, and made rapid speed over the reef to escape the breakers which followed. Soon turning about, I was surprised to find the boat just behind me, and the crew in the water alongside trying to steady her and save her from destruction. The man who held to the anchor behind had let go his hold, and the next sea, as it came careering on, had borne the boat over the edge of the reef, and far on its surface. With even greater risk, after our ramble was completed, we succeeded in launching again and reached the open sea. This was one of many similar dangers experienced in these seas.

Otuhu, Paumotu Archipelago. $14^{\circ} 5' S.$ $141^{\circ} 30' W.$ $1\frac{1}{2}$ miles by $\frac{2}{3}$, trending north and south. No lagoon. Wooded.

Margaret, Paumotu Archipelago. $20^{\circ} 42' S.$ $143^{\circ} 4' W.$ Diameter one mile, nearly circular. A small shallow lagoon with no entrance. Northeast side alone wooded, and in two patches.

Teku or *Four Crowns*, Paumotu Archipelago. $20^{\circ} 28' S.$ $143^{\circ} 18' W.$ Diameter $1\frac{1}{2}$ miles, nearly circular. A small lagoon with no entrance. Southwestern reef bare; five patches of forest on the other part.

Washington Island. Lat. $4^{\circ} 41' N.$ Long. $160^{\circ} 15' W.$ 3 miles by $1\frac{1}{4}$, trending east and west. It is a dense cocoanut grove, with luxuriant shrubbery. No lagoon. The shore platform is rather narrow. A point of submerged reef one and a half miles long stretches out from southwest end. Could not land on account of bad weather.

Enderby's. $3^{\circ} 8' S.$ $171^{\circ} 16' W.$ $2\frac{3}{4}$ miles by 1 mile nearly, trending NNW. and SSE.; form trapezoidal or nearly rectangular. Little vegetation in any part, and but few trees. The lagoon very shallow and containing no growing coral; its shores a coral mud, allowing the foot to sink in eight or ten inches, and covered in places with saline incrustations. Shore platform one hundred feet or less in width, and surface inclined outward at a very small angle; covered with three or four feet of water at high tide, and with few corals or shells; beyond this, falls off four to six feet, and then the bottom gradually inclines for one hundred yards or more. The beach very high and regular; rises eight feet, at an inclination of thirty to thirty-five degrees; then horizontal for eighty to two hundred, after which another rise of three or four feet. It consists below of pebbles and fine sand, but above of slabs and blocks of coral rock and the beach sandrock, those of the latter nearly rectangular and flat. This beach sandrock occurs in layers from ten to twenty inches thick along the shore, and is inclined from five to seven degrees seaward. Some portions are very compact, and ring under the hammer, while others enclose fragments of different sizes to a foot or more in diameter. The most common coral of the beach was an *Astræa* with small cells, (near *A. cerium*, D.;—the specimens were afterwards lost.) There were also other *Astræas*, a large lamellar *Madrepore*, (*M. cyclopea*), some fragments of which were six feet square and three inches thick; also *Meandrinæ*, *Porites*, &c. Large trunks of transported trees lay upon the island, one of which was forty feet

long and four in diameter. The shore platform was much intersected by channels.

Captain Hudson obtained soundings half a mile off in two hundred fathoms; the lead struck upon a sandy bottom but was indented by coral.

Honden, or *Henuake*, Paumotu Archipelago.—Size $3\frac{1}{2}$ miles by 2 miles. Oblong, five-sided; trending west-northwest. A small shallow lagoon, communicating with the sea only at high tide, on the west side. There are two other entrances, which are seldom if ever covered with water, and appeared merely as dry beds of coral rock. Height of the island, twelve feet: lowest on the south side. Belt of verdure complete, and consisting of large forest trees, with the Pandanus and other species, but no cocoanuts. Breadth $\frac{1}{2}$ mile, and in some parts $\frac{3}{4}$. Among the trees, large masses of coral rock often exposed to view, and the surface in many parts very rough. It seemed surprising at all these islands to find so luxuriant a growth of trees and shrubbery over so rough a region. Shores of the lagoon nearly flat. On one side there was a large area of extremely fine coral sand and mud, which extended a long distance into the lagoon. Elsewhere, about the centre of the island, the reef-rock was bare, and contained numerous shells of *Tridacnæ*. A few small Madrepores still growing in the lagoon. Beach on the sea-shore side eight feet high. In lower part of beach, several layers of white limestone, formed of coral fragments or sand, shells, &c., much of which was very compact. The layers inclined towards the sea at an angle of about five degrees. Shore platform as elsewhere in this archipelago.—See figure 2, page 53.

The facts above stated are evidence of a slight elevation, not exceeding two or three feet.

Taiara, or *King's*, Paumotu Archipelago.— $15^{\circ} 42' S.$; $144^{\circ} 46' W.$ $2\frac{3}{4}$ miles by $1\frac{3}{4}$, trending northwest. A small lagoon with no entrance. Reef almost continuously wooded around, somewhat broken into patches.—See figure 1, page 53.

Maraki, Tarawan Group.—5 miles by 2, and having a lagoon. Trending north. Shape oblong triangular. Belt of forest complete. Appearance of a former entrance to the lagoon on the east side.

Whytuhu, one of the two Disappointment Islands, Paumotu Archipelago.— $14^{\circ} 10' S.$, $141^{\circ} 24' W.$ $5\frac{1}{2}$ by 2 miles, trending northwest. The reef fronting northeast almost continuously wooded. On the opposite side three islets, one of rather large size. Lagoon with no entrance.

Sydney Island.—Lat. $4^{\circ} 20'$ S. Long. $171^{\circ} 15'$ W. Trending northeast and southwest. Well wooded nearly all round; but on leeward side the forest in patches, with breaks of bare coral. Lagoon narrow, without entrance. Width of island from sea to lagoon, one hundred to four hundred yards: width greatest at south end. Beach ten feet high. The soil of the island consisted of coral fragments and sand. Shore platform fifty to eighty feet wide; five or six feet water over it at high tide. Cut up very irregularly by channels three to eight or ten feet wide. Observed small corals growing on the bottom outside of the platform. Shores of lagoon shallow for fifty yards, and consisting of coral sand. Beyond this a slope covered with growing corals. The corals rather tender species of Madreporae. In the interior of the lagoon many knolls and large patches of coral.

Duke of York's.— $8^{\circ} 38'$ S., $172^{\circ} 27'$ W. Form irregularly oblong, trending northwest. Length $3\frac{3}{4}$ miles; breadth 2 miles. Circuit $9\frac{1}{2}$ miles, and about one-half wooded in patches. Southwest reef mostly bare. A lagoon, but without entrance except for canoes at high tide, on leeward side. Island ten feet high. Shore platform narrow, and intersected by channels. Shores lined by reef-rock, two to three feet out of water, indicating an elevation of the island. This reef-rock consists of various corals firmly cemented. Within the lagoon, knolls of coral, but none near the shore on the leeward side.

Fakafo, or Bowditch's.— $9^{\circ} 20'$ S., $171^{\circ} 5'$ W. $6\frac{3}{4}$ miles by 4. Shape nearly triangular. Circuit seventeen miles, about six of which are wooded in several patches, separated by long intervals. A large lagoon, but no ship entrance. Height of island, fifteen feet. Width to the lagoon, one hundred to two hundred yards. Soil of the island coral sand, speckled black with results of vegetable decomposition. Shore platform narrow. At outer edge a depth of three fathoms, and from thence gradually deepens, and abounds in fine corals for fifty yards, when it deepens abruptly. Coral reef-rock elevated three or four feet, indicating an elevation of the island. Lagoon shallow, with some growing coral, but none near the shore. Some corals growing on the platform, near its margin, mostly small Madreporae, Astræas, Nullipores. Fragments of pumice were found among the natives, which had been floated to the island.—See figure 5, page 53.

Ahii, or Peacock's Island, Paumotu Archipelago.— $14^{\circ} 30'$ S., $146^{\circ} 20'$ W. 13 miles by 6, trending N.E. by E. Shape irregularly oblong. A large lagoon, having an entrance for small vessels, on the west. The reef wooded throughout nearly its whole circuit. Lagoon

shallow, and much obstructed by growing coral, the latter giving the water over it a clear light green colour. Platform, or outer coral shelf of the island, about two hundred and fifty feet wide; under water except at the lowest tides. Margin highest, and covered with Nullipore incrustations, which give it a variety of delicate shades of colour, mostly reddish, or peach-blossom red, rose, scarlet. For thirty to fifty feet from the margin, very cavernous, and containing many *Tridacnæ*, lying half imbedded, with the variously tinted mantle expanded when the surface is covered with water. Rock of the platform either a compact white limestone or a solid conglomerate; dead over its surface, excepting a few *Madrepore* tufts or *Astræas* near the margin in pools. In this shelf there were long fissures, extending nearly parallel with the shore, a quarter to half an inch wide at top, and continuing sometimes a fourth of a mile or more. These fissures were commonly filled with coral sand. The higher parts of the island either consisting of loose blocks of coral or covered with some soil; the soil mostly of comminuted coral and shells, with dark particles from vegetable decomposition intermingled. On the bottom exterior to the shore platform, observed the same corals growing as occurred in fragments upon the island; but the larger part of the bottom was without coral, or covered only with sand.

Raraka, Paumotu Archipelago.— $16^{\circ} 10'$ S., 145° W. 14 miles by 8 miles, trending east and west. Shape nearly triangular. North side nearly continuously wooded: south angle and southwest reef bare. A large lagoon with an entrance for small vessels on the north side. A rapid current flows from the entrance, which it was difficult for a boat to pull against. Shore platform, as usual, about a hundred yards wide, with the edge rather higher than the surface back; the platform mostly bare of water at low tide. Several large masses of coral and coral rock, one to four hundred cubic feet, on the platform and upon the higher parts of the island, some of which stood five and six feet above high water mark. They were cemented to the reef-rock below, and appeared like projecting parts of the reef. Layers of beach sand-rock on the lagoon shores, as well as on the seaward side, inclined at an angle of six or seven degrees: characters as already described. Growing coral in the entrance to the lagoon, within two feet of the surface, mostly a species of *Millepora*, (*M. squarrosa*.) Interior of the lagoon not examined for want of time. The water looked as blue as the ocean, and was much roughened by the winds.

Kawehe, or Vincennes Island, Paumotu Archipelago, $15^{\circ} 30' S.$, $145^{\circ} 10' W.$ 13 miles by 9, trending north-northwest. Shape irregularly oval. Having a large lagoon, and mostly wooded around, least so to leeward. Between the wooded islets, (as on Raraka and elsewhere,) surface consisted of angular masses of coral rock, (among which the *Porites* prevailed,) strewed in great numbers together; and in some parts bearing a few vines and purslane among the blocks, though scarcely any appearance of soil, or even of coral sand. In other parts, not as high, no vegetation, and surface still wet by high tide. A few large masses of coral on the shore platform, either lying loose, or firmly attached below. Some of these were six feet cube, and one was raised seven feet above high water mark. Those that were attached were so firmly cemented to the reef-rock as to seem to be a part of it, and they were partly worn off below by the wash of the sea. The surface was extremely rough, owing to wear by rains. These masses were sometimes single individual corals, and others were conglomerate in character. Shore platform about a hundred yards wide, rather the highest at the edge, and much of its surface two to four feet under water at low tide. As elsewhere, this platform is nothing but a compact coral conglomerate, having no growing coral over it, except in some shallow pools near its outer margin, where also there are numerous holes in which crabs are concealed, with small fish and other animals of the shores. On the lagoon shore, layers of beach sand-rock, six or seven in number, dipping at an angle of seven degrees towards the lagoon, and outcropping one from beneath the other. Similar layers on the sea-shore side.

Manhii, Wilson's or Waterlandt, Paumotu Archipelago, $14^{\circ} 25' S.$, $146^{\circ} W.$ 15 miles by 6, trending E.N.E. A large lagoon with a deep entrance on the west side. Shape oblong triangular.

Shore platform as usual; mostly under water at low tide. Large masses of coral here and there, standing on this reef, either cemented to it or not. One top-shaped mass is figured on p. 61. High water did not reach the part of it which was most worn; and this was evidently owing to the fact that the action of the swell, or waves, was greatest above the actual level of the tide at the time. This mass was not of fragmentary composition; it was apparently the remains of a single individual *Astræa*. Another loose mass was five and a half feet high, and averaged ten feet across, (fig. 3, p. 61.) It consisted of large masses of *Astræas*, *Madrepores*, and *Porites* cemented together, and contained imbedded shells, an *Astræa*, *Cypræa*, &c. The reef-

rock is either a compact limestone, showing no traces of its composite origin, or a conglomerate. Beach, regular as usual, 6 to 10 feet high, consisting of coral sand, and fragments of worn shells, with occasional exuviæ of crabs, remains of echini, fish, &c. The entrance to the lagoon is deep and narrow, with vertical sides.

Aratica or *Carlshoff*, Paumotu Archipelago, 15° 30' S. 145° 30' W. 17 miles by 10, trending N.E. Large lagoon, with a good entrance for vessels. The reef fronting south, bare for nine miles: on northwest side, mostly very low, with only here and there a clump of trees; occasionally a line of wooded land for a quarter of a mile on the east side; more continuously wooded on the north. The bare parts, mostly covered with blocks of coral, 1 to 30 cubic feet, and larger, tumbled together, as on the preceding. Some blocks of coral on the shore platform very large; one 8 feet high and 15 in diameter, containing at least 1000 cubic feet: it lay on the reef and was not connected with it; below it the platform was 6 inches higher than the surface either side, owing to the action of the sea. These blocks are in all instances rough angular, and appear as if they had been thrown up by the sea, and left exposed to wear from the rains and spray.

Nairsa or *Dean's*, Paumotu Archipelago, 15° S. 148° W. 44 miles by 17, trending W.N.W. Northern shore mostly wooded. Southern only an occasional islet, connected by long lines of bare reef. In these intervals the reef stood eight feet or so out of water, and was worn into a range of columns, or excavated with caverns, so as to look very much broken, though quite regularly even in the level of the top line.

We might continue these descriptions; but the above will convey a general idea of the whole.

c. *The Completed Coral Island.*

The coral island in its best condition is but a miserable residence for man. There is poetry in every feature: but the natives find this a poor substitute for the breadfruit and yams of more favoured lands. The cocoonut and pandanus are, in general, the only products of the vegetable kingdom afforded for their sustenance, and fish and crabs from the reefs their only animal food. Scanty too is the supply; and infanticide is resorted to in self-defence, where but a few years would

otherwise overstock the half-a-dozen square miles of which their little world consists.

Yet there are more comforts than might be expected on a land of so limited extent,—without rivers, without hills, in the midst of salt water, with the most elevated point but ten feet above high tide, and no part more than 300 yards from the ocean. Though the soil is light and the surface often strewed with blocks of coral, there is a dense covering of vegetation to shade the native villages from a tropical sun. The cocoanut, the tree of a thousand uses, grows luxuriantly on the coral-made land, after it has emerged from the ocean; and the scanty dresses of the natives, their drinking vessels and other utensils, mats, cordage, fishing-lines, and oil, besides food, drink, and building material, are all supplied from it. The Pandanus or screw-pine flourishes well, and is exactly fitted for such regions: as it enlarges and spreads its branches, one prop after another grows out from the trunk and plants itself in the ground; and by this means its base is widened and the growing tree supported. The fruit, a large ovoidal mass made up of oblong dry seed, diverging from a centre, each near two cubic inches in size, affords a sweetish husky article of food, which, though little better than prepared corn-stalks, admits of being stored away for use when other things fail. The extensive reefs, abound in fish which are easily captured, and the natives, with wooden hooks, often bring in larger kinds from the deep waters. From such resources a population of 10,000 persons is supported on the single island of Taputeouea, whose whole habitable area does not exceed six square miles.*

Water is usually to be found in sufficient quantities for the use of the natives, although the land is so low and flat. They dig wells five to ten feet deep in any part of the dry islets, and generally obtain a constant supply. These wells are sometimes fenced around with special care; and the houses of the villages, as at Fakaafo, are often clustered about them. On Aratica (Carlshoff) there is a watering place 50 feet in diameter, from which our vessels in a few hours obtained 390 gallons. The Tarawan Islands are generally provided with a supply sufficient for bathing, and each native takes his morning bath in fresh water, esteemed by them a great luxury. On Taritari,

* There are a few islands better supplied with vegetable food, though the above statements are literally true of a large majority.

as Mr. Hale was informed by a Scotch sailor by the name of Gray, taken from the island, there is a long trench or canal, described by him as several miles long, and two feet deep. They have *taro* plantations, which require a large supply of water, besides some breadfruit. These islands have been elevated a little, but are not over fifteen feet above the sea.*

The only source of this water, is the rains, which, percolating through the loose surface, settle upon the hardened coral rock that forms the basis of the island. As the soil is white or nearly so, it receives heat but slowly, and there is consequently but little evaporation of the water that is once absorbed.

These islands moreover enclose ports of great extent, many admitting even the largest class of vessels: and the same lagoons are the pearl fisheries of the Pacific.

An occasional log drifts to their shores, and at some of the more isolated atolls, where the natives are ignorant of any land but the spot they inhabit, they are deemed direct gifts from a propitiated deity. These drift-logs were noticed by Kotzebue, at the Marshall Islands, and he remarked also that they often brought stones in their roots. Similar facts were observed by us at the Tarawan Group, and also at Enderby's Island and elsewhere.

The stones at the Tarawan Islands, as far as we could learn, are generally basaltic, and they are highly valued for whetstones, pestles, and hatchets. The logs are claimed by the chiefs for canoes. Some of the logs on Enderby's Island were forty feet long, and four in diameter.

Fragments of pumice and resin are transported by the waves to the Tarawan Islands. We were informed that the pumice was gathered from the shores by the women, and pounded up to fertilize the soil of their taro patches; and it is so common that one woman will pick up a peck in a day. Pumice was also met with at Fakaafu. Volcanic

* The Scotchman (Gray) from whom this information was obtained, added that ten ships of the line might water there, though the place was not reached without some difficulty. There were fish in the pond which had been put in while young. The bottom was adhesive like clay. He spoke of the taro as growing to a very large size, and as being in great abundance; it was planted along each side of the pond.

Kotzebue observes, that "in the inner part of Otdia [one of the Marshall Islands], there is a lake of sweet water; and in Tabual, of the group Aur, a marshy ground exists. There is no want of fresh water in the larger islands; it rises in abundance in the pits dug for the purpose."—*Voyage*, London, 1821, iii. 145.

ashes are sometimes distributed over these islands, through the atmosphere; and in this manner the soil of the Tonga Islands is improved, and in some places it has received a reddish colour.

The officers of the *Vincennes* observed several large masses of compact and cellular basalt on Rose Island, a few degrees east of Samoa: they lie two hundred yards inside of the line of breakers. The island is uninhabited, and the origin of the stones is doubtful; they may have been brought there by roots of trees, or perhaps by some canoe.

Notwithstanding the great number of coral islands in the Paumotu Archipelago, the botanist finds there, as Dr. Pickering informs me, only twenty-eight or twenty-nine native species of plants. The following are the most common of them:—

Portulacca, two species.	<i>Pemphis acidula</i> .
<i>Scævola</i> Konigii.	<i>Guettarda speciosa</i> .
<i>Pisonia</i> ? one species.	<i>Triumphetta procumbens</i> .
<i>Tournefortia sericea</i> .	<i>Suriana maritima</i> .
<i>Pandanus odoratissimus</i> .	<i>Convolvulus</i> , one species.
<i>Lepidium</i> , one species.	<i>Urtica</i> , one or two species.
<i>Euphorbia</i> , one species.	<i>Asplenium nidus</i> .
<i>Morinda citrifolia</i> .	<i>Achyranthus</i> , one species.
<i>Boerhavia</i> , two species.	A species of grass.
<i>Cassytha</i> , one species.	One or two rubiaceous shrubs.
<i>Heliotropium prostratum</i> .	<i>Polypodium</i> .

On Rose Island Dr. Pickering found only the *Pisonia* and a *Portulacca*. The *Triumphetta procumbens*, a creeping plant, takes root like the *Portulacca*, in the most barren sands, and is very common. The *Tournefortia* and *Scævola* are also among the earliest species. The *Pisonia*, a tree of handsome foliage, the *Pandanus* or Screw-pine, and the *Cocoanut*, (always an introduced species,) constitute the larger part of the forests. In the Marshall Group, where the vegetation is more varied, Chamisso observed fifty-two native plants, and in a few instances the banana, taro, and breadfruit.

The language of the natives indicates their poverty, as well as the limited productions and unvarying features of the land. All words like those for mountain, hill, river, and many of the implements of their ancestors, as well as the trees and other vegetation of the land from which they are derived, are lost to them; and as words are but signs for ideas, they have fallen off in general intelligence. It would be an interesting inquiry for the philosopher, to what extent a race of men placed in such circumstances are capable of mental improvement. Perhaps the query might be best answered by another, How many

of the various arts of civilized life could exist in a land where shells are the only cutting instruments,—the plants in all but twenty-nine in number,—but a single mineral,—quadrupeds none, with the exception of foreign mice,—fresh water barely enough for household purposes,—no streams, nor mountains, nor hills? How much of the poetry or literature of Europe would be intelligible to persons whose ideas had expanded only to the limits of a coral island,—who had never conceived of a surface of land above half a mile in breadth,—of a slope higher than a beach,—of a change of seasons beyond a variation in the prevalence of rains? What elevation in morals should be expected upon a contracted islet, so readily over-peopled that threatened starvation drives to infanticide, and tends to cultivate the extremest selfishness? Assuredly there is not a more unfavourable spot for moral or intellectual development in the wide world than the coral island, with all its beauty of grove and lake.

These islands are exposed to earthquakes and storms like the continents, and occasionally a devastating wave sweeps across the land. During the heavier gales the natives sometimes secure their houses by tying them to the cocoanut trees, or to a stake planted for the purpose. A height of ten or twelve feet, the elevation of their land, is easily overtopped by the more violent seas; and great damage is sometimes experienced. The still more extensive earthquake-waves, such as those which have swept up the coast of Spain, Peru, and the Sandwich Islands, would produce a complete deluge over these islands. We were informed by both Gray and Kirby, that effects of this kind had been experienced at the Tarawan Islands; but the statements were too indefinite to determine whether the results should be attributed to storms or to this more violent cause.

The preceding pages have been occupied with a simple description of the actual condition, structure, and appearances of reefs and reef islands. From this review of their existing features, we may pass on to the consideration of those agencies by which these features were produced, tracing out the steps in the progress of such formations, and the influence of various causes on their forms and distribution. We may commence with a brief account of the living zoophyte, its habits and its mode of growth,—as some knowledge on these points is essential to the correct appreciation of the discussion before us. This branch of the subject has been treated of at length in another volume, to which reference may be made for fuller details.*

* Report on Zoophytes, by the author.

II. STRUCTURE, GROWTH, AND HABITS OF CORAL ZOOPHYTES.

1. *Structure and Growth of Zoophytes.*

A singular degree of obscurity has been thrown around the growth of coral zoophytes and coral formations, through the various speculations which have been offered in place of facts; and to the present day, the subject is seldom mentioned without the qualifying adjective *mysterious* expressed or understood. Some writers, scouting the idea that reefs of rocks can be due in any way to "animalcules," talk of electrical forces, the first and last appeal of ignorance. Others call in the fishes of the seas, suggesting that they are the masons, and work with their teeth in the accumulation of the calcareous material. Very many of those who discourse quite learnedly on zoophytes and reefs, imagine that the polyps are mechanical workers, heaping up these piles of rock by their united labours; and science still retains such terms as polypary, polypidom, as if each coral were the constructed hive or house of a swarm of polyps, like the honeycomb of the bee, or the hillock of a colony of ants.

It is vain to hope to understand fully the works of Him who is himself infinite and incomprehensible. The scrutinizing eye of science penetrates with far-reaching sight the system of things about us, and in the dim limits of vision reads everywhere the word mystery. All life, animal and vegetable, and all that is inanimate, declare it; surely there is no special reason, except such as may arise from want of study and consideration, for attributing it pre-eminently to the humblest grades of existence.

It is not more surprising nor a matter of more difficult comprehension that the polyp should form coral, than that the quadruped should form its bones, or the mollusc its shell. The processes are similar, and so the result: in each case it is a simple animal secretion, a formation of stony matter from the aliment which the animal receives, produced by certain parts of the animal fitted for this secreting process. This power of secretion is the first and most common of those that belong to living tissues; and though differing in different organs according to their end or function, it is all one process, both in nature or cause, whether in the animalcule or in man. Coral is never,

therefore, an agglutination of grains made by the handiwork of the many-armed polyps: for it is no more an act of labour than bone-making in ourselves. And again, it is not a collection of cells into which the coral animals may withdraw for concealment, any more than the skeleton of a dog is its house or cell: for every part of the coral of a polyp in most reef-making species is enclosed *within* the polyp, where it was formed by the secreting process.*

It is important that this point should be thoroughly understood, and fully appreciated. That error may no longer be perpetuated, the words polypary and the like, have been rejected by the author in the volume on Zoophytes, and the more familiar term *corallum* has been used instead.† With this introductory explanation, we proceed.

a. *Structure of Coral Animals or Polyps.*—A good idea of a coral polyp may be had from comparison with the garden aster: for the likeness in external form and delicacy of colouring is singularly close. The aster consists of a tinted disk bordered with one or more series of petals; and in exact analogy, the polyp-flower, in its most common form, has a disk often richly coloured, fringed around with petal-like organs called tentacles. Below the disk, in contrast with the slender pedicel of the plant, there is a stout cylindrical pedicel or body, often as broad as the disk itself, and usually not much longer, which contains the *stomach* and internal cavity of the polyp: and the *mouth*, which opens into the stomach, is placed at the centre of the disk. Here, then, the flower-animal and the garden-flower diverge in character, the difference being required by the different modes of nutrition in the two kingdoms of nature.

There are many species of polyps, which have all the external and internal characters of coral polyps, yet secrete no lime or coral. Our descriptions of structure may be best drawn from them, and afterwards the single peculiarity of the coral-making polyp—its secretion of

* It is not, perhaps, within the range of science to criticise the poet; yet we may say in this place, in view of the frequent use of the lines even by scientific men, that more error in the same compass could scarcely be found than in the part of Montgomery's *Pelican Island*, relating to coral formations. The poetry is beautiful, the facts nearly all errors—if literature allows of such an incongruity. For ourselves, we think that fancy transcends its appropriate limits when false to nature.

† See page 15, of the Report on Zoophytes. The term *corallium* has been set aside by authors because of its being used for a genus of corals. *Corallum* is an old form of the same word, as particularly explained on the page just referred to, and is not liable to this objection. The true nature of calcareous corals was first pointed out by Milne Edwards, and Ehrenberg.

coral—will come under consideration. The species here referred to are called *Actiniæ* in science, in allusion to the radiated or aster-like flower which forms the summit of the animal.* There is the same allusion in the common appellation *Sea-anemone*. The richest anemones, daisies and tulips of our gardens would not rival them in beauty, neither will they exceed them in the size of their flowers; for a breadth of two and three inches is common. The polyps here alluded to, along with the coral polyps allied, constitute the order or division of zoophytes called ACTINOIDEA.†

The Actiniæ are entirely fleshy, and usually live attached by their lower extremity to the submerged rocks of the shores. The mouth, at the centre of the flower-like disk forming the summit of the animal, is a simple opening without teeth or appendages of any kind. The tentacles—the petals of the flower—are tubular organs, and communicate internally with the interior cavity of the animal. The animal contracts, when disturbed, and conceals the flower by rolling inward over it the margin bearing the tentacles; and in this state it seems like a lifeless lump of animal matter. Left quiet for a while it again expands and appears as before. This expansion is produced by receiving water into the interior from without, mostly through the mouth, and thus filling the tentacles and swelling out its fleshy body. They are generally found expanded with the mouth wide open to receive their prey. As they are fixed to the rocks, they must wait for their food to come to them. When a crab, shell-fish, or anything alive, within the capabilities of their bodies, comes within reach, they usually secure it by closing upon the victim the tentacles, (which often have a stinging power,) and pushing it into the mouth. In many species the tentacles are too short to aid in capturing food; and they can then subserve only the purpose of aerating the blood, a function in which all parts of the body are more or less concerned.

The interior of the actinia contains a cylindrical stomach suspended from the disk, which opens at bottom into the general cavity of the body. This general cavity, below the stomach and around it, is divided into compartments by radiating fleshy lamellæ, the larger of which in their upper part connect the stomach with the sides of the animal. The most important function of these lamellæ is that of reproduction, some being spermatic, and the others bearing clusters of ova. These ova leave the body by passing out through the stomach

* From *ακτιν*, a ray of the sun.

† This term alludes to their general resemblance to Actiniæ.

and mouth; but in many instances this does not take place till the young animal has proceeded from them. The refuse from the food after digestion in the stomach is also ejected by the mouth, as this is the only opening to the alimentary cavity. Other excrementitious matters, separated on the final elaboration of the chyle and its assimilation, may escape through the sides of the animal, the openings at the extremities of the tentacles, or in general by whatever pores or passages water may be ejected in the contraction of the animal.

One of the most singular peculiarities of polyps is their ready restoration of a lost part. Even a fragment will go on to complete the entire animal again. As with the fabled hydra of old, the knife is used but to multiply, for every section becomes a new animal.

In all the points mentioned in the description here given, the polyp of ordinary coral and the actinia are identical.

b. *Process of budding.*—There is one mode of reproduction which, although having no necessary connexion with coral secretions, belongs almost exclusively to coral polyps. This is *reproduction by buds*; and the process is so similar to the production of buds in vegetation, that a remembrance of the latter will aid much in conceiving of it. The bud generally commences as a slight prominence on the side of the parent: the prominence enlarges, and soon a circle of tentacles grows out, with a mouth at the centre; enlargement goes on till the young finally equals the parent in size. Thus by budding, a compound group is commenced; and it is evident that if the parent and the new polyp go on budding again, and so on, the compound group may continue to enlarge. This is the fact in nature. The polyps, one and all, continue propagating by buds, until in some instances thousands, or hundreds of thousands, have proceeded from a single one, and the colony has spread to a large size. Such are the *Madrepora* and *Astræa*. There are modifications of this process, analogous to those in vegetation, but we need not dwell upon them in this place.

It is obvious that the connexion of the polyps in such a compound group must be of the most intimate kind. The several polyps have separate mouths and tentacles, and separate stomachs; but beyond this, there is no individual property. They coalesce, or are one, by intervening tissues, and there is a free circulation of fluids through the many pores or lacunes. The zoophyte is like a living sheet of animal matter, fed and nourished by numerous mouths and as many stomachs. In some species the coalescence is confined to the lower half of the polyps, or to a still less part; and in this case the animals project above the general living surface. Polyps thus clustered, spreading

at summit a star of tentacles, constitute the flowering zoophytes of coral reefs.

Those coral animals which do not bud are to all external appearance true actiniæ. The existence of coral in the living coral zoophyte is nowhere apparent, and would not be suspected if not previously known; for, as before stated, it is wholly internal, and the visible exterior is the fleshy skin of the polyp.

c. *Secretion of coral.*—We have already remarked on the general nature of coral secretions. These secretions, it should be further observed, increase within simultaneously with growth, and every new animal adds to those previously formed. They go on throughout the sides and base of each polyp, excepting generally the exterior skin, as above stated; and the whole forms a calcareous framework penetrated by the animal tissues, some of these tissues corresponding to and occupying the cellules of the corallum, and others penetrating the solid parts in minute ramifications. Coral is also secreted between the radiating fleshy lamellæ of the internal cavity of the polyp, producing the radiated calcareous lamellæ which constitute the star of a cell. In the corallum of a *Madrepora* or an *Astræa* each surface cell or star belonged to a separate polyp, and the star was formed as here explained.

It would lead to too long a digression from the main topic before us to explain the principles upon which the forms of zoophytes depend. They are dwelt upon at length in another volume. In this place we may briefly allude to the principal varieties of form proceeding from the budding process, and to a single point in their mode of growth, upon which much of their importance in reef-making depends.

d. *Forms of actinoid zoophytes.*—Zoophytes imitate nearly every variety of vegetation. Trees of coral are well known; and although not emulating in size the oaks of our forests,—for they do not exceed six or eight feet in height,—they are gracefully branched, and the whole surface blooms with coral polyps in place of leaves and flowers. Shrubbery, tufts of rushes, beds of pinks, and feathery mosses are most exactly imitated. Many species spread out in broad leaves or folia, and resemble some large-leaved plant just unfolding: when alive the surface of each leaf is covered with the polyp flowers. The cactus, the lichen clinging to the rock, and the fungus in all its varieties, have their representatives as regards external form. Besides these forms imitating vegetation, there are gracefully modelled vases, some of which are three or four feet in diameter, made up of a network of

branches and branchlets and sprigs of flowers. There are also solid coral domes among the vases and shrubbery, occasionally ten, or even twenty feet in diameter, whose regularly arched surface is gorgeously decked with polyp-stars of purple and emerald green.*

All the many shapes proceed in each instance from a single germ, which grows and buds under a few simple laws of development, and thus gives origin either to the branch, the broad leaf, the column, or the hemisphere.

e. Life and death in concurrent progress.—But the more massy forms would not exist, and others would be of diminutive size, were it not for a peculiar mode of growth which characterizes most coral zoophytes.

Life and death are here in concurrent or parallel progress, a condition favoured by the existence of coral secretions. In some instances a simple polyp, while growing at top and constantly lengthening itself upward, is dying at its lower extremity, leaving the base of the coral bare, and destitute of any living tissues. The polyp thus continues rising in height, and death progresses below at the same rate, till at last the live polyp may be at the extremity of a coral stem many times its own length. This process is illustrated by figures on pages 62 and 78 of the Report on Zoophytes.

In species which bud and form large groups, the same operation takes place. In some instances the summit polyp or polyps bud and grow, while at a certain distance below the summit the work of death is going on, and polyps are gradually disappearing. There is thus a certain interval of life, the length of which interval is different for different species. There are zoophytes which grow to a height of several feet, and still only the upper one or two inches are living. The recent polyps at the top of the column are active with life and vigorous in reproduction, while the more aged below, having reached the fixed limits of their existence, are disappearing. The enduring coral remains, and constitutes the basement or stage of action for future generations of polyps.

But this death is not in progress alone at the base of the column or branch. Generally the *whole interior* of a corallum is dead, a result of the same process, as just explained. Thus, a *Madrepora*, although the branch may be an inch in diameter, is alive only to a depth of

* See Report on Zoophytes, pp. 29 and 59-61.

a line or two, the growing polyps of the surface having progressively died at their lower or inner extremity as they increased outward.

The large domes of *Astræas*, which have been stated to attain sometimes a diameter of ten or twenty feet, and are alive over the whole surface, owing to a symmetrical and unlimited mode of budding, are nothing but lifeless coral throughout the interior. Could the living portion be separated, it would form a hemispherical shell of polyps, in most species about half an inch thick. In some *Porites* of the same size, the whole mass is lifeless, excepting the exterior for a sixth of an inch in depth.

With such a mode of increase, there is no necessary limit to the growth of zoophytes. The rising column may grow upward indefinitely, until it nears the surface of the sea, when death ensues simply from exposure, and not from any failure in its powers of life. The huge domes may enlarge till the same exposure just mentioned causes the death of the summit, and leaves only the sides to grow, which may increase indefinitely. Moreover, it is evident that if the land supporting the growing coral were very gradually sinking, the upward increase of the coral might still be without limit.

There is hence sufficient means provided for the production of coral material for islands, however numerous. These humble ministers of creative power might, without other attributes than those they now possess, have even laid the foundations of continents, and covered them with mountain ranges. This remark requires no limitation if we allow the requisite time, and connect with the power of growth such other agencies, soon to be explained, as have been at work in the Pacific since the reefs were there in progress.

The death of the polyps about the base of a coral tree would expose it seemingly to immediate wear from the waters around it, and especially as the texture is usually porous. But nature is not without an expedient to prevent a catastrophe that would be destructive to a large part of growing zoophytes, and would prevent the indefinite increase just explained. The dead surface becomes the resting-place of numberless small incrusting species of corals, besides *Nullipores*, *Serpulas*, and some molluscs. In many instances the lichen-like *Nullipore* grows at the same rate with the rate of death in the zoophyte, and keeps itself up to the very limit of the living part. The dead trunk of the forest becomes covered with lichens and fungi, or in tropical climes, with other foliage and various foreign flowers: so among the

coral productions of the sea, there are other forms of life which replace the dying polyp. The process of wear is thus entirely prevented.

The older polyps, before death, often increase their coral secretions within, filling the pores occupied by the tissues, and rendering the corallum more solid; and this is another means by which the trees of coral growth, though of slender form, are increased in strength and endurance.

The facility with which polyps repair a wound, aids in carrying forward the results above described. The breaking of a branch is no serious injury to a zoophyte. There is often some degree of sensibility apparent throughout a clump, even when of considerable size, and the shock, therefore, may occasion the polyps to close. But in an hour, or perhaps much less time, their tentacles will have again expanded; and such as were torn by the fracture will be in the process of complete restoration to their former size and powers. The fragment broken off, dropping in a favourable place, would become the germ of another coral plant, its base cementing by means of coral-secretions to the rock on which it might rest; or if still in contact with any part of the parent tree, it would be reunited and continue to grow as before. The coral zoophyte, may be levelled by transported masses swept over by the waves; yet like the trodden sod, it sprouts again, and continues to grow and flourish as before. The sod, however, has roots which are still unhurt; while the zoophyte, which may be dead at base, has a root—a source or centre of life—in every polyp that blossoms over its surface. Each animal might live and grow if separated from the rest, and would ultimately produce a mature zoophyte.

We close this review of the characters of coral animals, which is a mere abstract of the fuller descriptions in the General Report on Zoophytes, by alluding briefly to one division of the Actinoidea, not yet touched upon, and also to the Hydroidea and Bryozoa, which are likewise coral-making animals.

THE ALCYONACEA.

The polyps of the group among the Actinoidea, here referred to, differ from those which have been occupying us, in having but eight tentacles, and these are fringed with minute papillæ. The organ-pipe coral (*Tubipora*) is of this kind. When expanded in the sea, a clump resembles a bed of pinks, or looks like a lilac-cluster that had been dropped in the water; and this resemblance extends to colour and size as well as form.

Some of these zoophytes secrete lime and form a tube; and of this

kind is the Tubipora. Others secrete only scattered granules of lime through the tissues: and still others are fleshy throughout. Many of them, besides forming granular calcareous secretions within the body of the polyp, give origin to a horny secretion at base, analogous to the epidermic secretions (hair, nails) of other animals; and this secretion receiving constant additions from the polyps as they are successively budded out, forms the axis of the growing branch. Of this character is the horny axis of the Gorgonia or sea-fan, which was long taken for a vegetable production. The crust which covers the axis consists of united polyps, which expand over its surface; and when expanded, each branch becomes a spike of flowers.

THE HYDROIDEA.

The Hydroidea constitute the second grand division of zoophytes, corresponding in rank with Actinoidea. While the Actinoidea have a radiated interior cavity with internal organs of reproduction, and eject their ovules through the mouth, the Hydroidea have greater simplicity of structure—the internal cavity being a simple tube, without organs of reproduction, and the ovules pullulating (or growing out) singly or in clusters from the sides of an animal. The polyps are with few exceptions quite minute, and the zoophytes act no important part in reef-making. A coronet of tentacles surrounds the mouth, as in the Actiniæ, though somewhat different in character.

This order includes the Hydræ, the Sertulariæ, and the Tubulariæ. Some species form thready tufts and plumes of extreme delicacy, and others (the Hydræ) are simple polyps. The fine branchlets of the feathery species consist, when dead, of one or two series of microscopic cells: and when alive each cell is the site of a minute flower-animal. The Hydra, an animal a line or less in length, consists of a tubular body, with a mouth at one extremity surrounded by a circle of tentacles; and the structure of the animal is so simple that it may be turned inside out, and still live and eat; it may be cut into forty or more parts, and from the dissected body, will grow as many distinct Hydræ.

THE BRYOZOA.—The Bryozoa are other coral-making species; but they are related to certain molluscs called Ascidæ rather than to zoophytes. In habit and size they much resemble the Hydroidea. From a minute cabin-like cell, they extend a circlet of slender arms or tentacles, and expand into a delicate goblet-shape flower, seldom over a line in diameter. These polyps differ both from the Actinoidea and Hydroidea, in having two extremities to the alimentary canal—

an anus, as well as a mouth; the intestine curves around and terminates in the disk. They are widely removed from true Zoophytes, both by this character, and also by having the tentacles furnished with vibratile cilia—that is, minute appendages resembling short hairs, which are kept in nearly constant vibration.

Some species of Bryozoa form thin crusts over rocks or sea-weeds, consisting of united cells, scarcely distinguishable unless magnified. The coralla of other species are branching or thin foliaceous; and these also consist of series of minute cells.

2. TEXTURE AND COMPOSITION OF CORALS.

The *texture* of calcareous corals is in general quite porous or cellular. Small stars or rounded depressions are scattered over the surface, and sometimes these stars form the centres of small prominences, called calicles (little cups). Besides these polyp-cells, which mark the position, each of a separate polyp, there are pores or cellules penetrating the texture of the coral mass; yet in some zoophytes, the coral secretions continue increasing in the animal till the pores are almost or quite obliterated, and the texture is nearly compact, the polyp-cells alone remaining. In many species, wherever there are concavities of much depth in the surface of a zoophyte, the coral of these concavities is looser or more spongy than elsewhere, for the reason, apparently, that the polyps in such parts have a poorer chance for securing food and fresh portions of water.

In the Gorgoniæ, and other species forming a distinct axis to the branches, this axis is solid, without a trace of a cell, and usually with faint evidences of a concentric structure. It is thus that the red coral of commerce, used in jewellery, differs from the Madreporæ or common white coral: it is the *axis* of a species of *Corallium*; and the polyps constituted a layer about it, in the same manner as the polyps of a *Gorgonia* cover the horny axis of these species.

In *hardness*, the common calcareous corals are a little above ordinary limestone or marble, the degree being represented in the mineralogical scale of Mohs by 3·5 to 4, while, in limestone, it is about 3. The ringing sound given when coral is struck with a hammer, indicates this superior hardness. It is a common error of old date to suppose that coral when first removed from the water is soft, and afterwards hardens on exposure. In fact, there is scarcely an appreciable difference; the live coral has a slimy feel in the fingers; but if washed

clear of the animal matter, it is found to be quite firm. The waters with which it is penetrated may contain a trace of lime in solution, which evaporates on drying, and adds slightly to the strength of the coral, but the change is hardly appreciable. A branched Madrepora rings, on being struck, when first collected; and a blow in any part puts in hazard every branch throughout it, on account of its elasticity and brittleness. Its *specific gravity* varies from 2.5 to 2.8: 2.523 was the average from fifteen specimens examined by B. Silliman, Jr.*

Composition. The common reef-corals, of which the branching Madrepora, and the massive *Astræas* are good examples, consist almost wholly of carbonate of lime, the same ingredient which constitutes ordinary limestone. In 100 parts, 90 to 96 parts are of this constituent; of the remainder, there are 3 to 8 parts of organic matter, with some earthy ingredients amounting in certain species to 2 parts, though often less than 1. These earthy ingredients are silica, magnesia, alumina, oxyd of iron, phosphate of magnesia, and fluorids of magnesium and calcium. The following is the result of one of Mr. Silliman's analyses from those made by him for the Report on Zoophytes.† The specimen was a *Porites* from the Sandwich Islands. It afforded—

Carbonate of lime	.	.	.	.	.	95.84
Phosphates, fluorids, &c.	.	.	.	.	.	2.05
Organic matter	.	.	.	.	.	2.11

The various earthy ingredients are included in the second line of the analysis, and in this species amounted to 2.05 per cent. One hundred parts of the same, subjected to exact analysis, gave the following result:—

Silica	.	.	.	.	.	22.00
Lime	.	.	.	.	.	13.03
Magnesia	.	.	.	.	.	7.66
Fluorid of calcium	.	.	.	.	.	7.83
Fluorid of magnesium	.	.	.	.	.	12.48

* Report on Zoophytes, page 713. On page 711, it is suggested by the author that the high degree of hardness, which characterizes corals and also the shells of many molluscs, may arise from the structure of the calcareous secretions being like that of arragonite, instead of common calc-spar. The hardness is near that of arragonite, though sometimes a little exceeding it.

† Op. cit. p. 712.

Phosphate of magnesia	-	-	-	-	-	2.70
Alumina (and iron)	-	-	-	-	-	16.00
Oxyd of iron	-	-	-	-	-	18.30

In other analyses similar results were obtained, with sometimes a larger proportion of fluorids.

The horny corals, (axes of *Gorgoniæ* and *Antipathi*,) were found by Hatchett to have nearly the constitution of ordinary horn.*

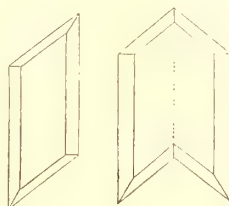
The sea-water and the ordinary food of the polyps are evidently the source from which the ingredients of coral are obtained. As coral is an animal secretion, there is no good reason for the surprise with which this subject is sometimes approached. The same powers of elaboration which exist in other animals belong to polyps; for this function, as we have remarked, is the lowest attribute of vitality.

Neither is it at all necessary to inquire whether the lime in sea-water exists as carbonate or sulphate, or whether chlorid of calcium takes the place of these. Vitality may make from the elements present whatever results the functions of the animal require.†

Various waters were collected in the vicinity of the coral islands, and at different distances from them, for the purpose of analysis and to compare the constitution of the sea in different parts; but they were lost with the Peacock on the bar of the Columbia River. The proportion of lime salts which occurs in the water of the ocean is about $\frac{1}{30}$ to $\frac{1}{35}$ of all the ingredients in solution. Prof. Forchhammer has ascertained that around the West Indian seas, where corals abound, lime is not as abundant as elsewhere in the ocean, the proportion, according to five analyses, being 10,000 to 247; while in the Kattegat, where the rivers of the Baltic carry it in considerable quantities, the

* Ibid, p. 56.

† If a drop of sea-water be slowly evaporated under a microscope of high power, crystals of selenite (sulphate of lime) are produced, having the annexed forms, the most common presented by native crystals of this mineral, as stated in works on mineralogy. On adding more water, they are again dissolved; and this may be repeated indefinitely. These results would seem to indicate that the lime was mostly in the state of a sulphate.



Mr. Darwin states the remarkable fact, described by Mr. Webster, (*Voyage of the Chanticleer*, ii. 319,) that a deposit of salt and gypsum two feet thick occurs on the shores of Ascension, which was formed by the dash of the waves. Beautiful crystals of selenite were obtained by the writer in logs of half decomposed wood in the shore-cliffs near Callao, which were of similar origin.

proportion, from four analyses, is 10,000 to 371.* Schweitzer obtained the following result for water taken from the British Channel.†

Water	-	-	-	-	-	964·74 grains.
Chlorid of sodium	-	-	-	-	-	27·06 “
Chlorid of potassium	-	-	-	-	-	0·77 “
Chlorid of magnesium	-	-	-	-	-	3·67 “
Bromid of magnesium	-	-	-	-	-	0·03 “
Sulphate of magnesia	-	-	-	-	-	2·29 “
Sulphate of lime	-	-	-	-	-	1·41 “
Carbonate of lime	-	-	-	-	-	0·03 “
						1000·00

Recently, Mr. G. Wilson has detected fluorine in sea-water, showing that all the ingredients of coral are actually contained in the waters of the ocean.‡

It has been common to attribute the origin of the lime of corals to the existence of carbonated springs in the vicinity of coral islands. But it is an objection to such an hypothesis, that in the first place the facts do not require it; and in the second, there is no foundation for it. The islands have been supposed to rest on volcanic summits, thus making one hypothesis the basis of another. Carbonic acid springs are by no means a universal attendant on volcanic action. The Pacific affords no one fact in support of such an opinion. There are none on Hawaii, where are the most active fires in Polynesia; and the many explorations of the Society and Navigator Islands have brought none to light. Some of the largest reefs of the Pacific, those of New Holland and New Caledonia, occur where there is no evidence of former volcanic action.§

The currents of the Pacific are constantly bearing new supplies of water over the growing coral beds, and the whole ocean is thus engaged in contributing to their nutriment. Fish, molluscs, and zoophytes are thus provided with earthy ingredients for their calcareous secretions, if their food fails of giving the necessary amount;

* On Comparative Analytical Researches on Sea Water, by Prof. Forchhammer,—Rep. Brit. Assoc. for 1846, p. 90.

† Lond. and Ed. Phil. Mag. for July, 1839, xv. 51; Amer. Jour. Sci., xxxviii. 12.

‡ Trans. Roy. Soc. of Edinburgh, xvi. 145, 1846; Amer. Jour. Sci. 2d ser. ii. 114, 1846.

§ See also Darwin, op. cit. p. 60.

and by means of the powers of animal life, bones, shells, and corals alike are formed.

The origin of the lime in solution throughout the ocean is an inquiry foreign to our present subject. It is sufficient here to show that this lime, whatever its source, is adequate to explain all the results under consideration.

3. CAUSES INFLUENCING THE GROWTH OF CORAL ZOOPHYTES.

Marine zoophytes generally require pure ocean water, and they abound especially in the broad inner channels among the reefs, or the large lagoons, and in the shallow waters outside of the breakers. In these channels at the Feejee Group, there are species of every genus, and they grow in the greatest luxuriance, exceeding in profusion and display, all that was elsewhere seen in the Pacific. Here are found the huge *Astræa* domes, the *Meandrinæ*, *Porites*, the leafy clusters of the *Merulinæ*, numerous *Madrepores*;—indeed nearly all the Pacific corals described in the Report on Zoophytes, exclusive of those from the Tahitian and Hawaiian Islands, were obtained from the inner reefs of the Feejees. It is therefore an assertion wide from the fact, that only smaller corals grow in the lagoons and channels, though true of lagoons and channels of small size, or of such parts of the larger channels as immediately adjoin the mouths of fresh-water streams.

There are undoubtedly species especially fitted for the open ocean; but as peculiar conveniences are required for the collection of zoophytes outside of the line of breakers, we have not the facts necessary for a list of such species. From the very abundant masses of *Astræas*, *Meandrinæ*, *Porites*, and *Madrepores* thrown up by the waves on the exposed reefs, it was evident that these genera were well represented in the outer seas.* In the Paumotus, the single individuals of *Porites* lying upon the shores were at times six or eight feet in diameter. Around the Duke of York's Island the bottom was observed to be covered with small branching and foliaceous *Madrepores*, (*Manoporæ*,) as delicate as any of the species in more protected waters.

* *Porites* and *Milleporæ*, according to Mr. Darwin, prevail on the surf-reef of Keeling's Island. Chamisso states that the large *Astræas* live and grow in the breakers.

From the facts which came under our observation, both by direct examination and the collection of beach specimens, it was inferred that there were few species occurring in the open ocean that may not also grow in the larger lagoons and channels. The Nullipores forming the margin of many reefs may here be mentioned, (though not properly corals,) as requiring the surf. There are also several Millipores, some small Madreporæ, Pocilloporæ, and small Astræas that grow in the face of the breakers, where larger or weaker species would be dislodged or broken.*

Within the inner channels, the presence of fresh water in the immediate vicinity is known to be fatal to many zoophytes. Yet the dilution may be at least one-half before all species are excluded. Upon the reefs enclosing the harbour of Rewa, (Viti Lebu,) where a large river three hundred yards wide empties, which during freshets enables vessels at anchor two and a half miles off its mouth to dip up fresh water alongside, there is a single porous species of Madrepora, (*M. cribripora*,) growing here and there in patches over a surface of dead coral rock or sand. In similar places about other regions, species of Porites are most common. In many instances, the living Porites were seen standing six inches above low tide, where they were exposed to the sunshine and to rains; and associated with them in such exposed situations there were usually great numbers of *Alcyonia* and *Xenia*. Even in the impure waters adjoining the shores, these corals occur; and the massive Porites in such places usually spread out into flat disks, the top dying from the deposition of sediment upon it.

The exposure of six inches above low tide, where the tide is six feet, as in the Feejees, is of much shorter duration than in the Paumotus, where the tide is less than half this amount; and consequently the height of growing coral, as compared with low tide level, varies with the height of the tides.

The powers of endurance in some coral zoophytes cannot surprise us, for it is well known that these animals are often very tenacious of life. The hardier species belong mostly to the genera *Porites* and *Pocillopora*, besides the family *Alcyonidæ*.

The small lagoons, when shut out from the influx of the sea, are often rendered too salt for growing zoophytes, in consequence of evaporation,—a condition of the lagoon of Enderby's Island.

* The author's observations on the *species* of corals were not commenced till reaching the Feejees, where we were among the *inner* reefs. Previous to that time, this Department in Zoology was in the hands of Mr. J. P. Couthouy.

Coral zoophytes sometimes suffer injury from being near large fleshy *Alcyonia*, whose crowded drooping branches lying over against them, destroy the polyps and mar the growing mass. But *Serpulas*, and certain species of barnacles constituting the genus *Criseis*, fix themselves upon the living *Astræa*, *Millepora*, and other corals, and finally become imbedded by the increase of the zoophyte, without producing any defacement of the surface, or affecting its growth. Many of these *Serpulas* grow with the same rapidity as the zoophyte, and finally produce a long tube, which penetrates deep within the coral mass; and, when alive, they expand a large and brilliant circle or spiral of delicate rays, making a gorgeous display among the coral polyps. Instinct seems to guide these animals in selecting those corals which correspond with themselves in rate of growth; and there is in general a resemblance between the markings of a *Criseis* and the character of the radiations of the *Astræa* it inhabits.

The effects of sediment on growing zoophytes are strongly marked, and may be often perceived when a mingling of fresh water alone produces little influence. We have mentioned that the *Porites* are reduced to flattened masses by the lodgment of sediment. The same takes place with the hemispheres of *Astrææ*; and it is not uncommon that in this way large areas at top are deprived of life. The other portions still live unaffected by the injury thus sustained. Even the *Fungiæ*, which are broad simple species, are occasionally destroyed over a part of the disk through the same cause, and yet the rest remains alive. Wherever streams or currents are moving or transporting sediment, there no corals grow; and for the same reason we find no living zoophytes upon sandy or muddy shores.

The influence of *temperature* on the development of animal life, and the distribution of species is well known. But in no department is it more strikingly displayed than in that of zoophytes. In a former Report we have considered the general influence of temperature on the several divisions of this order of animals. The remarks which follow are consequently confined to the *reef-forming* species. We reserve for still another page the influence of this cause on the distribution of reefs, since we are occupied here with zoophytes as animal species, and not with reefs, a result from the growth of corals.

The temperature of the ocean in which reef-corals grow is evidently the temperature congenial to them. From a general survey of facts, it appears that these species are not met with where the winter temperature remains much time below 66° F.; though a temporary reduction to 64°, or even lower (as at the Bermudas), may occur. Where the tempe-

rature is above this, even in the hottest parts of the torrid zone, coral zoophytes thrive well. An isothermal line, crossing the ocean where this winter-temperature of the sea is experienced, one north of the line, and another south, bending in its course by divergence or convergence, wherever the marine currents change its position, will include all the growing reefs of the world; and the area of waters may be properly called the *coral-reef seas*. This *limiting* temperature is found near latitude 28°. Under the equator in the Pacific, the waters where warmest, have the temperature 85° F., and in the Atlantic 83° F.; 66° to 85° is therefore not too great a range of temperature for the various reef-forming corals. Particular species, however, have smaller limits; but these limits have not yet been accurately ascertained.*

The *Porites* and *Pocilloporæ* predominate at Oahu, (Sandwich Islands,) and there are but few of the *Astræidæ*,—a fact which appears to be explained on the ground that the reefs of that island are not far from the *cold* limits of the coral seas: and it is interesting to observe that these same corals are the hardiest under exposures to impure waters. The warmest parts of the ocean are favourable to the growth of *Astræas*, *Meandrinæ*, and the allied species; and at the same time, these regions abound in *Porites* and *Pocilloporæ*, although the proportion of these corals is smaller than at Oahu.

The genera of reef-forming corals which occur out of the coral-reef seas, belong almost exclusively to the *Caryophyllia* family, and especially to the genera *Dendrophyllia*, *Caryophyllia*, *Astroides*,† *Oculina*, and *Cyathina*, some species of which exist in the Norwegian seas. The *Gorgonidæ*, *Alcyonidæ*, *Hydroidea*, and *Actinidæ*, extend from the equator nearly to the frigid zone. The *Bryozoa* have an equally wide range.‡

The liability of the lagoons, when contracted in size, to become

* The first application of the well-established principle that temperature influences the growth and distribution of corals is claimed by Mr. J. P. Couthouy equally with myself. Any attempt, however, to determine a limiting temperature he disclaims, and in this particular, as well as the conclusions arrived at, our views are very different. The facts and inferences stated in this place, and on a following page, are deduced throughout from my own study and investigation.

† The corals of the *Astroides* closely resemble those of the *Astrææ*, and have been referred to the latter group by many authors. A related species is found on the coast of this country as high up as lat. 42°. An *Astræa* has been reported from Sydney, New South Wales, which, if a true *Astræa*, (it has not been described or figured,) gives this genus a wider limit than the coral-reef seas.

‡ See farther, Report on Zoophytes, p. 102.

highly heated by the sun, is probably one cause leading to the depopulation of these internal waters. The temperature becomes raised, as in a puddle of standing water elsewhere, and is quite unfitted, therefore, for species accustomed only to the ordinary tropical temperature of the ocean.

Light and *pressure* and probably the amount of air in sea-water, influence the growth of corals, so far as to fix limits to their distribution in *depth*. It is a little remarkable that those families which have a wide geographical range, have also a great range in depth: for Caryophylliæ, Dendrophylliæ, Oculinæ, Gorgonidæ, and Hydroidea, are found even at depths of one or two hundred fathoms; while Madrepores and Astræas, and all the ordinary reef-forming species, scarcely exceed a depth of twenty fathoms.

Temperature has little or no influence in determining this range, although it has been so asserted: 66° is not met with under the equator short of 75 or 100 fathoms. The following table gives approximate results for the winter months, from observations on this point by different navigators in the Pacific. It is well known that these averages are much varied in particular regions by currents.

	Latitude.			Depth of 66° Fahrenheit.
N. Latitude.	28°—30°	-	-	15—25 fathoms, to surface.
	25°	-	-	25—30 “
	20°	-	-	30—50 “
	15°	-	-	40—60 “
	10°	-	-	50—75 “
	5°	-	-	75 “
EQUATOR.	0°	-	-	75—100 “
S. Latitude.	5°	-	-	50—75 “
	10°	-	-	50 “
	15°	-	-	50 “
	20°	-	-	40 “
	25°	-	-	25 “
	28°—30°	-	-	Surface.

It appears, therefore, that among the causes limiting the range of corals in depth, light and hydraulic pressure must have great influence. The proportion of atmospheric air present may be another cause. Yet according to Darondeau, the deeper waters contain more atmospheric air and also more carbonic acid,—the difference being as much as $\frac{1}{100}$ th the volume of the water.*

* Examination of Sea Water collected during the Voyage of the Bonite, Jameson's Edinb. Jour., July 1838, p. 164. Darondeau's observations require confirmation.

Quoy and Gaymard were the first authors who ascertained that reef-forming corals were confined to small depths, contrary to the account of Forster and the early navigators. The mistake of previous voyagers was a natural one, for coral reefs were proved to stand in an unfathomable ocean; yet it was from the first a mere opinion, as the fact of corals growing at such depths had never been ascertained. It is now considered altogether probable that the bottom of the ocean is without life of any kind, or is but sparingly populated. The few Caryophylliæ and other species which are met with in deep waters, have been shown to be sparsely scattered, mostly of small size, and nowhere form accumulations or beds.

The above-mentioned authors, who explored the Pacific in the *Uranie* under D'Urville,* concluded from their observations that 5 or 6 fathoms (30 or 36 feet) limited their downward distribution. Ehrenberg, by his observations on the reefs of the Red Sea, confirmed the observations of Quoy and Gaymard; he concluded that living corals do not occur beyond six fathoms. Mr. Stutchbury, after a visit to some of the Paumotus and Tahiti, remarks that the living clumps do not rise from a greater depth than 16 or 17 fathoms.† Mr. Darwin, who traversed the Pacific with Captain Fitzroy, R. N., gives 20 fathoms as not too great a range, and mentions reported instances of growing reefs in 25 or even 30 fathoms. He states that in the Red Sea, according to Captain Morehead, living corals occur at 25 fathoms. At Keeling Atoll, growing corals are described by him as wholly disappearing beyond 20 fathoms; and at the Maldives and Chagos, at a less depth. Other facts brought forward by Mr. Darwin, relate to Caryophylliæ and those species which have a wide range beyond reef-forming zoophytes.

It thus appears that all recent investigators since Quoy and Gaymard have agreed in assigning a comparatively small depth to growing corals. The observations on this point, made during the cruise of the Expedition, tend to confirm this opinion. The conclusion is borne out by the fact that soundings in the course of the various and extensive surveys afford no evidence of growing coral beyond twenty fathoms. Where the depth was fifteen fathoms, coral sand and fragments were almost uniformly reported. Among the Feejee Islands, the extent of coral reef-grounds surveyed was many hundreds of square miles, besides the more careful examination of harbours.

* Afterwards also in the *Astrolabe*.

† S. Stutchbury, *West of England Journal*, i. 48.

The reefs of the Navigator Islands were also sounded out, with others at the Society Group, besides numerous coral islands; and through all these regions no evidence was obtained of corals living at a greater depth than 15 or 20 fathoms. Within the reefs west of Viti Lebu and Vanua Lebu, the anchor of the Peacock was dropped sixty times in water from 12 to 24 fathoms deep, and in no case struck among growing corals; it usually sunk into a muddy or sandy bottom. Patches of reef were encountered at times, but they were at a less depth than 12 fathoms. By means of a drag, occasionally dropped in the same channels, some fleshy *Alcyonia*, and a few *Hydroidea* were brought up, but no reef-forming species.

Outside of the reef of Upolu, corals were seen by the writer growing in twelve fathoms. Lieutenant Emmons brought up with a boat-anchor a large *Dendrophyllia* from a depth of fourteen and a half fathoms at the Feejees; and this species was afterwards found near the surface. *Dendrophyllia*, it may be remembered, is one of the deep-water genera.

These facts, it may be said, are only negative, as the sounding-lead, especially in the manner it is thrown in surveys, would fail of giving decisive results. The character of a growing coral bed is so strongly marked in its uneven surface, its deep holes and many entangling stems, to the vexation of the surveyor, that in general the danger of mistake is small. But allowing uncertainty as great as supposed, there can be little doubt after so numerous observations over extended regions of reefs.

The depth of the water in harbours and about shores where there is no coral, confirms the view here presented. At Upolu, the depth of the harbours varies generally from twelve to twenty fathoms. On the south side of this island, Lieutenant Perry, off Falealili, one hundred yards from the rocky shores, found bare rocks in eighteen and nineteen fathoms, with no evidence of coral. There is no cause here which will explain the absence of coral, except the depth of water; for corals and coral reefs abound on most other parts of Upolu. Below Falelatai, of the same island, an equal depth was found with no coral. Off the east cape of Falifa harbour, on the north side of Upolu, Lieutenant Emmons found no coral, although the depth was but eighteen fathoms. About the outer capes of Fungasar harbour, Tutuila, there was no coral, with a depth of fifteen to twenty fathoms; and a line of soundings across from cape to cape afforded a bottom of sand and shells in fifteen to twenty-one and a half fathoms. About

the capes of Oafonu harbour, on the same island, there was no coral, with a depth of fifteen fathoms.

Similar results were obtained about all the islands surveyed, as the charts satisfactorily show. There is hence little room to doubt that twenty fathoms may be received as near the range in depth for reef corals; and probably the limit lies between fifteen and twenty fathoms, or not far from one hundred feet.

It may be here remarked, that soundings with reference to this subject are liable to be incorrectly reported by persons who have not particularly studied living zoophytes. It is of the utmost importance, in order that an observation supposed to prove the occurrence of living coral should be of any value, that it be unequivocally determined whether the fragments which a lead may bring up are alive or not when broken off; for a dead fragment proves nothing. Even a strong impression upon the lead, showing the form and character of the surface-cells of a coral, is not wholly satisfactory, as it may have been given by a mass not living. A living fragment, placed in water, will be seen to have a fleshy surface, even if the polyps do not expand. The best observations with reference to this subject would be made with a diving bell.

Much yet remains for farther investigation. Mr. Edward Forbes, in his Zoological Explorations of the Ægean, distinguished three separate regions of invertebrate species within twenty fathoms of the surface: the *first*, or littoral, extending to two fathoms in depth; the *second* from two to ten fathoms; the *third* from ten to twenty fathoms.* Similar subdivisions, or others on the same general principle, may yet be detected in the Pacific, indicated perhaps by zoophytes as well as molluscs. There is no evidence, however, that there are successive beds, composed of a distinct set of species, as has been sometimes suggested. The upraised reefs of Metia afford no proofs of such a mode of formation; on the contrary, they show that the process is continuous and uniform in character through the reef-growing depths. The species in the lower part of the sixteen fathoms are probably different from many of those above; but they pertain to the same genera in most instances, and moreover there are no abrupt transitions; consequently the resulting reefs should have a nearly uniform character, as here stated. This fact may be better appreciated after perusing the following chapter.

* On the Ægean Invertebrata, E. Forbes, Rep. Brit. Assoc. for 1843, p. 154.

The Nullipore zone along the reef-line between low and high tide, is clearly made out by Mr. Darwin, and is one of the interesting results of his investigations. It performs a very important part, by the protection it gives the reef from abrasion. The exposed reef is thus gathering lime from the waters, and extending itself, when, if devoid of this protection, it would be constantly yielding to the sea. On the inner reefs, where the protection is not needed, it is not given. Some species of Nullipore, however, occur in these regions, and others are found at various depths.

As the Caryophyllia family extend into deeper waters than most other reef-corals, it might be inferred that these at least may constitute a lower bed, or substratum. But this is by no means the case. The Caryophylliæ are but sparingly distributed; the species are few, and mostly small; and not a dozen different kinds were detected in the Pacific. Their contributions to reefs are, therefore, inconsiderable.

4. RATE OF GROWTH OF ZOOPHYTES.

The rate of growth of zoophytes, is a subject but little understood. We do not refer here to the progress of a reef in formation, which is another question complicated by many co-operating causes; but simply to the rapidity with which particular species of coral-zoophytes increase in size. There is no doubt that the rate is different for different species. It is moreover probable that it corresponds with the rate of growth of other allied polyps that do not secrete lime. The rate of growth of Actiniæ might give us an approximation to the rate of growth in a *Mussa*, which are coral animals of like size and general characters; for the additional function of secreting lime would not retard necessarily the maturing of the polyp; and from the rate of growth of the same animals in the young state, we might perhaps draw some inferences as to the rate in polyps of corresponding size. But no observations on this point were made by us while abroad.

Although the rapidity is undoubtedly far less than was formerly stated, the following facts from different sources seem to show that the rate is still greater than has been of late believed. Mr. Darwin, citing from a manuscript by Dr. Allen of Forres, some experiments made on the east coast of Madagascar, states that, in December, 1830, twenty corals were placed by this gentleman apart on a sandbank, in three feet water, (low tide,) and in the July following, each had nearly reached

the surface, and was quite immovable; and some had grown over the others. Mr. Stutchbury describes a specimen consisting of a species of oyster, whose age could not be over two years, which was encrusted by an *Agaricia*, weighing two pounds nine ounces.* It is stated by M. Duchassaing, in a letter from Guadeloupe, that in two months, some large individuals of the *Madrepora prolifera*, which he broke away, were restored to their original size.†

Since the return of the Expedition, I have received a letter containing some facts on the growth of Actiniæ from Sir J. G. Dalyell, whose able observations in this department of science are highly curious and important. After speaking of the various conditions and sizes of the young at birth, and of the difference in the rapidity of growth depending on the amount of nutriment at hand, he says, speaking of a Scottish species of Actinia, "The dimensions will generally double in a fortnight from its birth. The diameter of the base being originally about an eighth of an inch, or hardly as much, will be five-eighths in six months, and the tentacles will occupy a circle of an inch and a half in diameter. In twelve or thirteen months, the diameter of the base will reach an inch and the expansion of the tentacles two inches between the tips. An Actinia whose tentacula expanded a quarter of an inch three weeks after it was produced, enlarged so much in five months that they expanded an inch, and the body was then half an inch thick." If we reason upon this data, and assume that the Madrepora polyps may increase lineally in six months as much as the young Actinia, we shall have an elongation of five-eighths or three-fourths of an inch in six months. Taking the still more rapid rate, of doubling in a fortnight, which might be more correct, since the Madrepora polyps are about the size of the Actinia in its earliest state, we should have a lengthening of a fourth of an inch in a month, and three inches a year. The data upon which this conclusion is based, though important, are uncertain, but would probably give too high rather than too low an estimate. And yet it is far below the rate apparently established by the experiments with corals cited in the preceding paragraph. We must admit that the subject requires more accurate investigation.

The stay of the Expedition near any particular reef in the Pacific was too short for any examinations by us. They might easily be

* West of England Journal, vol. i. p. 50.

† L'Institut, No. 639, April 1, 1846, p. 111.

made by those residing in coral seas, either in the manner adopted by Mr. Allan, or more definitely by placing marks upon particular species. By inserting slender glass pins a certain distance from the summit of a Madrepora, its growth might be accurately measured from month to month. Two such pins in the surface of an *Astræa*, would in the same manner, by the enlarging distance between, show the rate of increase in the circumference of the hemisphere; or if four were placed so as to enclose an area, and the number of polyps counted, the numerical increase of polyps resulting from budding, might be ascertained. It is to be hoped that some of the foreign residents at the Sandwich, Society, Samoan or Feejee Islands will take this subject in hand. There are also many parts of the West Indies, where these investigations might be conveniently made.

III. FORMATION OF REEFS, AND CAUSES OF THEIR FEATURES AND GEOGRAPHICAL DISTRIBUTION.

An inquiry into the causes and origin of the features presented by coral reefs and islands, has led us to glance at the nature of coral-zoophytes, and at the effects of various agents upon their development. The way has thus been prepared for considering the bearing of these facts, and of other influencing causes, on the growth of the coral plantation as a whole. While, therefore, the preceding pages treat of zoophytes as individual species, the following will relate to those results which proceed from their accumulation, and the causes which have determined the features and geographical distribution of reefs and islands.

I. FORMATION OF REEFS.

Very erroneous ideas prevail, respecting the appearance of a bed or area of growing corals. The submerged reef is often thought of as an extended mass of coral, alive uniformly over its upper surface, and, by this living growth, gradually enlarging upward: and such preconceived views, when ascertained to be erroneous by observation, have sometimes led to scepticism with regard to the zoophyte origin of the reef-rock. Nothing is wider from the truth: and this must have been inferred from the descriptions already given. Another glance

at the coral plantation should be taken by the reader, before proceeding with the explanations which follow.

Coral plantation and coral field, are more appropriate appellations than coral garden, and convey a juster impression of the surface of a growing reef. Like a spot of wild land, covered in some parts with varied shrubbery, in other parts bearing only occasional tufts of vegetation over barren plains of sand, here a clump of saplings, and there a carpet of variously coloured flowers—such is the coral plantation. Numerous kinds of zoophytes grow scattered over the surface, like the vegetation of the land: there are large areas that bear nothing, and others that are thickly overgrown. There is no green sward to the landscape, and here the comparison fails. Sand and fragments fill up the bare intervals between the flowering tufts: or where the zoophytes are crowded, there are deep holes among the stony stems and folia, that seem as if formed among the aggregated roots of the living corals.

These observations will prepare the mind for some disappointment in a first view of coral reefs. Nature does not make green-houses; but distributes widely her beauties, and leaves it for man to gather into gardens the choicer varieties. Yet there are scenes in the coral landscape, which justify the brightest colourings of the poet: where coral shrubbery and living flowers are mingled in profusion; where *Astræa* domes seem like the gemmed temples of the coral world, and *Madrepore* vases, the decorations of the groves; and as the forests and flowers of land have their birds and butterflies, so

— “ Life in rare and beautiful forms
Is sporting amid those bowers of stone.”

These fields of growing coral spread over submarine lands, such as the shores of islands and continents, where the depth is not greater than their habits require, just as vegetation extends itself through regions that are congenial. The germ or ovule, which, when first produced, swims free, finds afterward a point of rock, or dead coral, to plant itself upon, and thence springs the tree, or some other form of coral growth.

The analogy to vegetation does not stop here. It is well known that the debris of the forest, decaying leaves and stems, and animal remains, add to the soil; and that accumulations of this kind are ceaselessly in progress: that by this means, in the luxuriant swamp, deep beds of peaty earth are formed. So it is in the coral mead.

Accumulations of fragments and sand from the coral zoophytes, and of shells and other relics of organic life, are in constant progress ; and thus a bed of coral debris is formed and compacted. There is this difference, that a large part of the vegetable material consists of elements which escape as gases on decomposition, whereas coral is itself an enduring rock-material, undergoing no essential change except the mechanical one of comminution. The animal portion is but a mere fraction of the whole zoophyte.

In these few hints, we have the whole theory of reef-making : not a speculative opinion, but a legitimate deduction from a few simple facts, and bearing close analogy to operations on land. The coral debris and shells fill up the intervals between the coral patches, and the cavities among the living tufts, and in this manner produce the reef deposit, which is consolidated by the filtrating sea-water, having more or less lime in solution. The coral-zoophyte is especially adapted for such a mode of reef-accumulation. Were the nourishment drawn from below, as in most plants, the solidifying coral rock would soon destroy all life : instead of this, the tree is gradually dying below while growing above ; and the accumulations cover only the dead portions. Moreover, to prevent accident, where these accumulations do not keep pace with the progress of death, organic incrustations cover the lifeless trunk, and protect it from the dissolving waters.

But on land, there is annual and also senile decay to produce vegetable debris ; and lightning and storms prostrate forests. And are there any corresponding effects among the groves of the sea ? It has been shown that coral plantations, from which reefs proceed, do not grow in the "calm and still" depths of the ocean. They are to be found amid the very waves, and extend but little below a hundred feet, which is far within the reach of the sea's heavier commotions.* Here is an agent which is not without its effects. The enormous masses of upturn rock found on many of the islands may give some

* During the more violent gales, the bottom of the sea is said, by different authors, to be disturbed to a depth of three hundred, three hundred and fifty, or even five hundred feet, and De la Beche remarks, that when the depth is fifteen fathoms, the water is very evidently discolored by the action of the waves on the sand and mud of the bottom. In the *Comptes Rendus*, t. xii. 774, M. Siau mentions that parallel ridges are formed on the bottom, by the motion of the water, which may be readily distinguished at a depth of at least twenty meters. The hollows between such ridges or zones are occupied by the heavier substances of the bottom. Similar zones were distinguished at a depth of one hundred and eighty-eight meters, to the northwest of the St. Paul's Roads.

idea of the force of the lifting wave ; and there are examples on record, to be found in various treatises on Geology, of still more surprising effects.*

We must, therefore, allow that some effect will be produced upon the coral groves. There will be trees prostrated by gales, as on land, fragments scattered, and fragmentary and sand accumulations commenced. Besides, masses of the heavier corals will be uptorn, and carried along over the coral plantation, which will destroy and grind down everything in their way. So many are the accidents of this kind to which zoophytes appear to be exposed, that we might believe

* Lyell, vol. ii. p. 38-40. Speaking of the force of waves on coasts, Lyell mentions the transportation of a block of stone, ninety feet from its bed, which was eight feet two inches, by seven feet, and five feet one inch, in its dimensions, and another nine feet two inches, by six and a half feet, by four feet, which "was hurried up an acclivity to a distance of one hundred and fifty feet."

In an article on this subject, by Thomas Stevenson, of Edinburgh, published in the Transactions of the Royal Society of Edinburgh (vol. xvi., 1845), it is stated, as a deduction from two hundred and sixty-seven experiments, extending over twenty-three successive months, that the average force for Skerryvore, for five of the summer months, during the years 1843, 1844, was six hundred and eleven pounds per square foot ; and for six of the winter months of the same year, it was two thousand and eighty-six pounds per square foot, or three times as great as during the summer months. During a westerly gale, at the same place, in March, 1845, a pressure of six thousand and eighty-three pounds was registered by Mr. Stevenson's dynamometer, (the name of the instrument used.) He mentions several remarkable instances of transported blocks. One of gneiss, containing five hundred and four cubic feet, was carried by the waves five feet from the place where it lay, and there became wedged so as no longer to be moved. Of the manner in which it was moved, Mr. Reid (as cited by Mr. Stevenson) says : "The sea, when I saw it striking the stone, would wholly immerse or bury it out of sight, and the run extended up to the grass line above it, making a perpendicular rise of from thirty-nine to forty feet above high water level. On the incoming waves striking the stone, we could see this monstrous mass, of upwards of forty tons weight, lean landwards, and the back-run would uplift it again with a jerk, leaving it with very little water about it, when the next incoming wave made it recline again."

Mr. Stevenson states also that the Bell Rock Lighthouse in the German Ocean, though one hundred and twelve feet in height, is literally buried in foam and spray, to the very top, during ground swells, when there is no wind. On the 20th of November, 1827, the spray rose to the height of one hundred and seventeen feet above the foundations or low water mark ; and deducting eleven feet for the tide that day, it leaves one hundred and six feet, which is equivalent to a pressure of *nearly three tons per square foot*.

With such facts, any incredulity respecting the power of waves should be laid aside. Moreover, it may be remarked that the Pacific is a much wider ocean than the Atlantic, with far heavier waves in its ordinary state.

they would often be exterminated, were they not singularly tenacious of life, and ready to sprout anew on any rock where they may find quiet long enough to give themselves again a firm attachment.

But it should be observed, that the sea would have far less effect upon the slender forms characterizing many zoophytes, among which the water finds free passage, than on the massive rock, against whose sides a large volume may drive unbroken. Moreover, much the greater part of the strength of the ocean is exerted near tide level, where it rises in breakers which plunge against the shores. Yet, owing to the many nooks and recesses deep among the corals, the rapidly moving waters, during the heavier swells, must produce whirling eddies of considerable force, tending to uproot or break the coral clumps. These disrupting and transporting effects, will be less and less as we recede from the shores; yet all coral depths will experience them in some degree.

There is another process going on over the coral field, somewhat analogous to vegetable decay, though still very different. Zoophytes have been described as ever dying while living. The dead portions are much smoothed down, or deprived of the roughening points which belong to the living coral, and the cells are sometimes half obliterated, or the delicate lamellæ are worn away. This may be viewed as one source of fine coral particles; and as the process is constantly going on, it is not an unimportant source. This material is in a fit condition to enter into solution, and it cannot be doubted that the water receives lime from this source, which is afterwards yielded to the reef.

In the Alcyonia family, which includes semi-fleshy corals, and the Gorgoniæ, the lime is often scattered through the polyps in granules; and the process of death sets these calcareous grains free, which are consequently added to the coral sands. The same process has been supposed to take place in the more common reef corals, the Madrepores and Astræas, and it is possible that this may be to some extent the case. Yet it would seem, from facts observed, that after the secretion has begun, the secretion of lime going on takes place *against* the portions already formed, and in direct union with them, and not as granules to be afterwards cemented.

The *mud-like* deposits about coral reefs have been attributed to the causes just mentioned, but without due consideration. There is an unfailing and abundant source of this material in the self-triturating sands of the reefs acted upon by the moving waters. On the seaward side of coral islands, and on the shores of the larger lagoons, where

the surface rises into waves of much magnitude, the finer portions are carried off, and the coarser sand alone remains to form the beaches. This is a well-known fact common on all shores exposed to the waves, coral or not coral, and to this cause the sandy character is attributed. But in the smaller lagoons, where the water is only rippled by the winds, or roughened for short intervals, the trituration is of the gentlest kind possible, and, moreover, the finely pulverized material remains as part of the shores. Thus the fine material of the mud must be constantly forming, on all the shores, for the sands are perpetually wearing themselves out; but the mud *accumulates* only in the more quiet waters, and within the lagoons and channels, where it settles, after being washed out from the beaches. This corresponds exactly with the facts; and every lake and pool of water of our continents illustrates the same point.*

The coral world, as we thus perceive, is planted, like the land, with a variety of shrubs and smaller plants, and the elements and natural decay are producing gradual accumulations of material, like those of vegetation. The history of the growing reef has consequently its counterpart among the ordinary occurrences of the land about us.

The progress of the coral formation is like its commencement. The same causes continue with similar results, and the reader might easily supply the details from the facts already presented. The production of debris will necessarily continue to go on; a part will be

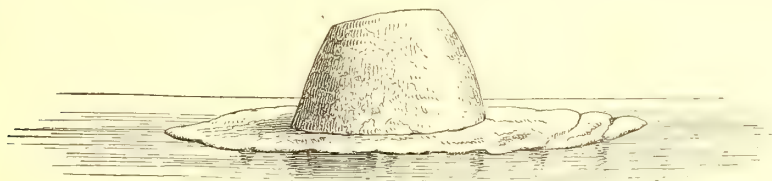
* Mr. Darwin, in discussing the origin of the finer calcareous mud, (op. cit. p. 14), supposes that it is derived, in part, from fishes and Holothurians, and other authors have thrown out the same suggestion. He cites as a fact, on the authority of Mr. Liesk, that certain fish browse on the living zoophytes; and from Mr. Allan, of Forres, he learned also that Holothurians subsisted on them. With regard to the facts here stated, I can make no definite assertion. Small fish swarm about the branching clumps, and when disturbed, seek shelter at once among the branches, where they are safe from pursuit. I have often witnessed this fact, and never saw reason to suppose that they clustered about the coral for any other purpose. It is an undoubted fact, however, as stated by Mr. Darwin, that fragments of coral and sand may be found in the stomachs of these animals, though this is no evidence of their browsing on the coral. The conclusion deduced by him from the facts may be justly doubted. The fish and Holothurians, though numerous, are quite inadequate for the supply; and, moreover, we have, as explained above, an abundant source of the finest coral material without such aid. Motion of particle over particle, will necessarily wear to dust, even though the particles be diamonds; and this incessant grinding action about reefs, accounts satisfactorily for the deposits of coral mud, however large they may be.

swept by the waves, across the patch of reef, into the lagoon or channel beyond, while other portions lodge on its surface. But besides the small fragments, larger masses will be thrown on the reefs, by the more violent waves, and commence to raise them above the sea. The *clinker fields* of coral, by this means produced, constitute the first step in the formation of dry land. Afterwards, by farther contributions of the coarse and fine coral material, the islets are completed, and raised as far out of water as the waves can reach—that is, from six to ten feet. The ocean is thus the architect, while the coral polyps afford the material for the structure: and when all is ready, it sows the land with seed brought from distant shores, covering it with verdure and flowers.

The growth of the reefs and islands around high lands, is the same as here described for the atoll.

Among the peculiarities of coral islands, the *shore platform* appears to be one of the most singular. It will be remembered that it lies but little above low tide level, and is often three hundred feet in width, with a nearly flat surface throughout.

Though apparently so peculiar, the existence of this platform is due to the simple action of the sea, and is a necessary result of this action. Passing to New Holland, from the coral islands of the tropics, we there found the same structure exemplified along the *sandstone* shores of this semi-continent, where it is continued for scores of miles. At the base of the sandstone cliff, in most places one or more hundred feet in height, there is a layer of sandstone rock, lying, like the shore platform of the coral island, near low tide level, and from fifty to one hundred and fifty yards in width. It is continuous with the bottom layer of the cliff: the rocks which once covered it, have been removed by the sea. Its outer edge is the surf-line of the shore. At low tide it



“THE OLD HAT,” BAY OF ISLANDS.

is mostly a naked flat of rock, while at high tide it is wholly under water, and the sea reaches the cliff. New Zealand, at the Bay of Islands, afforded us the same fact, again, in an argillaceous sandrock; and there was no stratification in this case to favour the production of

a horizontal surface ; it was a direct result from the causes at work. The shore shelf stands about five feet above low water. A small island in this bay is well named the " Old Hat," the platform encircling it, as shown in the preceding figure, forming a broad brim to a rude conical crown. The water, in these cases, has worn away the cliffs, leaving the basement untouched.

A surging wave, as it comes upon a coast, gradually rears itself on the shallowing shores ; finally, the waters at top, through their greater velocity, plunge with violence upon the barrier before it. The force of the ocean's surges is, therefore, mostly confined to their summit waters, which add weight to superior velocity, and drive violently upon whatever obstacle is presented. The *lower* waters of the surge advance steadily, but more slowly, owing to the retarding friction of the bottom ; the motion they have is directly forward, and thus they act with little mechanical advantage ; moreover, they gradually swell over the shores, and receive, in part, the force of the *upper* waters. The wave, after breaking, sweeps up the shore till it gradually dies away. Degradation from this source is consequently most active where the upper or plunging portion of the breaker strikes.

But, further, we observe that at low tide the sea is comparatively quiet ; it is during the influx and efflux that the surges are heaviest. The action commences after the rise, is strongest from half to three fourths tide, and then diminishes again near high tide. Moreover, the plunging part of the wave is raised considerably above the general level of the water. From these considerations, it is apparent that the line of greatest wave-action, must be above low water level. Let us suppose a tide of three feet, in which the action would probably be strongest when the tide had risen two feet out of the three ; and let the height of the advancing surge be four feet :—the wave, at the time of striking, would stand, with its summit, three feet above high tide level ; and from this height would plunge obliquely downward against the rock, or any obstacle before it. It is obvious, that under such circumstances, the greatest force would be felt, not far from the line of high tide, or between that line and three feet above it. In regions where the tide is higher than just supposed, as six feet, for example, the same height of wave would give nearly the same height to the line of wave-action, as compared with high tide level. Under the influence of heavier waves, such as are common during storms, the line of wave-action would be at a still higher elevation, as may be readily estimated by the reader.

Besides a line of the *greatest* wave-action, we may also distinguish a height where this action will entirely cease; and it is evident, from facts already stated, that the point will be found somewhat above low tide level. The lower waters of the surge, instead of causing degradation, are *accumulative* in their ordinary action, when the material exposed to them is movable: they are constantly piling up, while the upper waters are rending and preparing material to be carried off. The height at which these two operations balance one another will be the height, therefore, of the line of no degradation. As the sea at low tide is mostly quiet, and the lower of the surging waters swell on to receive the upper, and parry the blow, and, moreover, there is next a return current outward,—we should infer that the line would be situated more or less above low tide, according to the height of the tide, and the surges accompanying it. We are not left to conjecture on this point; for the examples presented by the shores of New Holland and New Zealand afford definite facts. Degradation has there taken place sufficient to carry off cliffs of rock, of great extent; yet below a certain level, the sea has had little or no effect. This height, at New Holland, is three feet above ordinary low tide, and at New Zealand, about five feet. With regard to the height varying with the tides, we observe that in the Paumotus, where the water rises but two or three feet, the platform is seldom over four to six inches above low tide, which is proportionally less than at New Holland and New Zealand, where the tide is six and eight feet. From these observations, it appears that the height of *no wave-action*, as regards the degradation of a coast under ordinary seas, is situated near one-fifth tide, in the Paumotus, and above half tide at New Zealand, showing a great difference between the effect of the comparatively quiet surges of the middle Pacific, and the more violent of New Zealand. Within the Bay of Islands, where the sea has not its full force, the platform, as around the “Old Hat,” is but little above low water level. The exact relation of the height of the platform to the height and force of the tides remains to be determined more accurately by observation. While the height of the shore platform depends, therefore, on the tides, and the usual strength of the waves, the breadth of it will be determined by the same causes in connexion with the nature of the rock material.*

* On basaltic shores it is not usual to find a shore platform, as the rock scarcely undergoes any degradation, except from the most violent seas; such coasts are consequently often covered with large fragments of the basaltic rocks. But on sandstone shores, this

It is apparent that one single principle meets all the various cases. The rocky platform of some sea-shores, the low tide sand-spit on others, and the coral-reef platform of others, require but one explanation. The material of the coral platform is piled up by the advancing surges, and cemented through the infiltrating waters, which take lime into solution, and again distribute it. These surges, advancing towards the edge of the shelf, swell over it before breaking, and thus throw a protection about the exposed rocks; and as the tide rises this protection is complete. They move on, sweeping over the shelf, but only clear it of sand and fragments, which they bear to the beach.

The isolated blocks which stand on the platform, attached to it below, are generally most worn one or two feet above high tide level, a fact which corresponds with the statement in a preceding paragraph with regard to the height of the greatest wave-action.

In addition to this ordinary wave-action, there are also more violent effects from storms; and these are observed alike on the Australian shores referred to, and on those of coral islands. The waters, moving through greater depths, and driving on with increased velocity, up the shallowing shores among cavities or under shelving layers, break and lift the rocks of the edge of the platform, and throw them on the reef. From the observations of Mr. Stevenson, cited in the note to page 106, it appears that the force of the waves during the summer and winter months differs at Skerryvore more than 1200 pounds to the square foot,—in the former it averaging but 636 pounds, and in the latter 2086 pounds, while in storms it was at times equivalent to 6083 pounds. The seasons are not as unlike in the tropical part of the Pacific. Still there must be a marked difference between the ordinary seas and those during stormy weather. We have therefore no difficulty in comprehending how the ordinary wave-action should build up and keep entire the shore platform, while the more agitated seas may tear up parts of the structure formed, and bear them on to the higher parts of the island. Still more violent in action are the great earthquake-waves, which move through the very depths of the ocean.

These principles offer an explanation also of the general fact that the windward reef is the highest. The ordinary seas, both on the leeward and windward sides, are sufficient for producing coral debris

gradual action keeps the platform of nearly uniform breadth. Moreover, any uptorn masses thrown upon it, are soon destroyed by the same action, and carried off; and thus the platform is kept nearly clean of debris, even to the base of the cliff.

and building up the reef, and in this work the two sides may go on with almost equal rate of progress: consequently we may often find no very great difference in the *width* of the leeward and windward reefs, especially as the wind for some parts of the year has a course opposite to its usual direction. But seldom, except on the side to windward, is a sufficient force brought to bear upon the edge of the platform, to detach and uplift the larger coral blocks. The distance to which the waves may roll on without becoming too much weakened for the transportation of the uptorn blocks, will determine the outline of the forming land. With proper data as to the force of the waves, the tides, and the soundings around, the extent of the shore platform might be made a subject of calculation.

The effect of a windward reef in diminishing the force of the sea is sometimes shown in the influence of one island on another. A striking instance of this is presented by the northernmost of the Tarawan Islands. All the islands of this group are well wooded to windward—the side fronting east, between north and south. But the north side of Tari-tari is nothing but a bare reef, through a distance of twenty miles, although the southeast reef is a continuous line of verdure. The small island of Makin, just north of Tari-tari, (see plate, page 50,) is the breakwater which has protected the reef referred to from the heavier seas.

Coral island accumulations have one advantage over all other shore deposits, owing to the ready agglutination of calcareous grains, as explained on a following page. It has been stated that coral sand-rocks are forming along the beaches, while the reef-rock is consolidating in the water. A defence of rock against encroachment is thus produced, and is in continual progress. Moreover, the structure built amid the waves will necessarily have the form and condition best fitted for withstanding their action. The little islet of an atoll is therefore more enduring than those of harder basaltic rocks. Reefs of zoophyte growth but “mock the leaping billows,” while other lands of the same height would gradually yield to the assaults of the ocean. There are cases, however, of wear from the sea, owing to some change of condition in the island, or in the currents about it, in consequence of which parts once built up are again carried off. Moreover, those devastating seas which overleap the whole land may occasion unusual degradation from some parts. Yet these islets have within themselves the source of their own repair, and are secure from all serious injury.

The lagoons in coral islands are constantly receiving more or less debris from the reefs; and patches of growing coral within also tend to fill them up. But the effect is slow in its progress, and none but islands of small size show any approximation, as before stated, to an obliteration of the lagoon.

2. CAUSES MODIFYING THE FORMS AND GROWTH OF REEFS.

Coral reefs although (1) *dependent on the configuration of the submarine lands for many of their features*, undergo various modifications of form or condition through the influence of extraneous causes, such as (2) *unequal exposure to the waves*; (3) *oceanic or local currents*; (4) *presence of fresh or impure waters*. In briefly treating of these topics, we may consider *first*, reefs around high islands, and *next* atoll reefs. The effect of the waves on the different sides of reefs has already been considered, and we pass on, therefore, at once to the influence of oceanic or local currents, and fresh or impure waters.

a. *Barrier and Fringing Reefs.*

The *existence of harbours* about coral-bound lands, and of entrances through reefs, is largely attributable to the action of tidal or local marine currents. The presence of fresh-water streams, has some effect towards the same end, but much less than has been usually imputed to their action.*

There are usually strong tidal currents through the reef channels and openings. These currents are modified in character by the outline of the coast, and are strongest wherever there are coves or bays to receive the advancing tides. The harbour of Apia, on the north side of Upolu, affords a striking illustration of this general principle. The coast at this place has an indentation 2000 yards wide and

* The view here supported, is nearly identical with that presented by Mr. Darwin, (op. cit. page 68.) The arguments given were, however, written out (in 1840), before his descriptions of coral islands were known to me. This fact may give additional weight to the opinions, inasmuch as they are therefore the conclusions of independent observers, and are substantiated by a distinct set of observations.

nearly 1000 deep, as in the accompanying sketch, reduced from the chart by the Expedition. The reef extends from either side or cape a mile out to sea, leaving between, an entrance for ships. The harbour averages ten feet in depth, and at the entrance is fifteen feet. In this harbour there is a remarkable out-current along the bottom, which during gales, is so strong at certain states of the tide, that a ship at anchor, although a wind is blowing directly in the harbour, often rides with a slack cable; and in more moderate weather the vessel tails out *against* the wind. Thus when no current but one inward is perceived at the surface, there is an under current acting against the keel and bottom of the vessel, which is of sufficient strength to counteract the influence of the winds on the rigging and hull. The cause of such a current is obvious. The sea is constantly pouring water over the reefs into the harbour, and the tides are periodically adding to the accumulation; the indented shores form a narrowing space where these waters tend to pile up: escape consequently takes place along the bottom by the harbour-entrance, this being the only means of exit. This is a correct history of numerous cases about all the islands. In a group like the Feejees, where many of the islands are large, and the reefs very extensive, the currents are still more remarkable, and change in direction with the tides. The general mode of action, however, is the same.



HARBOUR OF APIA, UPOLU.

A current of water of the kind here represented, will carry out much coral debris, and strew it also along its course. The transported material will vary in amount from time to time, according to the force and direction of the current. It is therefore evident that the ground over which it runs is wholly unfit for the growth of coral, since zoophytes are readily destroyed by depositions of earth or sand, and require a firm basement to commence growth. The existence of an opening through a reef requires, therefore, no other explanation; and it is obvious that harbours may generally be expected to exist wherever the character of the coast is such as to produce currents and give a fixed direction to them.

The currents about the reef-grounds west of the large Feejee Islands, aid in distributing the debris both of the land and the reefs. In some parts the currents eddy and deposit their detritus; in others they sweep the bottom clean. Thus, under these varying conditions, there may be growing corals over the bottom in some places and not

in others; and the reefs may be distributed in patches, when without such an influence we should expect a general continuity of coral reef over the whole reef-grounds.

The results from marine currents are often increased by waters from the island streams; for the coves, where harbours are most likely to be found, are also the embouchures of valleys and the streamlets they contain. The fresh waters poured in add to the amount of water, and increase the rapidity of the out-current. At Apia, Upolu, there is a stream thirty yards wide, and many other similar instances might be mentioned. These waters from the land bring down also much detritus, especially during freshets, and the depositions aid those from marine currents in keeping the bottom clear of growing coral. These are the principal means by which fresh-water streams contribute towards determining the existence of harbours; for little is due to their freshening the salt waters of the sea.

The small influence of the last-mentioned cause—the one most commonly appealed to—will be obvious, when we consider the size of the streams of the Pacific islands, and the fact that fresh water is lighter than salt, and therefore, instead of sinking, flows on over its surface. The deepest rivers are seldom over six feet, even at their mouths; and three or four feet is a more usual depth. They will have little effect, therefore, on the sea-water beneath this depth, for they cannot sink below it; and corals may consequently grow even in front of a river's mouth. Moreover, the river-water becomes mingled with the salt, and, in most cases, a short distance out, would not be unfit for some species of coral zoophytes.

Yet when the rivers are large, like those of continents, the influence of the freshening waters is very decided, and prevails often over a wide extent of coast.

Fresh-water streams, acting in all the different modes pointed out, are of little importance in harbour-making about the islands of the Pacific. The harbours, with scarcely an exception, would have existed without them. They tend, however, to keep the bottom more free from growing patches of coral, and consequently produce better anchorage ground: moreover, within the harbours they usually keep channels open sufficiently deep and wide for a boat to reach the shore, and sometimes preserve a clean sand-beach throughout. That this is their principal effect will appear from a few facts.

The figure on page 41 has been described as a map of the reef

of North Tahiti, between Papieti, on the left, and Venus Point on the right.

a. The harbour of Papieti is enclosed by a reef about three-fourths of a mile from the shore. The entrance through the reef is narrow, with a depth of eleven fathoms at centre, six to seven fathoms either side, and three to five close to the reef. This fine harbour receives an unimportant streamlet, while a much larger stream empties just to the east of the east cape, *opposite which the reef is close at hand and unbroken.*

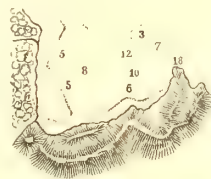
b. Toanoa is the harbour next east of Papieti. The entrance is thirty-five fathoms deep at middle, and three and a half to five fathoms near the points of reef. There is no fresh-water stream, excepting a trifling rivulet.

c. Papaoa is an open expanse of water, harbour-like in character, but is without any entrance; the reef is unbroken. Yet there are two streams emptying into it, one of which is of considerable size.

d. Off Matavai, the place next east, the reef is interrupted for about two miles. The harbour is formed by an extension of the reef off Point Venus, the east cape. There is no stream on the coast, opposite this interruption in the reef, except towards Point Venus, and at the present time the waters find their principal exit, east of the Point, behind a large coral reef, but a quarter of a mile distant.

From such facts, it would almost seem as if coral reefs grew best near fresh-water streams. We cannot be surprised at the little influence they appear to have exerted when knowing that none of these so-called rivers are over three feet in depth; and the most they can do is to produce a thin layer of brackish water over the sea within the channels.

e. The annexed figure of the harbour of Falifa, Upolu, represents another coral harbour, as surveyed by Lieutenant Emmons. At its head there is a fine stream twenty-five or thirty yards wide, and three feet deep. Notwithstanding the unusual size of the river, the coral reef lies near its mouth, and projects some distance in front of it. Its surface is dead, but corals are growing upon its outer slope.



HARBOUR OF FALIFA.

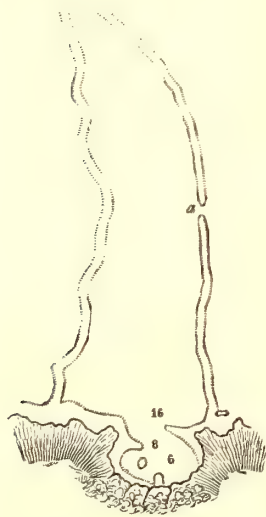
f. The harbour of Rewa, in the Feejees, may be again alluded to. The waters received by the bay amount to at least 500,000 cubic feet a minute. Yet there is an extensive reef enclosing the bay, lying but three miles from the shores, and with only two

narrow openings for ships. The case is so remarkable that we can hardly account for the facts without supposing the river's mouth to have neared the reef by depositions of detritus since the inner parts of the reef were formed; and there is some evidence that this was the case, though to what distance, we cannot definitely state. With this admission, the facts may still surprise us; yet they are explained on the principle that fresh water does not sink in the ocean, but is superficial, and runs on in a distinct channel; its effect is almost wholly through hydrostatic pressure, and detritus depositions. Besides these instances, there are many others in the Feejees, as will be observed on the Expedition charts. Mokungai has a large harbour, without a stream of fresh water;—so also Vakea, and Direction Island.

The instances brought forward are a fair example of what is to be found throughout coral seas; and they establish, beyond dispute, that while much in harbour-making should be attributed to the transported sand or earth of marine and fresh-water currents, in preventing the growth of coral, but little is due to the freshening influence of the streams of the islands.

But while observing that currents have so decided an influence on the condition of harbours, we should remember another prevalent cause, already remarked upon, and perhaps more wide in its effects than those just considered. I refer to the features of the supporting

land, or the character of soundings off a coast. We need not repeat here what has already been dwelt upon, showing that many of the interruptions of reefs have thus arisen. The wide break off Matavai may be of this kind. The widening of the inner channel at Papieti, forming a space for a harbour, may be another example of it; for the reef here is removed to a greater distance from the shores, as if because the waters shallowed more gradually outward off this part of the coast. The same cause—the depth of soundings—has more or less influence about all reefs in determining their configuration and the outlines of harbours. A remarkable instance of the latter is exemplified in the annexed chart of Whippey Harbour, Viti Lebu, reduced from the chart



WHIPPEY HARBOUR, VITI LEBU.

of the Expedition to the scale of half an inch to the mile.

The existence of harbours should therefore be attributed, to a great extent, to the configuration of the submarine land; while currents give aid in preventing the closing of channels, and keeping open grounds for anchorage. This subject will be further illustrated in the following pages.

The permanency of coral harbours follows directly from the facts above presented. They are secure against any immediate obstruction from reefs. Any growing patches within them may still grow, and the margins of the enclosing reefs may gradually extend and contract their limits; yet only at an extremely slow rate. Notwithstanding such changes, the channels will remain open, and large anchorage grounds clear, as long as the currents continue in action. Coral harbours are therefore nearly as secure from any new obstructions as those of our continents. The growing of a reef in an adjoining part of the coast may in some instances diminish or alter the currents, and thus prepare the way for more important changes in the harbours; but such effects need seldom be feared, and results from them would be appreciable only after long periods, since the growth of reefs is very slow in the most favourable circumstances.

When channels have a bottom of growing coral, they form an exception to the above remark; for as the coral is acted upon by no cause sufficient to prevent its growth, the reef will continue to rise slowly towards the surface.

Again, when the channels are more than twenty fathoms in depth, they have an additional security beyond that from currents, in the fact that corals will not grow at such a depth. The only possible way in which such channels could close, without first filling up by means of shore material, would be by the extension of the reef from either side, till they bridge over the bottom below. But such an event is not likely to happen in any but very narrow channels.

In recapitulation, the existence of passages through reefs, and the character of coral harbours may be attributed to the following causes:

1. The configuration and character of the submarine land;—corals not growing where the depth exceeds certain limits, or where there is no firm basement for the plantation.

2. The direction and force of marine currents with their transported detritus;—these currents deriving their course, as in other regions, from the features of the land, the form of the sea-bottom, and the reefs, and being sometimes increased in force by the contributions of island streams, which add to the detritus and to the weight of accumulating waters.

3. Harbours which receive fresh-water streams are more apt to be clear from sunken patches; and the same cause keeps open shallow passages to the shores, where there are shore reefs.

It should be remembered, that while the effects from fresh-water streams are so trifling around islands, they may be of very wide influence on the shores of continents, where the streams are large and deep, and transport much detritus. This point is illustrated beyond.

b. *Atoll Reefs.*

The remarks in the preceding pages respecting reefs around other lands, apply equally to atoll reefs. There are usually currents flowing to leeward through the lagoon, and out, over or through the leeward reef, and this action, as with the coral harbour, tends to keep open a leeward channel for the passage of the water. This is the common explanation of the origin of the channels opening into lagoons. These currents are strongest when the windward reef is low, and permits the waves in some parts to break over it; and the amount of coral debris they bear along will then be greatest. When a large part of the leeward reef is under water, or at low tide level, the waters may escape over the whole, and on this account we sometimes find large reefs without any proper channels. As the land to windward becomes raised throughout above the sea, and forms a continuous line which the waves cannot pass, the current is less perfectly sustained, being dependent entirely upon the influx and efflux of the tides; and the leeward channels, in such a case, may gradually become closed.

The action of currents on atolls is, therefore, in every way identical with what has been explained. The absence of coves of land to give force to the waters of the currents, and to direct their course, and the absence also of fresh-water streams, are the only modifying causes not present. It is readily understood, therefore, why lagoon entrances are more likely to become filled up by growing coral, than the passages through barrier reefs.

3. RATE OF GROWTH OF REEFS.

The formation of a reef has been shown to be a very different process from the growth of a zoophyte. Its rate of progress is a question to be settled by a consideration of many distinct causes, and the rapid voyage of an Expedition affords no opportunity for definite conclusions.

a. The rapidity of the growth of zoophytes is an element in this question of great importance, and one that should be determined by direct observation with respect to each of the species which contribute largely to reefs, both in the warmer and colder parts of coral-reef seas.

b. The character of the coral plantation under consideration should be carefully studied: for it is of no little consequence to know whether the clusters of zoophytes are scattered tufts over a barren plain, or whether in crowded profusion. Compare the debris of vegetation on the semideserts of California with that of regions buried in foliage; equally various may be the rate of growth of coral rock in different places. Some allowance should also be made for the shells and other reef relics. The amount of reef rock formed in a given time cannot exceed, in cubic feet, the aggregate of corals and shells added by growth—that is, if there are no additions from other distant or neighbouring plantations.

c. It is also necessary to examine into whatever has any bearing upon the marine or tidal currents of the region—their strength, velocity, direction, where they eddy, and where not, whether they flow over reefs that may afford debris or not. All the debris of one plantation may sometimes be swept away by currents to contribute to other patches, so that one will enlarge at the expense of others. Or, currents may carry the detritus into the channels or deeper waters around a coral patch, and leave little to aid the plantation itself in its increase and consolidation.

d. The course and extent of fresh waters from the land, and their detritus, should be ascertained.

e. The strength and height of the tides, and general force of the ocean waves, will have some influence.

Owing to the action of these causes, barrier reefs enlarge and extend more rapidly than inner reefs. The former have the full action

of the sea, and are farther removed from the deleterious influences which may affect the latter.

As stated above, no results were arrived at from observations made in the course of the voyage through the Pacific. The general impression that their progress is slow, was fully sustained. The facts, with regard to the growth of zoophytes, give some data, though by no means satisfactory.

If we allow that Madrepores may grow three inches a-year, it is far from admitting that a reef may increase as rapidly. In the best coral plantations, not over one-third of the surface is covered with growing zoophytes. It would therefore follow, supposing all the species to grow at this rate, and all the material to be retained on the plantation, that in twelve months the reef might possibly increase one inch in height; including shells and other animal remains, it might, perhaps, be one and one quarter inches. This estimate is based on too many assumptions to be received with any confidence, except it be the confidence that the result is overrated.

With reference to this subject, by the order of Captain Wilkes, a slab of rock was planted on Point Venus, Tahiti, and by soundings, the depth of Dolphin Shoal, below the level of this slab, was carefully ascertained. By adopting this precaution, any error from change of level in the island, was guarded against: the slab remains as a stationary mark for future voyagers to test the rate of increase of the shoal. Before, however, the results can be of any general value towards determining the average rate of growing reefs, it is still necessary that the growing condition of the reef should be ascertained, the species of corals upon it be identified, and the influence of the currents investigated which sweep in that direction out of Matavai Bay.

The depth to which Chamas or Tridacnas lie embedded in coral rock, has been supposed to afford some data for estimating the growth of reefs. But Mr. Darwin rightly argues that these molluscs have the power of sinking themselves in the rock, as they grow, by removing the lime about them. They occur in the dead rock,—generally where there are no growing corals, except rarely some small tufts. If they indicate anything, it must be the growth of the reef rock, and not of the corals themselves. But the shore platform where they are found is not increasing in height. They resemble, in fact, other saxicavous molluscs, several species of which are found in the same seas, some buried in the solid masses of dead coral lying on the reef. The bed they excavate for themselves is usually so complete

that only an inch or two in breadth of their ponderous shells are exposed to view. Without some means like this of securing their habitations, these molluscs would be destroyed by the waves. A tuft of byssus, however strong, which answers for some small bivalves, would be an imperfect security against the force of the sea for shells weighing one to five hundred pounds.

4. ORIGIN OF THE CHANNELS WITHIN BARRIERS, AND OF THE ATOLL FORM OF CORAL ISLANDS.

In the review of causes modifying the forms of reefs, no reason was assigned for the most striking, we may say the most surprising, of all their features,—that they so frequently take a belt-like form, and enclose a wide lagoon; or, in other cases, range along, at a distance of some miles, it may be, from the land they protect, with a deep sea separating them from the shores.

This peculiar character of the coral island was naturally the wonder of early voyagers, and the source of many speculations. The instinct of the polyp was made by some the subject of special admiration; for the “helpless animalcules” were supposed to have selected the very form best calculated to withstand the violence of the waves, and apparently with direct reference to the mighty forces which were to attack the rising battlements. They had thrown up a breastwork, as a shelter to an extensive working ground under its lee, “where their infant colonies might be safely sent forth.”*

It has been a more popular theory that the coral structures were built upon the summit of volcanoes;—that the crater of the volcano corresponded to the lagoon, and the rim to the belt of land; that the entrance to the lagoon was over a break in the crater, a common result of an eruption. This view was apparently supported by the volcanic character of the high islands in the same seas.—But since a more satisfactory explanation has been offered by Mr. Darwin, numerous objections to this hypothesis have become apparent.

a. The volcanic cones must either have been subaerial and were afterwards sunk beneath the waters, or else they were submarine from the first. In the former case the crater would have been destroyed, with rare exceptions, during the subsidence; and in the latter there is

* Flinders.

reason to believe that a distinct crater would seldom, if ever, be formed.

b. The hypothesis, moreover, requires that the ocean's bed should have been thickly planted with craters—seventy in a single archipelago,—and they should have been of nearly the same elevation; for if more than twenty fathoms below the surface, corals could not grow upon them. But no records warrant the supposition that such a volcanic area ever existed. The volcanoes of the Andes differ from one to ten thousand feet in altitude, and scarcely two cones throughout the world are as nearly of the same height as here supposed. Mount Loa and Mount Kea, of Hawaii, present a remarkable instance of approximation, as they differ but two hundred feet: but the two sides of the crater of Mount Loa differ three hundred and fourteen feet in height. Mount Kea, though of volcanic character, has no large crater at top. Hualalai, the third mountain of Hawaii, is 4000 feet lower than Mount Loa. The volcanic summit of East Maui is 10,000 feet high, and is a fine example of a large crater; but the wall of the crater on one side is 700 feet lower than the highest point of the mountain; and the bottom of the crater is 2000 feet below the rim of the crater. Similar facts are presented by all volcanic regions.

c. It further requires that there should be craters at least fifty miles in diameter, and that twenty and thirty miles should be a common size. Facts give no support to such an assumption.

d. It supposes that the high islands of the Pacific, in the vicinity of coral islands, abound in craters; while on the contrary there are none, as far as is known, in the Marquesas, Gambier, or Society Groups, the three which lie nearest to the Paumotus. Even this supposition fails, therefore, of giving plausibility to the crater hypothesis.

Thus at variance with facts, the theory has lost favour, and is no longer sustained even by those who were once its strongest advocates. The question still recurs with regard to the basement of coral islands, and the origin of their lagoon character. Shall we suppose, with some writers, that these islands were planted upon submarine banks, within one hundred and fifty feet of the surface of the sea? As has been said, there is no authority for the supposition. We nowhere find regions upon our continents with elevations so uniform in height; and submerged banks of this kind are of extremely rare occurrence. If such patches of submerged land existed, the lagoon structure would still be as inexplicable as ever; for the growing reefs of the Pacific

show that corals may flourish alike over all parts of the bank, when not too deep. The zoophyte can by no means be said to prefer the declivity to the central plateau of the submarine bank: on the contrary, the part nearest the surface appears to abound in the largest species of corals.*

A study and comparison of the reefs of different kinds,—fringing, barrier, and atoll,—throughout the oceans, is the only philosophical mode of arriving at any conclusion on this subject. This course Mr. Darwin has happily and successfully pursued, and has arrived, as we have reason to believe, at the true theory on the subject. It is satisfactory, because it is a simple generalization of facts. The explorations of the Expedition afford striking illustrations of his views, and elucidate some points which are still deemed obscure, establishing the theory on a firm basis of evidence, and exhibiting its complete correspondence with observation.†

Channels within barriers.—We may turn again to the chart of the Feejee Group, and glance successively at the islands Goro, Angau, Nairai, Lakemba, Argo Reef, Exploring Isles, and Nanuku. In Goro, the reef closely encircles the land upon whose submarine shores it was built up. In the island next mentioned, the reef has the same character, but is more distant from the shores, forming what has been termed a barrier reef; the name implying a difference in position, but none in mode of formation. In the last of the islands enumerated, the barrier reef includes a large sea, and the island it encloses is but a rocky peak in this sea.

Can we account for this diversity in the position of barrier reefs, and in their extent as compared with the enclosed land? There is evidently one way in which these features might have been produced. If, for example, such an island as Angau were very gradually to subside, from some subterranean cause, two results would take place:—the land would slowly disappear, while the coral reef, which is ever in constant increase, as has been explained, might retain itself at the surface, if the rapidity of subsidence was not beyond a certain rate. This subsidence might go on till the last mountain peak remained alone above the waters. Should we not then have a Nanuku? Suppose the subsidence not to have proceeded quite as far as this, it might

* Lieutenant Nelson, R. N., suggested this hypothesis before the publication of Mr. Darwin's views. See Geol. Trans., vol. v. 122; and Darwin, op. cit. p. 94.

† This is given as the conclusion of the author. A different view is offered by Captain Wilkes, in the Narrative of the Expedition, iv. 268.

leave only a single ridge and a few isolated summits peering above the waves. Would not its condition in this case be that of the Exploring Isles? On such a supposition, reefs of large size encircling a mere point of rock might be explained in every feature. The subsidence of Goro, on the same principle, would produce an Angau, or, carried further, a Nanuku.

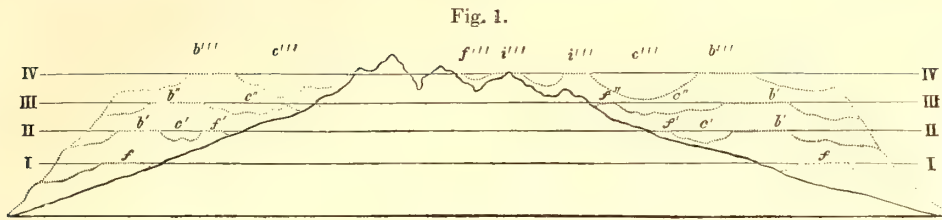
It may be here remarked, that the fact that changes of level in the earth's surface have taken place over vast areas, is fully proved, and accounts of some of them which are now in progress, as that of Sweden, are to be found in any geological treatise.

But it admits of direct demonstration that such a subsidence has actually taken place. It has been stated that the depth of the reef at different distances from the shore it encircles may generally be estimated from the slope of the shore. On this principle it has been shown that the thickness of the distant barrier reef cannot be less in some instances than a thousand feet; and in many cases it is probably much greater. Now as reef corals do not grow below twenty fathoms, there is no way in which this thousand feet of reef could have been formed except by a gradual subsiding of the land upon which it stands. The large number of instances of distant barriers in the Pacific remove any doubt with regard to these conclusions. The map of the Feejees abounds in them through its eastern part, and we may infer with reason that this has been a large area of subsidence, like that which is now going on in Greenland.

Evidence of subsidence still more conclusive, if possible, is obtained by actual observation at Metia and some of the elevated coral islands. This island is 250 feet in height, full twice the coral-growing depth. At another island in the Hervey Group, Mangaia, the coral rock is raised 300 feet out of water.

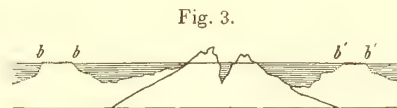
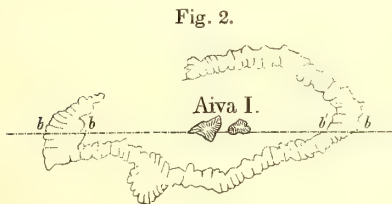
The fact of subsidence having actually taken place during the formation of many reefs, is therefore put beyond doubt. It must form a part of any true theory of reefs, whether it be the crater hypothesis or the view here advocated. The latter has this advantage, that it explains all the facts, and requires no other element but this single one of subsidence. It rests on a simple fact and demands no hypothesis whatever.

The manner in which subsidence would operate is shown in the following sketches, representing ideal transverse sections of an island and its reefs. In figure 1, if I be the water line, the island, like Goro, has a simple fringing reef, *ff*:—it is a narrow platform of rock



at the surface, dropping off at its edge to shallow depths, and then some distance out, declining more abruptly. Let the same island become submerged till II is the water line:—the reef extends itself upward, as submergence goes on, and may have the character at the surface represented by $b' f' b' f'$. There is here a fringing reef and also a barrier reef, with a narrow channel between, such as we have described as existing on the shores of Tahiti (see figure, page 41); b' is a section of the barrier, c' , of the channel, and f' of the fringing reef. Suppose a farther submergence, till III is the water line: then the channel ($c'' c''$) within the barrier is quite broad, as in the island of Nairai or Angau; on one side (f'') the fringing reef remains, but on the other it has disappeared, owing, perhaps, to some change of circumstance as regards currents, which retarded its growth, and prevented its keeping pace with the subsidence. With the water at IV, there are two islets of rock in a wide lagoon, along with other islets ($i''' i''''$) of reef over two peaks which have disappeared. The coral reef-rock by its gradual growth has attained a great thickness, and envelopes nearly the whole of the former land. Nanuku, the Argo Reef, and Exploring Isles are here exemplified, for the view is a good transverse section of either of them. $b''' b''''$ are sections of the distant enclosing barrier, and $c''' c''''$, and other intermediate spots, the water within.

The supposed similarity between these ideal sections and existing islands is fully sustained by actual comparison. The annexed figure (fig. 2) is a sketch of the island of Aiva in the Feejee



Group. There are two peaks in the lagoon precisely as above; and although we have no soundings of the waters in and about it, nor

sketches of the peaks, facts observed elsewhere, authorize in every essential point the transverse section given in figure 3, resembling closely, as is apparent, that in figure 1. The section is made through the line *bb, b'b'*, of figure 2. It is unnecessary to add other illustrations. They may be made out from any of the eastern groups of the Feejees, the Gambier Group of the Paumotus, or Hogoleu in the Carolines. Wallis's Island is another example of islets of rock in a large lagoon inclosed by a distant barrier.

It has been asked why the interior channels do not become filled by coral reef, as the island sinks, and thus a plane of coral result, instead of a narrow belt; and this has been urged against the theory of Mr. Darwin. But it is a sufficient reply to such an argument, to state the fact that the subsidence admits of no doubt, and that the islands referred to as exemplifications of it, present this very peculiarity. It should be received, therefore, as a consequence of it, instead of an objection to the view, for it is the most common feature with all islands that have broad reef-grounds, or in other words, that show evidence of subsidence during the growth of the reefs. Broad channels, and even open seas within, as in Nanuku and the Exploring Isles, are therefore to be received as results of the subsidence, for which explanations should be sought.

These explanations are at hand, and accord so exactly with facts ascertained, that the existence of inner passages becomes a necessary feature of such islands. It has been shown that the ocean acts an important part in reef-making;—that the outer reefs exposed to its action and to its pure waters, grow more rapidly than those within, which are under the influence of marine and fresh-water currents and transported detritus. It is obvious, therefore, that the former may retain themselves at the surface, when through a too rapid subsidence the inner patches would disappear. Moreover, after the barrier is once begun it has growing corals on both its inner and outer margin, while a fringing reef grows only on one margin. Again, the detritus of the outer reefs is, to a great extent, thrown back upon itself by the sea without and the currents within, while the inner reefs contribute a large proportion of their material to the wide channels between them. These channels, it is true, are filled in part from the outer reefs, but proportionally less from them than from the inner. The extent of reef-grounds within a barrier, raised by accumulations, at the same time with the reefs, is often fifty times greater than the area of the barrier itself. Owing to these causes the rate of growth of the

barrier may be at least twice more rapid than that of the inner reefs. If the barrier increases twenty feet in height in a century, the inner reef according to this supposition would increase but ten feet; and any rate of subsidence between the two mentioned, would sink the inner reefs more rapidly than they could grow, and cause them to disappear. A wide flat reef, continuous over such extensive reef-grounds, could be formed only with an extremely slow rate of subsidence; and even then they would be liable to be cut up by the production of inner currents, destroying growing corals over the interior parts of the coral reef; so that whatever the rate of subsidence, the inner portions would grow less rapidly. There is therefore not only no objection to the theory from the existence of wide channels and open seas; on the contrary, their non-existence is incompatible with the mode of action going on. They afford the strongest support to the theory.

From these considerations it is evident that a barrier reef indicates very nearly the former limits or extent of the land enclosed. The Exploring Islets (Feejee chart), instead of an area of *six* square miles, the whole extent of the existing land, once covered *three hundred* square miles; and the outline of the former land is indicated by the course of the enclosing reef. A still greater extent may be justly inferred. For the barrier, as subsidence goes on, gradually contracts its area, owing to the fact that the sea bears a great part of the material inward over the reefs: and, consequently, the declivity forming the outer limit of the submarine coral formation, has a steep angle of inclination.

In the same manner it follows that the island Nanuku, instead of *one* square mile, extended once over *two hundred* square miles, or had two hundred times the present area of high land. Bacon's Isles once formed a large triangular island of equal extent, though now but two points of rock remain above the water.

The two large islands in the western part of the group, Vanua Levu and Viti Levu, have distant barriers on the western side. Off the north point of the former, the reef begins to diverge from the coast, and stretches off from the shores till it is twenty and twenty-five miles distant; then, after a narrow interruption, without soundings, the Asaua Islands commence in the same line, and sweep around to the reef which unites with the south side of Viti Levu; and tracing the reef along the south and east shores, we find it at last nearly connecting with a reef extending southward from Vanua Levu. Thus these two large islands are nearly encircled in a single belt; and it would

be doing no violence to principles or probabilities, to suppose them once to have formed a single island, which subsidence has separated by inundating the low intermediate area. The singular reef of Whippley Harbour, p. 118, is fully explained by the hypothesis. We may thus not only trace out the general form of the land which once occupied this large area, (at least 10,000 square miles,) but may detect some of its prominent capes, as in Wakaia and Direction Island. The present area is not far from 4,500 square miles.

The whole Feejee Group, exclusive of coral islets, includes an area of about 5,500 square miles of dry land ; while, at the period when the coral commenced to grow, there was, at the least, as the facts show, 15,000 square miles of land, or nearly three times the present extent of surface.

B. Lagoons of Atolls.

We pass from these remarks on the channels and seas within barrier reefs, to the consideration of the seas or lagoons of coral atolls. The inference has probably been already made by the reader that the same subsidence which has produced the distant barrier, if continued a step further, would produce the lagoon island. Nanuku is

actually a lagoon island, with a single mountain peak still visible ; and Nuku-Levu, north of it, is a lagoon island, with the last peak submerged. This mode of origin may evidently be true of all atolls ; for with the exception of the points of high land in the inner waters, there is no one essential character, distinguishing many of the eastern Feejee Islands from the Carolines to the north. The Gambier Group, near the Paumotus, appears to have afforded the philosophical mind of Mr. Darwin the first hint with regard to the origin of the atoll ; the contrast, and, at the same

time, the resemblance, was striking ; the conclusion was natural and most happy.* As some interest is connected with the history

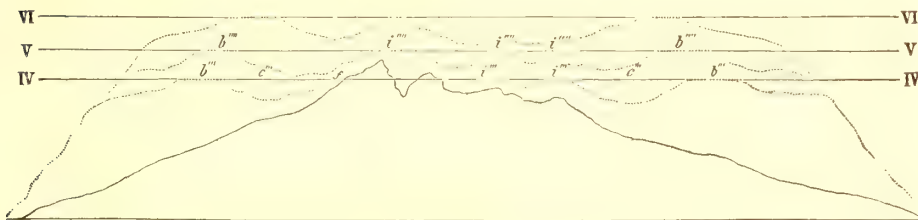


* Captain Beechey, in his voyage in the Pacific, implies this resemblance, when he says of the Gambier Group, which he surveyed, "It consists of five large islands and

of new principles, and the illustration afforded is highly satisfactory, we have given a sketch of the Gambier Group. The very features of the land, the deep indentations, are sufficient evidence of subsidence to one who has studied the character of the Pacific islands:* for these indentations correspond to valleys or gorges formed by denudation, during a long period, while the island stood above the sea.

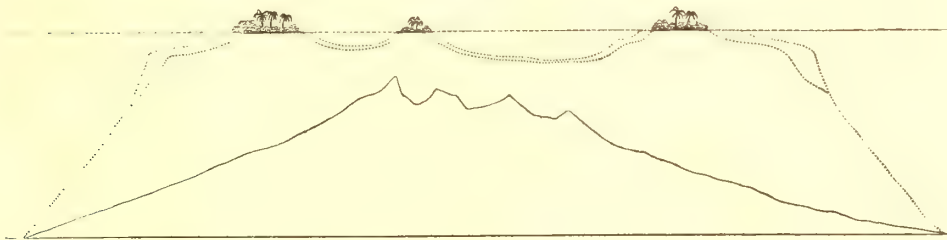
The manner in which a farther subsidence results in producing the atoll, may be illustrated by the following figure. Viewing V, as the water line, the land is entirely submerged; the barrier, b''' ,

Fig. 5.



b''' , is an annular reef, enclosing a broad area of waters, or lagoon, with a few island-patches of reef, over the peaks of the mountains.† At a still greater subsidence, (to the line VI,) the

Fig. 6.



islets, excepting one, have disappeared, owing to their increasing less rapidly than the barrier. The lagoon is in exact correspon-

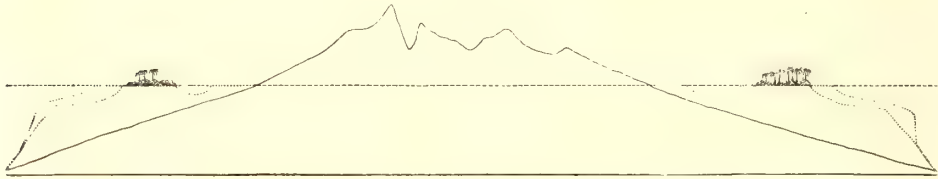
several small ones, *all situated in a lagoon formed by a reef of coral.*—p. 120, Amer. ed. Balbi, the geographer, as Mr. Darwin remarks, describes those barrier reefs which encircle islands of moderate size, by calling them atolls, with high lands rising from their central expanse.—Darwin, op. cit. p. 41.

* This subject is discussed in the chapter on the valleys of the Pacific islands.

† As the lagoon islets cover the summits of the subsided mountains, they afford the most favourable spots for reaching the rocks below by boring. In the figure above given, the depth required for this purpose on an islet in the lagoon would be hardly a fourth what would be necessary on the enclosing reef.

dence, in all its characters, with those of atoll reefs. Should subsidence now cease, the reefs, no longer increasing in height, would go on to widen, and the accumulations produced by the sea, would commence the formation of dry land, as exhibited in figure 6. Verdure may soon after appear, and the coral island is finally completed. It is not impossible that the land should form, in certain favourable spots, while the subsidence is in progress, if it be not beyond a certain rate. The following figure represents the effect

Fig. 7.



of a cessation or diminution of subsidence on the barrier reef, about a high island, represented in figure 1, II, page 127. The barrier reef has become a finished island, and forms a green belt to the land. The figure shows a section of this belt.

All the features of atolls harmonize completely with this view of their origin. In form they are as various and irregular as the outlines of barrier reefs. Compare Angau of the Feejees, with Tari-tari of the Tarawan Group (page 50); Nairai or Moala with Tarawa; Nanuku with Maiana or Apamama. The resemblance is close; and in the same manner we might find all the forms of lagoon reefs represented among barrier reefs. We observe all those configurations which would be derived from land of various shapes of outline, whether the narrow mountain ridge, (as at Taputeouea, one of the Tarawan Islands,) or a wide area of irregular slopes and mountain ranges. Among the groups of high islands, we observe that abrupt shores may occasion the absence of a reef on one side, as on Moala; and a like interruption is found among coral islands, (Tarawa.) Many of the passages through the reefs may be thus accounted for.

The fact that the submerged reef is often much prolonged from the capes or points of a coral island, accords well with these views. These points or capes correspond to points in the original land, and often to the line of a prominent ridge; and it is well known that such ridges often extend a long distance, with slight inclination compared with the slopes or declivities bounding the ridge on either side.

Coral islands or reefs often lie in a chain like the peaks of a single

mountain range:—for example, the sickle-shape line of islets north of Nanuku. Taritari and Makin, (Tarawan,) lie together as if belonging to parts of one land. Menchicoff atoll, in the Caroline Archipelago, consists of three long loops or lagoon islands, united by their extremities, and further subsidence might reduce it to three islands.*

The sizes of atolls offer no objection to these views, as they are no larger than many barrier reefs. Some of the larger Maldives, according to the crater theory, would require a crater seventy miles in diameter, with a rim made up of subordinate craters. No hypothesis of such extravagance is necessary. The facts all fall in with known principles, and are illustrated by known and established facts, rejecting hypotheses of every kind.

It is of some interest to follow still further the subsidence of a coral island, the earlier steps in which are illustrated in the preceding figures. One obvious result of its continuation is a gradual contraction of the lagoon and diminution of the size of the atoll, owing to the fact already noted, that the detritus is mostly thrown inward by the sea. The lagoon will consequently become smaller and shallower, and the outline of the island in general more nearly circular. Finally the reefs of the different sides may so far approximate by this process, that the lagoon is gradually obliterated, and the large atoll is thus reduced to a small level islet, with only traces of a former depression about the centre. Thus subsidence is connected with detritus accumulations in filling up the lagoon; and as filled lagoons are found only in the smallest islands, such as Swain's and Jarvis, the two agencies have beyond doubt been generally united.

This subsidence, if more rapid than the increase of the coral reef, becomes fatal to the atoll, by gradually sinking it beneath the sea. Of this character evidently is the Chagos Bank.† The southern

* See Darwin on the probable dismemberment of the Maldives, *op. cit.*, p. 37, in which he points out indications of a breaking up of a large atoll into several smaller. A land with many summits or ranges of heights may at first have its single enclosing reef; but as it subsides, this reef contracting upon itself may encircle separately the several ranges of which the island consisted, and thus several atoll reefs may result in place of the large one; and further, each peak may finally become the basis of a separate lagoon island, under a certain rate of subsidence or variations in it, provided the outer reef is so broken as to admit the influence of waves and winds. The Maldives are a fine exemplification of this result. Some of the large atolls are properly atoll archipelagoes.

† For a detailed account of this and other submerged reefs, see Darwin, p. 106.

Maldives have deeper lagoons than the northern, fifty or sixty fathoms being found in them. This fact indicates that subsidence was probably most extensive to the south, and perhaps also most rapid. The sinking of the Chagos Bank still further south, in nearly the same line, may therefore have some connexion with the subsidence of the Maldives.

In view of the facts which have been presented, it appears that the coral atoll once formed a fringing reef around a high island. The fringing reef, as the island subsided, became a barrier reef, which continued its growth while the land was slowly disappearing. The area of waters within finally contained the last sinking peak: another period, and this had gone—the island had sunk, leaving only the barrier at the surface and an islet or two of coral in the enclosed lagoon. Thus the coral wreath thrown around the lofty island to beautify and protect, becomes afterwards its monument, and the only record of its past existence. The Paumotu Archipelago is a vast island cemetery, where each atoll marks the site of a buried island. The whole Pacific is scattered over with these simple memorials, and they are the brightest spots in that desert of waters.

5. GEOGRAPHICAL DISTRIBUTION OF CORAL REEFS AND ISLANDS.

The distribution of coral reefs over the globe depends on the following circumstances, arising from the habitudes of polyps already explained:

1. The temperature of the ocean.
2. The character of coasts as regards (*a*) the depth of water,—(*b*) the nature of the shores,—(*c*) the presence of streams.
3. Liability to exposure to destructive agents, such as volcanic heat.

It has been stated that reef-growing corals will flourish in the hottest seas of the equator, and over the ocean wherever the winter temperature is not below 66° F. The isocheimal line of this temperature therefore forms the boundary line of the coral-reef seas.

This line traverses the oceans between the parallels 26° and 30°, or in general near 28°. But in the vicinity of the continents it undergoes remarkable flexures, from the influence of oceanic currents, the polar currents bending it towards the equator, while the tropical cause

a divergence. From a comparison of the thermometrical observations of various voyagers with those of the Expedition, I have been enabled to draw this coral boundary with a considerable degree of accuracy; and it is laid down upon the chart of the world accompanying this volume. In the Pacific it is observed to exclude the Galapagos,* and reach the South American coast *north* of the equator, instead of at the parallel of 28° S., the position in mid-ocean. On the coast of Asia it curves from the equator beyond latitude 30° . In the Atlantic it forms an abrupt bend far to the north, in the line of the Gulf Stream, and includes the Bermudas in latitude 32° N.; while on the African coast the northern line curves downward to the latitude of the Cape Verds, and the southern upward nearly to the equator. The following table will give more definitely the position of the coral boundary line where it meets the coasts of the continents.

	Pacific Ocean.	Atlantic Ocean.
East side of ocean—Northern,	Latitude 21° N.	Latitude 10° N.
Southern,	4° N.	5° S.
West side of ocean—Northern,	34° N.	34° N.
Southern,	{ 30° S., New Holland. }	22° S.
	{ 29° S., Africa. }	

It follows from the above, that while the coral-reef seas are about fifty-six degrees wide in mid-ocean, they are *in the Pacific* seventeen degrees wide on the west coast of America, and sixty-four degrees on the Asiatic side. *In the Atlantic*, they are about fifteen degrees wide on the African coast, and fifty-six degrees on the coast of America. If we reckon to the extremity of the bend in the Gulf Stream, the whole width off the east coast of America, north of the equator, will be over forty degrees. It is obvious that these facts enable us to explain many seeming anomalies in the distribution of coral reefs.

Within the limits included by the coral-reef boundary line, those other causes operate which influence the distribution of reefs. The effect of a deep, abrupt coast has been pointed out. The unfavourable character of sandy or muddy shores, and the action of detritus, marine currents, and fresh waters, have also been stated.

* Captain Fitzroy, R. N., found the surface temperature of the sea at the Galapagos, from Sept. 16 to Oct. 18, 1835, 62° to 70° F. Oct. 23, in lat. $0^{\circ} 30'$ S., and long. $99^{\circ} 4'$ W., the temperature of the sea was 66° F. Oct. 24, lat. $0^{\circ} 23'$ N., long. $96^{\circ} 53'$ W., temp. $70\frac{1}{2}^{\circ}$, $71\frac{1}{2}^{\circ}$ F. While under the equator, about the middle of the Pacific, the range of surface temperature of the sea through the year is 81° to 88° F.

No less striking are the effects of *volcanic action* in preventing the formation of reefs; and instances of this influence are numerous throughout the Pacific. The existence of narrow reefs, or their entire absence, may often be thus accounted for. For example, in the Sandwich Group, the island Hawaii, still active with volcanic fires, has but few traces of corals about it, while the westernmost islands, which have been longest free from such action, have reefs of considerable extent. The island of Maui exemplifies well the general fact. The island consists of two peninsulas: one, the eastern, recent volcanic, with a large crater at summit, and the other, the western, presenting every evidence in its gorges and peaks and absence of volcanic cones, of having become extinct ages since. In conformity with the view expressed, the coral reefs are confined almost exclusively to the latter peninsula. Other examples are afforded by the Samoan Islands. Savaii abounds in extinct craters and lava streams, and much resembles Hawaii in character; it bears proof in every part of being the last seat of the volcanic fires of Samoa. Its reefs are consequently few and small: there is but a narrow line on part of the northern shores, although on the other islands they are very extensive. The absence of corals results obviously from the destruction of zoophytes by heat, consequent on volcanic action. Submarine eruptions, which are frequent as long as a volcano near the sea is in action, heat the waters, and destroy whatever of life they may contain. After the eruption of Kilauea, in 1840, there were numerous dead fish thrown on the beach; and many such instances in different regions are on record. Other facts, illustrating the effects of volcanic heat in preventing the growth of reefs, will be brought forward in the following pages.

The agencies affecting the growth of coral reefs being before the mind, we may proceed to notice the actual distribution of reefs through the coral seas. The review given is a rapid one, as our present object is simply to explain the absence or presence of reefs within the coral-reef limits, by reference to the above facts.*

* In the valuable work by Mr. Darwin, the geographical distribution of reefs is treated of at length in the Appendix, pp. 151-205. The facts here detailed have been obtained from independent sources, except where otherwise acknowledged. In accounting for the character and distribution of reefs, Mr. Darwin has erred in attributing too much weight to a supposed difference in the amount of subsidence in different regions, neglecting to allow the requisite limiting influence to volcanic agency, and to the other causes mentioned.

Pacific Ocean.

The west coast of South America is known to be without coral reefs even immediately beneath the equator; and the seas of the Galapagos also grow no coral. The northward deflection of the coral boundary line, as shown, accounts for their absence. In the harbour of Callao (the seaport of Lima), the temperature is sometimes down to 59° or 60° F., and at the Galapagos, Captain Fitzroy found the waters in September to fall often to 62° F., and once to $58\frac{1}{2}^{\circ}$ F. This month, it should be observed, cannot be the coldest of the year. In the bay of Panama, coral is reported to occur, but there are no reefs.*

The coast to the north, as far as latitude 21° N., is within the warm limits, but without reefs. In Captain Colnett's voyage, allusion is made to a beach of coral sand on one of the Revillagigedo Islands, in latitude 18° ; beside this statement, I have met with no allusion to corals on any of the islands off the Mexican coast. The paucity of corals in this region may perhaps be owing, in some degree, to the fact that the tropical currents of the ocean flow *westward* instead of eastward; and, consequently, they prove an obstacle to the distribution of polyps to this coast from the islands of the Pacific. Moreover, the cold currents which pass the Galapagos form an impassable barrier between the Paumotus and Mexico.

Between the South American coast and the Paumotus are two rocky islands, Easter or Waihu, and Sala-y-Gomez, both of which are without reefs.†

The Paumotus commence in longitude 130° W., and embrace eighty coral islands, all of which, excepting about eight of small size, contain lagoons. Besides these, there are, near the southern limits of the archipelago, the Gambier Islands, and Pitcairn's, of basaltic constitution. The former, in 23° S., has extensive reefs; about the latter, in 25° S., there are some growing corals, but no proper reefs.

The Marquesas, in latitude 10° S., have but little coral about them; and this is the more remarkable, as they are in close proximity to the Paumotus. But their shores are, in general, very abrupt, with deep waters close to the rocks. An island which, before subsidence has commenced, has some extent of shallow waters around, might have very bold shores, after it had half sunk beneath the waves. This

* Jour. Roy. Geog. Soc. i. 69, on the Isthmus of Panama, by J. A. Lloyd.

† Captain Beechey mentions that at forty-one fathoms, near Sala-y-Gomez, he found a bottom of sand and coral.

would be the case with the island of Tahiti; for its mountain declivities are, in general, singularly precipitous, except at base. The Marquesas may, therefore, have once had barrier reefs, which were sunk from too rapid subsidence; and afterwards, on the cessation of the subsidence, others failed to form again, on account of the deep waters.

The Society Islands have extensive coral reefs, with distant barriers. The reefs of Tahiti extend, in some parts, a mile from the shores. Tethuroa, to the north of Tahiti, and Tubuai, near Bolabola, are lagoon islands. Maitea, east of Tahiti, is a sugar-loaf truncated at summit, four miles in compass, and is said by Forster to have an encircling reef.*

South of the Society Islands, near 25° S., is Rapa, which is represented as a collection of rugged peaks without coral shores. The Rurutu and Hervey Islands, just northwest, have coral reefs fringing the shores. There is no evidence of recent volcanic action among them. Some of them are elevated coral islands, as Mitiaro, Atiu, Mangaia and Mauki, and also, according to Stutchbury, Rurutu. Okatutaia is a low coral island but six or seven feet out of water.

Between the Paumotus and the longitude of Samoa, are numerous small islands, all of coral origin.

The Samoan Islands have extensive reefs. About Tutuila they are somewhat less extensive than around Upolu, owing to its abrupt shores; and about Savaii they are still smaller, as already explained. The influence of abrupt shores may also be seen in some parts of Upolu; for example,—to the west of the harbour of Falifa, where, for several miles, there is no reef, except in some of the indentations of the coast. Manua is described as having only shore reefs.†

The Tonga Islands, south of Samoa, for the most part, abound in coral reefs, and Tongatabu and the Hapai Group are solely of coral. Eoa is a moderately high island, with a narrow reef. Tafoa, an active volcano, and Kao an extinct cone, are *without* reefs. Vavau, according to Williams,‡ is an elevated coral island. Pylstaarts, near Eoa, is a naked rock, with abrupt shores, and little or no coral. Sunday Island, farther south, (29° 12' S.,) is beyond the coral-reef limits.

North of Samoa are several scattered islands, of small size, all of coral.

* Darwin, *op. cit.* p. 153. † Narrative, ii. 65. ‡ Miss. Enterprises, p. 427, Amer. ed.

The Feejee Group, as we have sufficiently described, abounds in reefs of great extent. There are no active volcanoes, and, where examined, no evidence of very recent volcanic action. The many islands afford a most favourable region for the growth of zoophytes, and the displays of reefs and living corals were the finest seen by the writer in the Pacific.

North of the Feejees are numerous islands, leading up to the Carolines. They are all of coral, excepting Rotuma, Horne, and Wallis Islands, which are high, and have fringing or barrier reefs. The reefs of Wallis Island are very extensive.

The Tarawan Islands, and the Carolines including the Marshall Islands, eighty-seven in number, are all atolls, excepting the three Carolines, Ascension or Banabe, (Pouynipete of Lutke,) Ualan, and Hogoleu (or Roug).

The westernmost of the Sandwich Islands, Kauai and Oahu, have fringing reefs, while eastern Maui and the island of Hawaii have but few traces of corals. On Hawaii, the only spot of reef seen by us, was a submerged patch off the southern cape of Byron's Bay. We have already attributed their absence to the volcanic character of the island. The small islands to the northwest of Kauai, are represented as coral reefs, excepting the rocks Necker and Bird Island; the line stretches on to $28^{\circ} 30' N.$,* or the northern limit of the coral seas.

The Ladrões, like the Sandwich Group, constitute a line or linear series of islands, one end of which has been long free from volcanic action, while the other has still its smoking cones. While the appearances of recent igneous action increase therefore as we go northward, the extent of the coral reefs increase as we go southward; none occur about the northernmost islands, while they are quite extensive on the shores of Guam. This group consequently, like the Hawaiian and Samoa, illustrates the influence of volcanic action on the distribution of reefs.

A short distance southwest of the Ladrões, and nearly in the same line, lie extensive reefs. Mackenzie's is an atoll of large size. Yap, Hunter, Los Matelotas and the Pelews are high islands, with large reefs. In the last mentioned, the reef-grounds cover at least six times the area occupied by the high land. Still farther south, towards New Zealand, lie the large atolls Aiou, Asie, and Los Guedes.

* For an account of some of these islands, see Lisiansky's Voyage, 1803-6, in the *Neva*, 4to. London, 1814, pp. 254, 257; also Hawaiian Spectator, vol. i.

South of the equator again:—

The New Hebrides constitute a long group of high islands, remarkable for the absence of coral reefs of any extent, though situated between two of the most extensive coral regions in the world,—the Feejees and New Caledonia. But the volcanic nature of the group, and the still active fires of two vents in opposite extremities are a sufficient reason for this peculiarity. Tanna is one of the largest volcanoes of the Pacific; and nearly all the islands of the New Hebrides, as far as known, indicate comparatively recent igneous action, in which respect they differ decidedly from the Feejees.

The Vanikoro Group, north of the New Hebrides, according to Quoy, has large barrier reefs about the southernmost island, Vanikoro; but at the northern extremity of the range there is an active volcano, Tinakoro, and no coral. Tikopia, to the southeast of Vanikoro, is high and volcanic, according to Quoy, though not now with active fires; and it appears from the descriptions given to have no reefs. Mendana, northeast of Tinakoro, according to Kruesenstern, as stated by Darwin, is low with large reefs; Duff's Islands have bold summits with wide reefs.

New Caledonia and the northeast coast of New Holland, with the intermediate seas, constitute one of the grandest reef regions in the world. On the New Caledonia shores the reefs are of great width, and occur not only along the whole length of the western coast, a distance of 200 miles, but extend beyond the main land, to the south 50 miles, and north 150 miles, making in all a line of reef full 400 miles in length. Towards the north extremity, however, it is interrupted or broken into detached reefs. This surprising extent is partly explained by the fact that New Caledonia is not a land of volcanoes; but on the contrary, consists of the older Plutonic or metamorphic rocks, with probably some sedimentary rocks. The streams of so large a land might be expected to exclude reefs from certain parts: and in accordance with this fact, we find the reefs of the windward or rainy side comparatively small, and scarcely indicated on our charts; while on the dry or western side, they often extend 30 miles from the shores. The theory of subsidence accounts fully for the great prolongation of the New Caledonia reefs; they indicate, moreover, the existence of a former land near three times the area of the present island.

Between New Caledonia and the New Hebrides are several high islands, one of which, *Lafu*, has been recently described by Rev. W.

B. Clarke as an elevated coral island, with fringing reefs; and it appears also from the remarks of this writer, that the other islets of what is called the Loyalty Group, are of the same kind. Lafu, the largest of the number, is about ninety miles in circumference.*

South of New Caledonia lies Norfolk Island, in latitude 29° S., about which there is said to be some coral which is occasionally thrown on the beach, but no reefs.

Between Australia and New Caledonia the islands are all of coral. The New Holland reef extends from Torres Straits to the east cape in latitude 24° S., a distance of 1000 nautical miles, though much interrupted along its course. It has been shown how this broken character results during a subsidence, owing to a change in the abruptness of the land successively becoming the coast line, and also to the variations in the currents, retarding the growth in some places and aiding it in others. These causes might make a broken reef that was originally continuous: yet we have no reason to believe that the reef ever was continuous. It will be found, as we proceed, that long reefs on the shores of continents are not common. In this case the zoophytes are not exposed to the destructive agents usual on such shores, as the land is in a dry climate, the shores are mostly rocky, and there are no streams of any extent emptying into the ocean. The east cape is the southern limit, because here the tropical current, owing to the direction of the coast above, trends off to the eastward of south, away from the land, while a polar current follows up the shores from the south as far as this cape. South of this cape there are only a few scattered species of coral zoophytes.

The Louisiade Group is described as a region of extensive reefs.

The Salomon Islands, as far as ascertained, are but sparingly fringed, excepting the two western, which are said to have large reefs. The peculiar character of these lands is too imperfectly known to allow of our deducing the cause of so restricted reefs. Off to the north of the Salomon Islands, there are several atolls of considerable size. New Ireland, according to D'Urville, has distant reefs on part of its shores.

The Admiralty Islands, farther west, are enclosed by barrier reefs; and beyond this group there are a few lagoon islands.

The north side of New Guinea is mostly without coral. There are several islands off this coast, which are conical volcanic summits, and

* Quarterly Journal of the Geological Society, No. 9, p. 61.

one of them, near New Britain, and another (Vulcano) near longitude 145° E., are in action.

From the facts thus far detailed, the connexion between the prevalence or extent of reefs, and the various causes assigned as limiting or promoting their growth, is obvious. The amount of subsidence determines in some cases the distance of barrier reefs from shores; but it by no means accounts for the difference in their extent in different parts of a single group of islands. Indeed, if this cause be considered alone, every grade of extent, from no subsidence to the largest amount, might in many instances be proved as having occurred on a single island. Of far greater importance, as has appeared, is the volcanic character of the land. At whatever time the existing reefs in the Pacific commenced their growth, they began about those of the igneous islands whose fires had become nearly or quite extinct; and as others in succession were extinguished, these became in their turn the sites of corals, and reefs began to form. Those lands whose volcanoes still burn, are yet without corals, or there are only limited patches on some favoured spots. Zoophytes and volcanoes are the land-making agents of the Pacific. The latter prepare the way by pouring forth the liquid rock, and building up the lofty summit. Quiet succeeds, and then commences the work of the zoophyte beneath the sea, while verdure covers the exposed heights.

We may add a few more illustrations from other parts of the coral-reef seas.

Along the north and northwest coast of New Holland, there appears to be little or no coral in the Gulf of Carpentaria, while some extensive patches occur on the shores west of this gulf, as far as the northwest cape in latitude 23° S.

In the East Indies, there are large, scattered reef-islands, south of Borneo and Celebes, and the west end of New Guinea. The islands of Timor-laut, and Timor, with many of those intermediate, have large reefs. The Arru Group consists wholly of coral. This sea, from Arru to the islands south of Borneo, is more thriving in corals than any other in the East Indies.

Another East India coral reef region, of some extent, is the Sooloo Sea, between Mindanao and the north of Borneo. Yet the reefs are mostly submerged. We saw no wide platforms bordering the high lands, like those of the Pacific. There are, however, some small coral islets in the Balabac Passage.

In other parts of the East Indies, coral reefs are quite inconsider-

able. Occasional traces, sometimes amounting to a fringing reef, occur along Luzon and the other Philippines.

We coasted by the west shore of Luzon to Manilla, and thence by Luban, Mindoro, Panay, to Caldera, near Samboangan in Mindanao; and through this distance, no reefs were distinguished, as would have been the case had there been any of much extent. At the last-mentioned place we found coral pebbles on the beach, and by dredging obtained living specimens in six to eight fathoms of water. The only large reefs were those between Mindoro and the Calaminianes. There are fringing reefs at Singapore. The islands of Borneo, Celebes, Java, and Sumatra, according to all the authorities seen by the writer, have but few coral patches about their shores, although affording long lines of coast for their growth. In the China Seas, there are numerous shoals, banks and island reefs of coral. Moreover, shore-reefs occur about Loochoo, and the islands between it and Formosa. But the whole eastern coast of China appears to be without coral. Quelpaert's Island, south of Corea, in 34° N., is described as having coral about it; and this has been confirmed by late information.

Why should the reefs of the East India Archipelago be so limited in extent, and large parts be almost destitute, notwithstanding their situation in the warmest seas of the ocean, and in the most favourable region for tropical productions? We are not prepared for a full answer to this inquiry, which demands a thorough knowledge of the shores, as well as of the currents, and the former and present condition of volcanic fires. From personal observation, we may reply satisfactorily, as far as regards part of the southern half of the east coast of Sumatra. This coast is low, and sandy or muddy, and thus affords the most unfavourable place for zoophytes. A strong current sweeps through the straits of Banka, which keeps the water muddy and the shores in constant change. The same cause may operate on the coasts of other islands, but we are ignorant to what extent.

The East Indies have been remarkable for their volcanoes, exceeding, for the area, every other part of the world: and this fact must have had influence on the formation of coral reefs, though we have not the data for fixing the extent of the influence. Of the numerous vents which have been in action, several still make themselves felt over wide areas. The Sooloo Islands are about one hundred in number, and nearly all are pointed with volcanic cones; and while some have the broken declivities that are marks of age, others have regular slopes, as if but just now extinguished; a dozen of these cones may

sometimes be seen on a single island. These volcanic peaks often rise out of the sea, as if their formation had begun with a submarine eruption. In a region so extensively and so recently igneous, the coral polyp would have found little chance to develop itself, until volcanic action had become comparatively quiet, and deluges of hot water ceased. There appears, therefore, to be some reason for the fact that the reefs are small, and have seldom reached the surface.

The Sooloo Sea is but one of the volcanic clusters in these seas. Java, several of the Philippines, and other islands south of these last, with the northern shore of New Guinea, make up a wide region of fires, and it cannot be doubted that the frequent eruptions prevented the growth of coral, for a long period, over large areas. For other causes we must look to the nature of the coasts, fresh-water streams and marine currents; we leave it for other investigators to apply the explanation to particular coasts.

The coast of China probably owes its freedom from corals to its alluvial character and its fresh-water streams.

One interesting fact should be noted:—the most extensive reefs in the East Indies are to be found in the open seas, between the large islands; these islands, at the same time, often being without proper reefs, or with mere traces of coral. This is the case between Borneo and the range of large islands south: the China Sea is another instance of it; north of New Guinea, a few degrees, is another. How far this is due to their being distant from the scenes of igneous action, and from the detritus and fresh water of island streams, remains to be determined. A sinking island becomes a more and more favourable spot for the growth of coral, as it descends; for as its extent diminishes, its streams of fresh water and detritus also decrease. It might therefore be expected, on this account alone, that such isolated spots of land, away from all impure waters, in the open ocean, should become the bases of large reefs. The existence of these reef-islands is, therefore, no necessary proof of greater subsidence than the coast adjoining has undergone, though the fact of a greater subsidence is by no means impossible.

In the Indian Ocean, the Asiatic coast is mostly free from growing coral.* The great rivers of the continent are probably the most efficient cause of their absence, both directly, through their fresh waters, and through the detritus they transport and distribute along the shores.

* Mr. Darwin alludes to small patches in the Persian Gulf.

It will be observed that this agent, so ineffectual on small islands, is one of vast influence upon larger lands. Ceylon has some fringing reefs.

The islands of the Indian Ocean are, to a great extent, purely of coral. Of this character are the Laccadives, Maldives, Keelings, Saya-de-Malha, Almirante, and Cosmoledo. The Chagos shoal is of the same character: and the shoal Cargados is probably similar. The Seychelles are small islands with extensive reefs. We remark here the same fact alluded to above, that reefs abound in the open ocean, though absent from the Continental coasts; and the same reason may apply to both cases.

Madagascar has a fringing reef upon its southwestern point, according to Mr. Darwin, and on some parts of the coast above; also on the north and eastern shores as far down as latitude 18° S.* The Comoro Islands, between Madagascar and the continent, have large barrier reefs.

The eastern coast of Africa has narrow reefs extending north with some interruptions from Mozambique, in latitude 16° S., to a short distance from the equator. Corals also abound in the Red Sea, occurring in some parts on both shores, though most frequent on the eastern, from Tor, in the Gulf of Suez, to Konfodah. This long Continental reef may at first be deemed a little remarkable, after what we have remarked upon such reefs elsewhere. Yet the surprise is at once set aside by the striking fact that this whole coast, from the isthmus of Suez south, has no rivers, excepting some inconsiderable streamlets. It affords, therefore, an interesting elucidation of the subject under consideration, and confirms the view taken to account for the absence of reefs from the China and South Asiatic coasts. It is a fact almost universal, that where there are large fresh-water streams, there are earthy or sandy shores; and where there are no such streams, rocky shores, though not uniformly occurring, are common.

Passing from the Indian to the Atlantic Ocean, we find little or no coral on the west coast of Africa. The islands of Cape St. Anne and Sherboro, south of Sierra-Leone, are described as coral by Captain Owen, R. N.† But this has been since denied. The island of Ascension, in $7^{\circ} 56'$ S. and $14^{\circ} 16'$ W., must have been formerly bordered by growing coral, as Quoy and Gaymard mention that a bed of coral rock may be seen buried beneath streams of lava. Quoy also states that the corals which formed these reefs are no longer found

* Darwin, *op. cit.*, p. 187. † Journal of the Royal Geographical Society, ii. 89.

alive, and adds that volcanic eruptions have probably destroyed them. The cold polar currents along the African coast, although generally leaving about fifteen degrees of latitude within the coral-reef seas, may at times close up and reduce it to still narrower limits. The same obstacle to the diffusion of species eastward, mentioned as occurring in the Pacific—that is, westerly currents—exists also in the Atlantic, and probably with the same effect.

On the American shores of the Atlantic there are few reefs, except in the West Indies. The waters of the Orinoko and Amazon, and the alluvial shores they occasion, exclude corals from that part of the coast. But about Pernambuco, as I am informed by Mr. Titian R. Peale, there are some patches of growing corals, and they are said to extend along to 20° or 21° S.

The Bermudas are of coral origin, and are the most northern point of growing reefs.

In the West Indies, the reefs of Key West, Cuba, the Bahamas, and many of the eastern islands are well known. On the east coast of Florida they continue up as far as Cape Florida, in latitude $25^{\circ} 40'$ N.: the west coast is free of them. There are also said to be patches at intervals along the coast of Venezuela and Guatemala; but the west shores of the Gulf of Mexico, as well as the northern, like West Florida, are mostly low, and everywhere without corals. They are within the influence of the Mississippi and other large rivers.

We have thus seen that the earth is belted by a coral zone, corresponding nearly to the tropics in extent, and that the oceans throughout it abound in zoophyte reefs, wherever congenial sites are afforded for their growth. We have found that the currents of extra-tropical seas, which flow westward, and are interrupted and trended *towards* the equator by the continents, contract the coral seas in width, narrowing them to a few degrees on the western coasts of the continents; while the tropical currents, flowing eastward, *diverge* from the equator and cause the belt to widen near the eastern shores. The polar currents flow also by the eastern coasts, preventing the warmer waters from increasing the width of the coral zone as much as it is contracted on the western coasts. Moreover, the trend and capes of the coast produce other modifications in the direction of the currents, the most of which are apparent in the actual distribution of coral reefs. On the shores of the continents we have observed that there were no extensive reefs, except along eastern Africa; and, while other lands

abundant in rivers, this African coast has only some small streamlets. Thus the influence of Continental waters and detritus on the distribution of reefs, has been shown to be very marked. But about the Pacific islands, where streams are small, the same cause has had little effect, seldom doing more than modifying somewhat the shores and bottom of a harbour. We have ascertained that in different groups, as the Ladrões, the Sandwich Islands, Samoa, New Hebrides, there is an inverse relation between the extent of reefs and the evidences of recent volcanic action in the islands; and that the largest reefs exist where there is no proof of former igneous action, or where it has long ceased. The influence of volcanic agency on the planting and increase of coral reefs is thus satisfactorily exhibited. The existence of large reef-islands in open seas, where the neighbouring lands are mostly destitute of coral reefs, has farther supported our conclusions, as such islands are in general removed from the deleterious influences just mentioned.

The modifications of form and interruptions of reefs arising from abrupt or sloping shores, and tidal or local currents, have also been exemplified. The origin of the distant barrier has been traced to a sinking of the land which it once simply fringed; and the lagoon island to a continuation of this subsidence till the original land had disappeared.

This account of coral reefs and islands may be closed by a statement or recapitulation of some deductions which have a special bearing upon geology.

IV. GEOLOGICAL CONCLUSIONS FROM THE STRUCTURE AND COMPOSITION OF CORAL REEFS AND ISLANDS.

I. The *coral reef-rock* has been described as solid limestone of coral origin. In some parts it is a coral conglomerate, or breccia, made up of fragments firmly cemented. Over much larger areas it is a fine white limestone, as compact as any secondary marble, and as homogeneous in texture. It is often free from any traces of organic life, or proofs of an organic origin. Only now and then an imbedded shell or some other relic evinces that animals of any kind were living in the seas. This white limestone breaks with a conchoidal fracture, a splintery surface, and rings under the hammer. These facts are of great importance in deciding upon the origin of the

older limestone strata. Other portions of the rock, of less extent, are made of standing corals with the intervals filled in by reef-debris, and the whole cemented solid. The former variety here mentioned prevails about *outer* reefs exposed to the open seas; the latter among the *inner* patches growing in quiet waters. The first kind is common about outer reefs, as large areas in the coral plantation are mere sand. It is still more abundant, forming the bottom among the inner patches, or in the lagoons, where the finer detritus is washed by the sea. A glance at the chart of the Feejees and Kingsmills will show how large a portion of the body of the reef increases from these fine accumulations. The exterior of a coral island, for a few hundred yards, excepting some islets within, is the only part which is the proper growth of the living reef. Within the exterior reef the coral structure may consist almost wholly of the compact homogeneous white limestone we have described. The elevated island of Metia was for a long time after elevation exposed to the ravages of the sea, before the present shore-reefs accumulated to give it protection. Proofs of degradation along the coast have been referred to. There is much reason, therefore, for believing that the Metia now existing exposes on its eastern and southern sides at least (where particularly examined by us,) the interior of the original structure; and this view is supported by the compact character of the rock, (p. 67.)

These reef-rocks receive also large contributions of sand or fragments from shells, which unite with the coral debris.

II. Coral reefs, though they may stretch along a coast for scores of miles, are seldom a single mile in width at the surface: and if elevated above the sea, they would stand as broad ramparts separated by passages mostly 20 to 200 feet deep, and often of great width. The substratum, however, is continuous coral-rock; and if these more elevated parts were removed by any process, after an elevation, they would leave an area of coral limestone often as extensive as the whole reef-grounds. This is at once seen from the preceding figures. In an island like Dean's, one of the Paumotus, these reef-grounds are 1000 square miles in extent. It is true that the reefs at the surface gradually widen if the land is undergoing no subsidence. But when situated on a sloping bank, as usual, this widening, as already illustrated, gradually renders the bank steeper, and the rate of increase in width is rapidly diminished. And if the bank were not sloping, there is still reason to believe that the patches would not attain a great width at the surface of the sea, owing to the currents sweeping over them, occasioned partly

by the position of a growing reef; and that therefore there would be unoccupied intervals or channels, as above alluded to, between the several reefs of a reef-ground.

The bearing of these facts upon the character and origin of ancient limestones, and the formation of channels, or valleys in such rocks, is apparent without particular explanation.

III. The occurrence of coral sand forming the exposed beaches, while the finer coral mud exists on the shores of the smaller lagoons, or at the bottom of the larger, affords an interesting illustration of the result produced by a triturating sea, as compared with that from more gently agitated waters. The seashore waves give rise to sand or pebbles; while the gentle undulations or ripples of inland waters produce mud by their finer trituration, (p. 108.)

IV. The beach conglomerate or sandrock, and the drift sandrock are examples of stratified deposits forming and consolidating along shores. The former has a nearly constant dip of a few degrees, not exceeding eight, towards the water. The latter is more finely laminated, less firmly cemented, and dips whichever way the accumulating sandhill sloped, the layers being the successive sheets of sand which were drifted over it, during the accumulation, (p. 45.)

V. The almost total absence of fossils from many parts of the coral reef-rock, and generally from the shore sandrocks, is one of the most striking facts here exemplified. These rocks are formed in the midst of life, and out of the enduring remains of animals; yet fossils, as shown at Metia and other elevated reefs, are often rare.

This absence of organic remains characterizes almost invariably the *drift* sandrock. On Oahu, where this rock forms hills thirty or forty feet in height above the reef-rock, not a fossil nor a fragment of one was distinguished by us, neither of shells nor corals. This fact had been previously remarked by some of the intelligent residents, and it was a matter of dispute whether one or two shells had not been found. These formations are but a few rods from waters prolific with the productions of the sea, and were made from them.

An explanation of this peculiarity, is obvious on the principle already discussed—the action of a triturating sea. Everything washed towards the shores, is ground down by this action and reduced to sand; and a large part of the sand is worn out and carried off by the sea; or, being thrown up by the reef, is blown inward by the winds.

It is a natural inference from these facts, that the non-fossiliferous sandstones of our continents are no good evidence of the absence of

sparing diffusion of animal life in the seas about whose shores they may have been formed. If this destruction of fossils is so complete when the sands are of limestone, much more rapid and thorough should it be when they are siliceous. As the sea by its action bears off the finer material, and leaves only what is in the condition of sand or a coarser material, the carbonate of lime of fossils might be almost wholly removed from among siliceous sands, and hardly a trace remain which the chemist could detect.

VI. The formation of *chalk* from coral is known to be exemplified at only one spot among the reefs of the Pacific. The coral mud described appears to be a fit material for its production; and when dried it takes much the appearance of chalk. This fact was pointed out by Mr. Darwin, and was suggested to the writer by the mud in the lagoon of Honden Island. Still it does not explain the main point; for under all ordinary circumstances, this mud solidifies into compact limestone, instead of chalk. This appears, moreover, to be the result which should be expected. What condition then is necessary to vary the result, and set aside the ordinary process?

The bed of chalk referred to was not found on any of the coral islands, but in the elevated reef of Oahu, of which reef it formed a constituent part. It is twenty or thirty feet in extent, and eight or ten deep. The rock could not be distinguished from much of the chalk of England: it is equally fine and even in its texture, as earthy in its fracture, and so soft as to be used on the blackboard in the native schools. Some imbedded shells look precisely like chalk fossils. It consists, according to an analysis by Prof. B. Silliman, Jr., of

Carbonate of lime	-	-	-	-	-	-	92.800
Carbonate of magnesia	-	-	-	-	-	-	2.385
Alumina	-	-	-	-	-	-	0.250
Oxyd of iron	-	-	-	-	-	-	0.543
Silica	-	-	-	-	-	-	0.750
Phosphoric acid and fluorine	-	-	-	-	-	-	2.113
Water and loss	-	-	-	-	-	-	1.148

The locality is situated on the shores just above high tide level, near the foot of Diamond Hill. This hill is an extinct tufa cone, near seven hundred feet in height, which rises from the water's edge, and in its origin must have been partly submarine. It is one of the lateral cones of eastern Oahu, and was thrown up at the time of an eruption through a fissure, the lavas of which appear at the base. There was

some coral on the shores when the eruption took place, as is evident from imbedded fragments in the tufa; but the reef containing the chalk appeared to have been subsequent in formation. There is no certain proof yet ascertained of any connexion between the fires of the mountain and the formation of the chalk.

The facts leave the subject of the origin of chalk still in uncertainty. Its fine earthy texture is evidence that the deposit was not subaerial seashore accumulation, as only sandstones and conglomerates, with rare instances of more compact rocks, are thus formed. Sandrock making is the peculiar prerogative, the world over, of shores exposed to waves, either marine or fresh water. We should infer, therefore, that the accumulations were produced either in confined areas, into which the fine material from a beach may have been washed, or on the shores of shallow, quiet seas: in other words, under the same conditions nearly as are required to produce the calcareous mud of the coral island. But, although the agency of fire in the result cannot be proved, it is by no means improbable, from the position of the bed of chalk, that there may have been a hot spring at the spot occupied by it. That there were some peculiar circumstances distinguishing this from other parts of the reefs, is evident; and this appears to be the only probable supposition. If this be admitted, the existence of an elevated temperature might be suggested for certain areas during the deposition of the chalk strata. It is well known that heated waters dissolve lime much less readily than cold; and this might be a reason for its inferior hardness and earthy texture. The character of the cretaceous deposits presents many interesting points bearing upon this subject; but a discussion of them would be out of place here, as our object is simply to state such inferences as the facts observed among existing reefs may have suggested.

This coral chalk has been examined microscopically by Professor Bailey, for infusoria and polythalamia, without detecting anything of this kind. It appeared to contain nothing organic.

VII. The analyses have shown that ordinary corals consist mainly of carbonate of lime, (p. 90.) There is a small proportion of fluorids and phosphates, with some silica, alumina, and oxyd of iron. These fluorids and phosphates, existing in the coral, must exist also in the limestone rock made from coral. It is probable from some trials made by Prof. Silliman, Jr., that these constituents may be found also in many shells.

From the several analyses of corals by Mr. Silliman, we infer that

the fluorids and phosphates amount, on an average, to about $\frac{1}{4}$ th per cent., or 0.25 parts in a hundred of coral : and the amount in the same manner of the phosphates, is 0.05 per cent. A cubic foot of coral, as deduced from the average specific gravity, weighs one hundred and fifty-seven pounds, and consequently, in each cubic foot, there must be full six and one-fourth ounces of fluorids, and one and one-fourth ounces of phosphates : and in each cubic rod seventeen hundred pounds of fluorids, and three hundred and forty pounds of phosphates. These fluorids are fluorids of calcium and magnesium, and the phosphates, phosphates of lime and magnesia. To obtain the amount of these ingredients in a reef a mile long, half a mile wide and a hundred feet deep, the estimate for a cubic rod should be multiplied by 320,000 ; which will give for the fluorids more than five hundred millions of pounds.

Late geological researches have placed it beyond doubt that the various limestones consist mainly, like coral limestone, of animal remains, among which, in many instances, corals have a conspicuous place. These limestones often contain crystallizations of fluorid of calcium (fluor spar) ; and in other beds which have been acted upon by heat, and thus rendered crystalline, there are, besides this mineral, crystallizations of apatite, (phosphate of lime,) and chondrodite (consisting of fluorine, magnesia and silica). Moreover, these are among the most common minerals of such limestones. The above facts supply us with a full explanation of their origin. The fluorine, phosphoric acid, magnesia, and silica present, are adequate for all results, without looking to other sources for the elements of these disseminated minerals. Instead, therefore, of being extraneous minerals introduced into the limestone rock, they are an essential part of its constitution. And they have been separated from the general mass by a segregation of like atoms, under well-known principles, while the rock was subjected to an elevated temperature. The fluorid of calcium appears to crystallize without much heat : but apatite and chondrodite are found in *granular* limestones, which show, by their crystalline texture, that they have been subjected either to a very high temperature, or to one long continued of more moderate degree.

Lord Byron, of the Blonde, states that specimens of *phosphate of lime*, (apatite,) were actually collected on Mauki, of the Hervey Group, one of the elevated coral islands.

VIII. The cementation of coral sand along shores and beneath the sea

is illustrated among all reefs, and is the process by which reef-rocks are formed. The sea-water receives some carbonate of lime into solution, and again deposits it among the deposited sand and fragments which lie compacted together. The same process takes place among the beach sands and the drift heaps. The eminences of drift sandrock at the Sandwich Islands were often covered in part by a smooth, solid crust, two or three lines thick, and made of layers like stalagmite, which was formed by the solution of lime from the surface by the rains, and its deposition again in evaporation.

The waters of the sea have been found to contain a small proportion of free carbonic acid, which is sufficient to enable it to dissolve the carbonate of lime of the corals.

Analyses of the coral limestone of the elevated coral island Matea, by Prof. B. Silliman, Jr., have determined the singular fact that although the corals themselves contain very little carbonate of magnesia, this salt is largely present in some specimens of the rock. The rock is hard (H. = 4.25), and splintery in fracture, with the specific gravity 2.690.

Carbonate of Lime,	-	-	-	-	-	61.93
Carbonate of Magnesia,	-	-	-	-	-	38.07

Another specimen from the same island, having the specific gravity 2.646, afforded 5.29 per cent. of carbonate of magnesia. The first was a compact, homogeneous specimen, and the other was partly fragmentary. Recent examinations of coral sand, and coral mud from the islands, give no different composition, as regards the magnesia, from that for corals. The coral sand from the straits of Balabac afforded carbonate of lime, 98.26, carbonate of magnesia, 1.38, alumina, 0.24, phosphoric acid and silica, a trace.

We cannot account for this supply of magnesia except by referring to the magnesian salts of the ocean. It is an instance of dolomization, during the consolidation of the rock beneath sea-water, and throws light on this much-vexed question.*

* While in the press, an article on the formation of dolomite from carbonate of lime came under the notice of the author, which affords a full demonstration of the view here suggested. It is by A. Von Morlot, and is published in the *Naturwissenschaftliche Abhandlungen*, herausgegeben von W. Haidinger, (4to. Vienna, 1847.) Von Morlot shows both by the frequent association of gypsum with dolomite, and by chemical experiment, that carbonate of lime and sulphate of magnesia, when together, undergo a double

IX. It is an inquiry of some interest, whether, in an archipelago like the Paumotus, coral debris is not carried from the coral islands, and distributed over the bottom of the ocean; and whether limestones thus originating, are not in process of formation. I venture no positive assertion on this subject, yet would express strong doubts. The fact that soundings off some islands, as we recede from the reef-growing depths, lose more and more in the proportion of coral sand, till we finally reach a bottom of earth, like the material of the island, bears against any such hypothesis. This was found to be the case off Upolu, where the reefs are extensive.

X. It remains still to speak of the proofs of elevation or subsidence presented by coral islands throughout the Pacific, and of the former extent of Pacific lands compared with the present. But these topics relating to the dynamics of the ocean, form a separate chapter, following our geological descriptions of the several groups of islands in the Pacific.

We might dwell also on the formation of caverns by the rains becoming subterranean waters; on the illustrations of the action of marine currents afforded by this subject; on the agency of polyps in rock-making. But the deductions are too obvious to require farther remark.

decomposition, the magnesia taking the place of part of the lime, and the excluded lime combining with the sulphuric acid set free. The result is *magnesian carbonate of lime*, (dolomite,) and *hydrrous sulphate of lime*, (gypsum,) the latter being separated, and either continuing in solution or solidifying, according to the amount formed or the proportion in the water. This author figures specimens from different localities in which gypsum and dolomite are intimately associated; and among them are some of fossil corals.

The hypothesis of Von Buch is thus set aside. We have a satisfactory explanation of the existence of *compact* magnesian limestones, like those of our Western States, as well as of the crystalline dolomites. The latter may have received some additional magnesia during the submarine heating that crystallized them.

The circumstance of a chemical change going on between the carbonate of lime and magnesian salt is especially favourable for consolidation. When the coral is a fine mud, and the grains are therefore extremely fine, the dolomization might extend to the grains themselves, as well as the infiltrating material acting as a cement. But when the grains of coral are large, or there are pebbles, the infiltrated material that might be magnesian would constitute but a small part of the whole bed. Hence it is obvious that such formations in cold waters would seldom in the mass have the proportions of a true dolomite, (54·2 of carbonate of lime, to 45·8 of carbonate of magnesia;) and they would attain such proportions under an ocean only during that action of heat required alike for crystallization and chemical combination.

CHAPTER III.

HAWAIIAN ISLANDS.

AMONG the groups of Polynesia, the Hawaiian exceeds all others in geological interest. The agency of both fire and water in the formation of rocks, is exemplified not only by results, but also by processes now in action; and the student of nature may watch the steps through the successive changes. He may descend to the boiling pit, and witness the operations in the vast laboratory, with the same deliberation as he would examine the crucible in a chemist's furnace. Thus the manner in which mountains are made, and islands built up, becomes a matter of observation. The volcanic dome may be seen in the process of accumulation from overflowing lavas, and may be traced as it increases in size. Again, disruptions of the accumulated rock may be observed, followed by their disappearance in the lavas below.

While these volcanic mountains are still extending their limits, in one part of the group, in others, those changes are finely illustrated which they undergo through the action of water, gradual decomposition, and other allied causes: and these effects are in every stage of progress:—in some instances, the slopes retain the even surface of the most recent lava stream; in others, they are altered in every feature, the heights worn down, the whole surface gorged out with valleys, and the depth of these furrowings of time indicate that the several islands differ widely in the length of the period since they were finished by the fires, and left to the action of the elements.

Moreover, the coral formations of the shores present us with reefs now in progress from the growing zoophytes; and there are also reefs elevated many feet above the sea, having a close resemblance to beds of limestone. Besides these, there are hills of drift sand-rock of coral origin. The various facts illustrate, therefore, all the results of coral growth and accumulation.

The group is consequently the key to Polynesian Geology. It combines all the features which are elsewhere widely scattered, and they are so exhibited in progressive stages as to afford mutual illustration. An island like Tahiti, so broken into peaks and ridges, may excite wonder and doubt. The Hawaiian Group suggests the same difficult problem as Tahiti; but an intelligible solution is at the same time presented for our contemplation and study.

GENERAL FEATURES OF THE HAWAIIAN GROUP.

The islands of the Hawaiian Group are eight in number, and lie near the northern tropic between the parallels of latitude 19° and $22\frac{1}{2}^{\circ}$. Commencing with the southwest extremity of the line, they are as follows:—Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau.* The length of the whole line is about 400 miles. It has already been remarked that the range properly continues to the northwest, and includes the two rocky islets, Necker and Bird, and some coral reefs beyond, embracing in all an extent of nearly 2000 statute miles.

This group constitutes properly a long range of mountain heights, the whole of which is submerged, excepting those parts which now form islands. The highest points are in the southeastern island—Hawaii; Mount Loa, according to the measurements of the Expedition, is 13,760 feet above half tide, and Mount Kea, 13,950 feet; and upon the same island, Mount Hualalai is not far from 10,000 feet.† Maui, the island next to the west, has one summit, Haleakala, exceeding 10,000 feet, (10,217,) and another, Eeka, 6130 feet. Oahu has

* These names are pronounced as if spelt Häh-wyee, Mōw-ee, Kah-hōō-lāh-wāy, Lāh-nīē, Mōl-ō-kīē, Wāw-hōo, Kōw-eīē, Nee-how. Besides these there is an islet near Maui, called *Molokini*, (pron. Molokeenee,) and another south of Niihau, called Kaula. Both are uninhabited.

† The height of *Mount Loa* has been variously stated by different travellers.

Captain Cook, (3d Voyage, iii. 104,) - - -	18,400	English feet.
Captain King, (Cook's Voyages,) - - -	16,480	"
Marchand, (Voyage, i. 428,) - - -	16,613	"
Kotzebue, (Entdeckungsreise, i. 21,) - - -	15,884	"
M. Horner, (in Kruesenstern's Reise, i. 215,) - - -	14,423	"
“ as calculated by Von Buch from the data given,	13,537	"
Mr. Douglass, (Journ. Roy. Geog. Soc. iv. 333,) - - -	13,230—13,175	
M. E. Chevalier, (Geol. Voy. Bonite, p. 200; from Kotzebue?)	15,880	

two ranges, each near 4000 feet high, and on Kauai there is a summit estimated at 8000 feet. Molokai rises to a height of 2500 feet, and Lanai to near two-thirds this elevation. This is certainly a remarkable series of elevations for an area hardly 76 geographical miles square, the whole amount of dry land. As no deep sea soundings have been made between the islands of the group in the line of the range, we have as yet no evidence respecting the elevation of the summits above the submerged ridge intermediate.

The Hawaiian Islands offer in every part abundant evidence of their igneous origin. Yet the active fires at the present time are confined to the island of Hawaii. We shall show in the sequel that Hawaii is not on this account to be considered the most recent island of the group. It is only the last of the number to become extinct. It will appear that the fires of the group first died out at the northwest extremity of the line, and so on in a nearly regular progression to the southeast.

We have already pointed out that the islands lie in two parallel series,—Mount Kea, the two summits of Maui, Molokai, and the northwest or Koolau range of Oahu, forming one line or series of heights;—while Lua Pele on the flanks of Mount Loa, Mount Loa itself, Mount Hualalai, island of Kahoolawe, Lanai, and the southeast range of Oahu, constitute another. Kauai is more nearly in the line of the latter. One may be designated the *Kea* series, and the other the *Loa* series. The trend of each is that of the group, or N. 55° W.

It is a striking feature of the Hawaiian Group that several of the islands are literally a twin of mountains. Maui is a remarkable example of this character; it consists of two peninsulas, each with its own lofty heights, and the two are united by a low plain. Oahu is another example; the two ranges of heights are separated by a plain, into which the mountains of either side gradually decline. Molokai is still another example of two elevations and an intermediate strip of comparatively low land. A slight subsidence of Maui would make it two distinct islands: and sinking it 5000 feet, Haleakala would still stand 5000 feet in elevation, and a sea which would be styled unfathomable would separate it from Eeka. Hawaii is an example

The height of *Mount Kea* is estimated by,

Kotzebue, (*Entdeckungsreise*, i. 21,) at - - 14,717 English feet.

Mr. Douglass, (*Journ. Roy. Geog. Soc.* iv.) at - 13,645—13,587

Marchand remarks that Mount Loa was visible at a distance of 53 leagues.

of a *triple* island, the three summits, Loa, Kea, and Hualalai, comprising the island; a subsidence of 6000 feet would make three islands of the three mountains, and Loa and Kea would still be 8000 feet in elevation. These facts are of special interest in a geological point of view, and help us to an insight into the past history of the islands, which will be considered and explained in the sequel.

I. ISLAND OF HAWAII.

Hawaii is the most extensive seat of volcanic action in the Pacific, and one of the most remarkable regions of eruption in the world.

Besides the three lofty summits which have been mentioned, there are great numbers of craters in all conditions, scattered over the slopes, some overgrown with forests, while about others, streams of lava, now hard, and black, may be traced along their course for miles. Areas, hundreds of square miles in extent, are covered with the refrigerated lava floods, over which the twistings and contortions of the sluggish stream as it flowed onward are everywhere apparent; other parts are desolate areas of ragged scoria. But a few months before our visit, a surface of fifteen square miles had been deluged with lavas, which came by an underground route from the crater Lua Pele. As we have therefore on Hawaii the most recent igneous action, we commence our survey of the group with this island.

I. GENERAL FEATURES.

The form of Hawaii is nearly triangular, with the three sides fronting severally, west, southeast, and northeast. The western side is about 85 geographical miles in length, the southeast 65, and the northeast 75 miles; the area is 3800 square miles. The whole surface pertains to its three lofty summits, forming their declivities or foot, excepting a single ridge on the north called Kohala.


The voyager approaching Hawaii, while admiring the sublimity of its swelling heights, is struck with the unbroken surface of the island. Lofty peaks, and alternating valleys and ridges are so generally characteristic of mountain scenery, that he views the even and gentle slope of the summits Loa and Kea with a degree of amazement.

The former rises with a scarcely perceptible inclination, (see annexed cut,) without a break in the surface apparent in the distant view; then gradually rounds over, and declines on the opposite side with the same gentle declivity. The eye following along, up and down the sides of Mount Kea, meets with the same slopes, and only few traces of indentations. Mount Loa is a flat dome. Mount Kea rises to the same altitude, and differs only in having the summit somewhat pointed. The two stand side by side, bathed below in the ocean, and usually mantled above with clouds. In winter they are both covered at top with snow; but in summer Kea is mostly bare, and Loa, owing probably to its fires within, is wholly without snow.

From these descriptions the statement will be appreciated that the heights of Hawaii are not peaks in a mountain range, but three isolated domes or low cones, united by a confluence of lavas at base. The surface of the island is not a mass of broken mountains, but the simple slopes of these elevations. Yet on an actual scramble over the sides, there are found occasional ravines and ridges of lava which impede the progress; and numerous craters form large hills, as they are usually between three and nine hundred feet in height. There are also deep gorges on the eastern and northern foot of Kea, which extend from the sea half-way up the mountain, and are from three hundred to a thousand feet in depth. The Kohala range on the north, which is the only part not conformable to this system, faces the interior of the island with a nearly vertical front, while northward the slopes are less abrupt and are profoundly intersected by valleys.

Upon the eastern or windward declivities of the island, where rains abound, there is some soil, and in many parts dense vegetation. With the first trace of earth, proceeding from the decomposition of the lavas, some kinds of shrubbery spring up, and flourish well amid the dreariest lavas. But over the leeward sides, (the southern and western,) where rains are unfrequent, a black desert of rocks everywhere prevails, and there is, with rare exceptions, only an alternation between the smoother fields of cooled lava and the rougher districts of scoria. Yet over the barest fields there is a sprinkling of verdure, growing from the many crevices

Mauna Loa.
OUTLINE VIEW OF HAWAII, FROM THE EASTWARD.
Mauna Kea.



or cavities. Whatever showers fall on this portion of Hawaii are at once absorbed by the cavernous rocks; and consequently through its whole extent, south and east, there are not two permanent streamlets. Water is to be found only in caverns; and often a journey of some miles must be taken by the villager to supply himself for his daily consumption. All the caverns about the lower parts of the mountains have been well explored in search of this necessary of life. The contrast with the windward side in this respect is very striking, for there, water and large streams are abundant. Each of the many valleys of Mount Kea and Kohala, "for thirty miles, one to every half-mile," is the course of a streamlet, which is of large size in the wet season; and a fine river, the Wailuku, rising from the southern slopes of Kea, between Kea and Loa, reaches the sea at the Bay of Hilo.

In farther explanation of the features of the island, a few facts may be stated from observations by the writer on a tour over the southern slopes of Mount Loa, from the western shores at Kealakekua Bay to the Bay of Hilo, on the east side of the island.*

South of Kailua, along the western shores of Hawaii, the country rises with an even slope for five to eight miles to a height of five or six thousand feet. Not a valley of any extent is to be seen. Beyond the summit of this slope, I was informed that there is a small descent, and then commences again the acclivity of Mount Loa. This shore slope is chequered sparsely with taro plantations and patches of thin forests; but more largely with black and brown fields of lava, as rugged and nearly as barren as the last eruptions of Lua Pele. Going to the southward in this direction, the stony districts are still more extensive; yet there is some shrubbery, and in holes among the

* This jaunt of five days, limited by the orders received, was the whole extent of the opportunities which the author enjoyed for examining the island. The distance traversed was about one hundred and forty miles. The party was landed for the tramp at Kealakekua, and, upon arriving at Hilo, rejoined the Flying Fish to return to Oahu, where we soon sailed in the Peacock on a cruise to the equatorial regions. The features of the island, the character of its rocks, and the operations of Lua Pele, as well as the appearances produced by the eruption six months previous, were attentively examined. But for information relative to the summits of Mount Loa and Mount Kea, and many particulars respecting the recent eruption, I cite from the journals of the officers of the Vincennes, and from the Narrative of the Expedition by Captain Wilkes. I would also mention here my indebtedness for many valuable facts to the Rev. Mr. Coan, of Hilo, and also to the Rev. Mr. Andrews of Lahaina, and Dr. Judd of Honolulu.

stones and small patches of earth the natives plant their upland taro and sweet potatoes.

The shore on this route is a rugged line of bare rocks, rising from amid the white surf. There is usually a cliff of fifty or one hundred feet, consisting of a few layers of lava broken down into jagged points and islets of every shape and description. Deep caverns open near the water's edge; and the breaking sea, dashing and foaming over the black rocks, drives furiously into their mouths, and often careers in lofty jets from open passages in their farther recesses. Such scenes excite in the beholder a feeling of wild delight, in which the ocean appears to participate. Besides the other features of this dreary coast, an occasional crater stands here and there on the shores, partly broken down by the waves. The villagers of the region are few in number, and live between a mountain and a coast settlement, using the latter for their fishing seasons, and the former for more permanent comforts. About the upper village are their only taro grounds.

Leaving the coast at Kaulanamauna, near the southwest point of the island, we travelled eastward to Manuka, and thence to Kailiki, near the southern cape. Throughout this region, a distance of twenty miles, there was an uninterrupted waste of lava. Forests in the distance seemed at times to promise a change; but when reached, there were only scattered trees and shrubbery, which had contrived to find support among the blocks of lava, or in the fissures that intersected the surface. The best spots afforded little soil and scanty sustenance to the mountaineers.

The fields of lava passed over were of the two kinds already alluded to. Large tracts consisted of the *smooth, solid lavas*, which were marked with rope-like lines and concentric folds, such as are seen on any densely viscid liquid, if drawn out as it hardens. The surface was undulating, owing to many rounded hillocks, or domes, and curving ridges, ten to twenty feet or as many yards in height; and often there was a constant succession of ascents and descents for miles. Numerous fissures intersected the lava plain; the domes were generally cracked or broken, and the loosened fragments had often fallen into the oven-shaped cavities they covered. The ridges, in like manner, were often broken through and disclosed long subterranean passages. It was evident that the domes and ridges were due to a bulging or expansion of the layer of lava, from the ascent of a large volume of vapours; for the roof of the ovens or caverns was but a continuation of the layer either side, and had the same thickness, varying

from one to ten feet. The concentric folds or plaitings of the surface of the lavas were most distinct on the slopes of these bulging elevations, and it was therefore obvious that the bulging had taken place while the lavas were still free to move, and also that the plaitings had arisen, after the expansion, from the moving down of the liquid against the motionless lavas below.

The folds and twistings in the surface of the lava, here explained, are the *ripple-marks* of some authors on the Hawaiian volcano; and from the rounded hillocks and ridges the *waves* of a molten sea have been fancifully made out.

Other regions consisted of lava and scoria in immense masses, piled together in the utmost confusion. They are styled *clinkers* or *clinker fields*. They look as if the mountain had been shattered to a chaos of ruins. The fragments vary from one to ten thousand cubic feet, or from a half bushel measure to a house of moderate size. They are of all shapes, often in angular blocks, sometimes in slabs, and have a horrible roughness beyond conception, points and angles standing out in every direction; they lie together, touching only by their edges or points, leaving deep recesses everywhere among them. Reaching a district thus bristled with scoria, we mounted on the blocks, and travelled by leaping from one to another; yet not without an involuntary shudder, lest a foot slipping should precipitate us into the deep cavities, among the jagged surfaces and edges. These clinker districts are often several miles in breadth; and upon some of them the whole horizon around is one wide waste of gray and black desolation, beyond the power of words to describe.

The solid lava fields, (the *pahoioi* of the natives,) and the clinker regions are generally associated together. In several instances we passed abruptly from the former to the latter, and then returned to the smooth lavas again. There is no doubt that the whole was one single region of eruption, and these different results arose from different phases in the volcanic action of one and the same period. The clinker fields are usually twenty or thirty feet the highest, and the passage from one to the other is by a steep ascent.

Clinker fields are a common feature over the whole surface of Mount Loa. They evidently proceed from a temporary cessation, (either complete or partial,) and a subsequent flow, of a stream of lava. The surface cools and hardens as soon as the stream slackens; afterwards there is another heaving of the lava, and an onward move, owing to a succeeding ejection or the removing of an obstacle, and

the motion breaks up the hardened crust, piling the masses together either in slabs or huge angular fragments, according to the thickness to which the crust had cooled. It is probable that these clinker regions are sometimes over a fissure of ejection, and arise in these cases from a second outbreak after the previous flow has partially cooled. We thus account for their forming a narrow district, crossing a field of *pahoehoi*. If the motion of a lava stream be quite slow, the cooling of the front of it may cause its cessation, thus damming it up and holding it back till the pressure from gradual accumulation behind sweeps away the barrier. It then flows on again, carrying on its surface masses of the hardened crust,—some, it may be, to sink and melt again, but the larger portion to remain as a field of clinkers. The breaking up of the ice of some streams in spring, exemplifies imperfectly this subject, especially those instances in which the crust of lava is thin, and *slabs* are formed. But to obtain a just conception of the magnitude of the effect, the mind must bring before it a stream, not of the limited extent of most rivers, but one of five or ten miles in breadth: besides, in place of smooth and clear ice, there should be substituted shaggy heaps of black scoria, and a depth or thickness of many yards in place of a few inches.*

Over the route to Kailiki the clinker districts were most extensive. Through part of the way, where the country was of this character, the natives had constructed a *macadamized* road five to six feet wide, by breaking down the smaller masses, which are almost as brittle as unannealed glass, and reducing the whole to fragments, over which

* The clinkers formed at the eruption of Vesuvius in 1779, are well described by Sir William Hamilton. He says (Lyell's Principles, ii. 177, from Otter's Life of Dr. Clark), "All lava, at its first exit from its native volcano, flows out in a liquid state, and is all equally in fusion. The appearance of the scoria is to be attributed only to the action of the external air, and not to any difference in the materials which compose it, since any lava whatever, separated from its channel, and exposed to the action of the external air, immediately cracks, becomes porous, and alters its form. As we proceeded downward, this became more and more evident; and the same lava which, at its original source, flowed in perfect solution, undivided, and free from encumbrances of any kind, a little further down had its surface loaded with scoriæ in such a manner, that upon its arrival at the bottom of the mountain, the whole current resembled nothing so much as a heap of unconnected cinders from an iron-foundry." The only error in the foregoing, is the statement that all lavas become scoriaceous, and covered with cinders, on exposure to the air. The *pahoehoi* regions of Hawaii are often more extensive than the associated clinker-fields; and the latter occur on the same slope or plain with the former, where there is nothing but a variation in the rapidity of motion, or a renewal of movement from a cessation, to cause the difference. Other facts will be stated in the sequel.

they strewed dried grass. We had good evidence in the wear and tear of leather, that the naked feet, even of the natives, could not long stand this clinker travelling. On reaching such districts, they usually put on sandals, made of grass or hide.

From Kailiki to Waiohinu, and beyond to Honuapo, the country bore evidence of having been longer exempt from eruptions than any portion elsewhere seen in the southern part of the island. A good growth of grass, with occasional forests and shrubbery, covered the hills. Yet notwithstanding the luxuriance, there was but a small depth of soil. It seldom exceeded a foot; and along the path we followed, which was worn down two or three inches, the rocks were generally exposed, and presented the characters of the smooth lava fields just described. At Waiohinu there is the only constant stream on the southern side of the island; the small valley it waters is green with taro beds and groves of banana. This part of the island is in a line with the southern point or cape, lying between this cape and the summit of Mount Loa; and it appears that the same eruptions which lengthened out the cape gave an elevation to the country back; as a consequence, subsequent lavas have flowed either side, and left this region to form soil and become covered with vegetation. Hence it is that this part of the country differs so widely from others, either to the east or west.

Between Honuapo and Punaluu, a distance of four miles, the seashore plains embrace both smooth lava fields and clinker districts, the former roped out and in plaited folds, like the beds before passed, and both regions as desolate as if from the fires of yesterday. The ridge that lies back of this plain is covered with verdure, and betokens a longer respite from deluges of lava than the plain below. The eruption must have taken place on the plain itself, or at the foot of the declivities. The clinker field intersected the smooth lava stream near its middle, and was elevated twenty feet above it. It was three-fourths of a mile wide, and lay nearly at right angles with the coast.

At Punaluu, situated south-southeast of the summit of Mount Loa, we left the coast, and travelled inland to the north-northeast, passing over tolerably good pasture land for twelve or fifteen miles, much resembling the region between Waiohinu and Honuapo. The grass was generally high, but the soil was seldom over a few inches in depth. The plains and slopes towards the seashore to the south of us were mostly black with the barren lavas: some slight variation in shade indicated a difference of age in the eruptions.

Fifteen miles from Punaluu, or five from Kapapala, at an elevation of 3000 feet, we went abruptly from the pasture land to one of the desolate lava tracts; for twelve miles we travelled over its naked surface, and finally reached the borders of Lua Pele. Though no soil was to be seen upon its surface, a few shrubs had taken root in nooks and crevices. The lava was swollen into knolls and rolling ridges, from half a dozen to a hundred feet in height, as we have already mentioned of similar districts beyond Waiohinu; and these knolls were often deeply fractured and fallen in, showing their arched form and the hollow cavity they covered. In many places there were fissures which had been filled by lavas after the crust had cooled, and these tiny dikes stood somewhat raised above the surface, forming little rounded ridges an inch or two in height. A narrow clinker district intersected the region of smoother lavas, elevated above the latter from fifteen to twenty-five feet. It curved around and continued along the inner edge of the lava field towards Lua Pele, (Kilauea.)

While crossing this black field of lava, the view of the seashore was cut off by a slight elevation of the plain; and along this elevation there were several extinct cones more or less broken down, marking it out as the course of the principal fissure from which these lavas had been ejected. We had no time to turn from the straight road, as our hours were limited. We learn from Mr. Ellis, who passed over the place in 1823, that it was then a region of smoking fissures and chasms, and presented also a valley or hollow, half a mile across and fifty feet deep. He was informed by the natives, that eleven moons before, (Sept. 1822,) the two larger chasms were formed: the principal was ten or twelve feet across, and extended as far as the eye could reach towards the sea. In many of the fissures there was a red heat, and in some no bottom could be seen. Through one there had been a recent ejection; the lava had flowed out from both sides of the opening in small streams, and having been thrown in masses in every direction, hung in stalactites from the shrubbery. A native stated that only two months previous to Mr. Ellis's visit, there had been a slight earthquake at Kapapala; and passing along soon after, he observed that the ground had fallen in, producing the valley or hollow above alluded to. At the same time, there was fresh lava around, and the branches of some trees that had been set on fire were still smoking.*

Thus far over Hawaii, little was met with but the gray and black

* Ellis's Polynesian Researches, vol. iv., pp. 221, 222.

products of its volcanic fires: of picturesque landscapes no trace was seen. There was only the wearying grandeur of desolation, in which but few spots were covered, and those thinly, with verdure. This same character prevails over the whole of the southern and southeastern portion of the island. We should hardly expect to find a large population in such regions, yet the natives are numerous and find means of support. Some of the potato fields in Puna look as unfavourable for cultivation as a bank of cobble-stones, or a freshly macadamised road. Not a particle of earth is to be seen, the whole consisting of fragments of lava from the size of a walnut to that of the fist or larger. Yet their sweet potatoes (*Convolvulus batata*) planted in a series of deep hollows, among the stones, grow well and yield a good crop. Dr. Pickering observed plantations of this kind among the rocks of Nanawale that six months before were flowing lavas.

The lava plain above described brought us to Lua Pele. We pass on, leaving a description of its features, and also of the recent eruption, for a following page. Before reaching it, for two miles the rocks were covered with a little soil, and vegetation was rather less sparse. On the slopes beyond, towards Hilo, we appeared to be in another land, for there were extensive forests, dense shrubbery, and a good growth of grass; some parts of the country were even marshy. The relative influence of the leeward and windward climate in the Pacific, was thus strongly exhibited. The rains promote the decomposition of the lavas, and a rank vegetation succeeds; the growth of vegetation aids farther in the work of decomposition, and hastens thus the accumulation of soil. Kilauea is usually covered with mists from the condensed vapours of the volcano, and it forms a limit between the wet and dry regions on this part of Hawaii. Its height above the sea, according to the measurements of the Expedition, is 3970 feet.*

From Kilauea we descended to Nanawale through Kapueuhi and Waipahoihoi. About Kapueuhi, ten miles from Kilauea, the country is rather wet, and is covered with grass, shrubbery, and some forests. East from Kapueuhi there is less soil, the rock showing itself over about one-sixth of the surface, and exhibiting the usual surface twistings—ripplemark-like—of the smoother lava tracks. Wherever soil appeared there was a rich growth of ferns, grasses, and some few groves.

* The barometrical measurements of Douglass gave for the height of the north-northeast bluffs, 3845·9—3873·7 feet, (*Journ. Roy. Geog. Soc. iv.*) and Strzelecki obtained for the height of the same 4101 feet.

About Hilo the country looks fresh and beautiful; three small craters in the landscape, overgrown with grass and shrubbery, contrast strongly with the barren lava cones of the southwestern coast. Clouds and sunshine offer their genial influences in nearly equal turns over the northeastern side of Hawaii, furnishing it richly with verdure, and affording a constant supply of water to the many streamlets. The river Wailuku, which empties into the bay of Waiakea, is remarkable, as well for its size, as for the falls of the "rainbow," as they are styled by the natives, a mile from its mouth. Between high vertical walls of basalt hung in tapestry of vines, shrubbery, ferns, and mosses, the waters plunge one hundred and twenty feet into a broad deep basin: a large cavern underneath forming a dark background to the foaming sheet. On the southern side there are a number of jets-d'eau playing from among the green leaves, and leaping gracefully into the pool below; and on either side several cascades form silver threads coursing down the verdant walls. Just below the basin the gorge is subdivided into two branches by a bluff ridge, famous for its fine basaltic columns; the stream follows the northern opening to the sea.

We here close our brief sketches of the features of the island, made on the jaunt over Hawaii. From the accounts of others, we are assured that the country examined gives a very correct idea of the whole surface. The party which ascended Mount Loa to its summit from the Vincennes, under the direction of Captain Wilkes, represent the country passed over as abounding in lava streams, *pahoioi*, and *clinkers*. Vegetation ceased at a height of 7000 feet: and beyond this, as Captain Wilkes remarks, there was nothing but widespread fields of black lava "which had apparently flowed in all directions from the summit." Caverns were very numerous beneath the layers of lava, some of which were many miles in length, and they afforded the party an occasional night's shelter.

The interior section of the island, or table-land, between the three great mountains, is described as mostly a waste of lavas with numberless cones, especially along the declivities of Mount Loa; towards Kea there is more verdure, and upon its southern slopes cattle range and find sufficient pasturage. The leeward declivities of this mountain are less fertile, and the Waimea district, which lies at its northwest foot, is said to be dry and unproductive. Vegetation continues on Mount Kea to a height of 12,000 feet, thus exceeding much the elevation to which it extends on Mount Loa. Yet it is not surprising when we consider the cavernous nature of the rocks of the

latter, which soak up all the rain that falls, so that there is little decomposition in progress. Besides, the mountain is still ejecting its lavas; while Kea has been long extinct, and the period elapsed has been sufficient to form water-courses, and produce a coating of soil over many parts of its surface.

The fertile district of the northeast extends around by the north, and the Kohala range has been styled "the ever-verdant hills." Waipio is spoken of as a most beautiful valley; Waimanu as "a lovely vale" on the northeast shore. Travelling northward from Hilo is extremely arduous, on account of the endless succession of deep gorges. A cliff of several hundred feet faces the sea, so that the only course for the traveller is to ascend and descend the ridges, and ford the many streams.

2. VOLCANOES OF HAWAII.

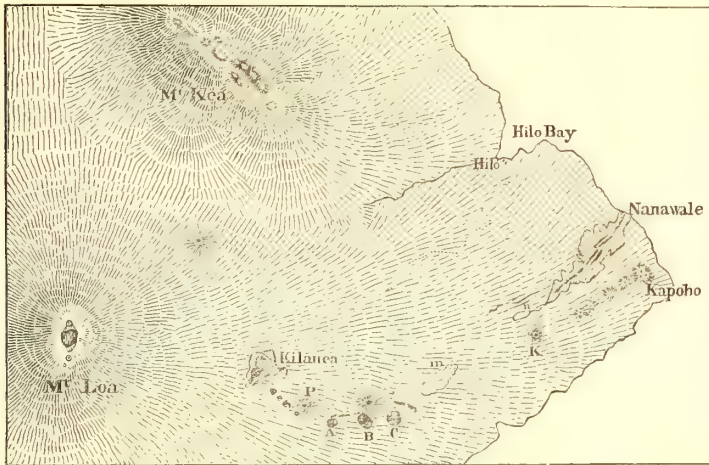
Volcanic action on Hawaii is at present confined to Loa and Hualalai. Mount Kea has been extinct since the earliest traditions of the natives.

a. MOUNT LOA.

General Features.—The form of Mount Loa, a flattened dome, is its most remarkable feature. The idea of a volcano is so generally connected with the figure of a cone, that the mind at once conceives of a lofty sugar-loaf ejecting fire, red-hot stones, and flowing lavas. But in place of slender walls around a deep crater, which the shaking of an eruption may tumble in, the summit of the Hawaiian volcano is nearly a plane, in which the crater, though several miles in circuit, is like a small quarry hole. Observing the mountain from a distance, as it appears lying low on the horizon, the mind has no conception of its magnitude. Even while travelling on its sides, the distance of its gradually receding summit is not apprehended, and the mountain might readily be mistaken for a swelling hill of small elevation. Such it appeared to the writer when traversing its slopes, about 3000 feet above the sea. Menzies was disappointed for this reason, when commencing the ascent from Captain Cook's vessel at Kealakekua Bay; his estimated twelve or fourteen miles turned out to be not half the distance. In certain views, however, when the state of the atmosphere is favourable,

it stands up in all its majesty, and the observer feels the oppressive sublimity of the simple mountain dome.

The accompanying map of a part of Hawaii* will assist in conveying an idea of its form, the position of the crater at summit, and of Kilauea on its east-southeastern flank, 3970 feet above the sea. Still



more definite information respecting the gentleness of its slopes, may be obtained from a few simple calculations.

The difference of height between Kilauea and the summit is 9790 feet, and the distance in statute miles from Kilauea horizontally to the axis of the cone is 15.9 statute miles. From these data, we obtain the small angle $6^{\circ} 42'$ for the average inclination from Kilauea to the summit.

Again, from Punaluu, the point on the southeastern coast nearest the summit, (see the general chart of the Islands,) to the same axis, is 19.8 miles, which gives for the average slope on this side $7^{\circ} 33'$.

From Honakua, just south of Kealahou, on the west side of the island, to the same axis, the distance is 26 miles, affording an average inclination for the west slope of $5^{\circ} 45'$. From Kealahou, the distance is $27\frac{1}{3}$ miles, giving an inclination of $5^{\circ} 28'$.

We may hence assume $6^{\circ} 30'$ as the average inclination of the great dome. This corresponds with a base to the dome of forty-five and three-fourths miles. We may consider this the size of the main

* This map is reduced from the chart published with the Narrative of the Expedition.

dome : but the slopes spread very much below, diminishing to a single degree, so that the whole region of volcanic action subordinate to Mount Loa, is about seventy miles in width, or includes the entire breadth of the island, from east to west. The main part of the mountain, if considered a portion of a great sphere,* will correspond to a segment 13,760 feet deep, cut from a globe four hundred miles in diameter ; or in form, to a segment about one-twelfth of an inch deep from a globe twelve inches in diameter : and in such a segment as last referred to, the terminal crater would be represented by an indentation one-fifteenth of an inch broad, and Kilauea by another one-tenth of an inch broad ; and both about a fifteenth of their breadth in depth. The dome, consequently, instead of having slender walls at top, has a horizontal thickness of full twenty miles eighteen hundred feet vertically below its summit.†

The slope from Kilauea to the east coast at Nanawale, (the scene of the late eruption), averages but $1^{\circ} 28'$, or one hundred and thirty-five feet to the mile ; it constitutes an extension of the base of the mountain in that direction. The southern point forms another example of the same kind, though of less extent.

The declivities of Mount Loa have been described as covered with black patches of lava from the sea to the very summit, which, in most parts, are still bare, or but sparsely covered with vegetation. These patches are a result of distinct eruptions, and they show that lavas have found their way out, not only from the large vents, which are

* It varies a little from a segment of a sphere, the upper parts being slightly more prominent.

† For comparison with other lofty volcanic mountains we here mention a few other inclinations, as determined in different instances.

The Peak of Teneriffe has an average inclination of $12^{\circ} 30'$, the proportion of height to diameter being given as 1 to 9.

Etna, according to Elie de Beaumont, has an average inclination of 8 degrees. M. von Buch makes the ratio of height to circumference as 1 to 34, giving the angle $10\frac{1}{4}$ degrees. The Chimborazo dome, according to Humboldt, is only 673 toises through at a level of 153 toises (or 978 feet) below the centre of the top.

It is much to be regretted that artists, when sketching mountains, are not content with giving them their actual slopes instead of attempting improvements by straightening up their sides, and sharpening their summits. Even in works of science, the same errors are common. We never see a drawing of Jorullo, which does not give the peak actually impossible slopes, taking Humboldt's own facts as a criterion. Drawings of Vesuvius and Etna, in the most prominent of our geological treatises, are equally objectionable. A simple outline, if correct, gives reliable information ; and is far more valuable to science, than one improved to suit the fancy, though sketched with the skill of a master.

constantly open, but also through fissures made by internal pressure: and thus, although we may speak of Kilauea and the summit crater as the active vents, the mountain may, with more propriety, be said to have exhibited its activity in every part. At these large openings the ordinary pressure is relieved by the constant escape of vapours; but they have ejected little of the material which forms the present surface of the mountain.

In the farther account of Mount Loa, we may speak first of Kilauea, the crater best known from the accounts of travellers; next, of Mokuaweo-weo, the summit crater; and then of other craters and points of eruption over the mountain.

a. *Kilauea.*

Kilauea is a deep pit in the sides of Mount Loa. The gentle slopes of the dome in this part scarcely vary from a plain, and the crater appears like a vast gulf, excavated out of the rock-built structure. Although there is no cone, the country around is slightly raised above the general level, as if by former eruptions over the surface; but this is hardly apparent without extended and careful examination.

The traveller perceives his approach to the crater in a few small clouds of steam rising from fissures not far from his path. While gazing for a second indication he stands unexpectedly upon the brink of the pit. A vast amphitheatre seven miles and a half in circuit has opened to view. Beneath a gray rocky precipice of 650 feet, forming the bold contour, a narrow plain of hardened lava, (the "black ledge,") extends like a vast gallery around the whole interior. Within this gallery, below another similar precipice of 340 feet, lies the bottom, a wide plain of bare rock more than two miles in length.

The eye naturally ranged over the whole area for something like volcanic action, as it is usually described. But all was singularly quiet. In the dark plain that forms the bottom, there was little to attract attention beside the utter dreariness of the place, excepting certain spots of a blood-red colour which appeared to be in constant yet gentle agitation. Instead of beholding a sea of molten lava "rolling to and fro its fiery surge and flaming billows," we were surprised at the stillness of the scene. The incessant motion in the blood-red pools was like that of a cauldron in constant ebullition. The lava in each boiled with such activity as to cause a rapid play of jets over its

surface. One pool, the largest of the three then in action, was afterwards ascertained by survey to measure one thousand five hundred feet in one diameter, and a thousand in the other: and this whole area, into which the Capitol grounds at Washington might be sunk entire, was boiling, as seemed from above, with nearly the mobility of water. Still all went on quietly. Not a whisper was heard from the fires below. White vapours rose in fleecy wreaths from the pools and numerous fissures, and above the large lake they collected into a broad canopy of clouds, not unlike the snowy heaps or cumuli that lie near the horizon in a clear day, though changing more rapidly their fanciful shapes. On descending afterwards to the black ledge, at the verge of the lower pit, a half-smothered gurgling sound was all that could be heard from the pools of lava. Occasionally there was a report like that of musketry, which died away, and left the same murmuring sound, the stifled mutterings of a boiling fluid.

Such was the general appearance of Pele's pit in a day view, at the time it was visited by the author.*

At night, though no less quiet, the scene was one of indescribable sublimity. We were encamped on the edge of the crater, with the fires full in view. The large cauldron, in place of its bloody glare, now glowed with intense brilliancy, and the surface sparkled with shifting points of dazzling light, occasioned by the jets in constant play. A row of small basins on the southeast side of the lake were also jetting out their glowing lavas. Two other pools in another part of the pit tossed up their molten rock much like the larger cauldron, and occasionally burst out with jets forty or fifty feet in height. The broad canopy of clouds above the pit which seemed to rest on a column of wreaths and curling heaps of lighted vapour, and the amphitheatre of rocks around the lower depths, were brightly illuminated from the boiling lavas; while a lurid red tinged the distant parts of the inclosing walls and threw into deeper shades of darkness the many cavernous recesses. And over this scene of restless fires and fiery vapours the heavens by contrast seemed unnaturally black, with only here and there a star like a dim point of light.

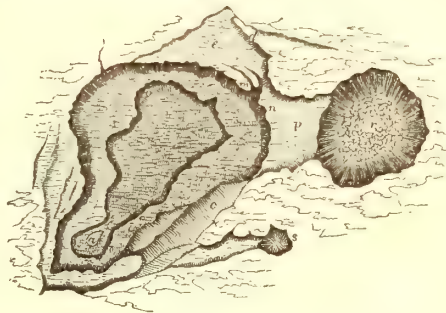
The next night, streams of lava boiled over from the lake, and formed several glowing lines diverging over the bottom of the crater. Towards morning, there was a dense mist, and the whole atmosphere seemed on fire. Through the haze, the lakes were barely distinguished by

* In November, 1840.

the spangles on the surface that were brightening and disappearing with incessant change.

From these views, which are correct to the letter, we proceed to a more minute description of the crater and its lavas. We are not responsible for any disappointment they may create, as we could see only what was actually before us. Pele was in one of her sober moods. Yet we have reason to believe that this is her usual state, and assuredly there is a terrible grandeur even in her quiet. The action when most roused has been much exaggerated in its character, for boiling and overflowing, with occasional detonating explosions, constitute in every condition its characteristic features; in its greatest violence, the cauldrons are more numerous and extensive, the spouting cones multiply in number, the explosions are loud and frequent, and the sheets of lava at each overflow spread through the whole crater. Such a scene over an area seven and a half miles in circuit, must be terrific beyond description, although the "sea" be no sea; and the "waves" but the agitations of violent ebullition and frequent overflowings.

The accompanying bird's-eye view of Kilauea, reduced from the surveys of the Expedition,* shows its oblong-ovate form and general features, though giving no adequate idea of its magnitude. The longest diameter lies nearly north-east and south-west, and is 16,000 feet in length; the average breadth is 7500 feet. The pit includes, therefore, an area of nearly four square miles,† thus exceeding in extent many a city of 150,000 inhabitants. Yet on looking into it from above, it is difficult to realize its extent, as there is no object within or about it which can serve for comparison. No one would imagine that 400 such structures as St. Peter's at Rome could be



* The fourth volume of the Narrative of the Exploring Expedition by Captain Wilkes, contains several finished sketches of the craters of Hawaii, with valuable descriptions of their conditions and operations. The surveys were conducted with great labour, and afford important data for determining the extent and character of future changes in these volcanic regions. The measurements given above are derived from these surveys.

† As nearly as can be ascertained from the map of the crater the area is three and two-thirds square miles, or 102,000,000 square feet.

accommodated within its walls, or that the lofty dome of this cathedral would stand with its pinnacle but 120 feet above the black ledge. The great lake of boiling lava, 1000 feet by 1500, as above mentioned, is a small object in such an area.

A better idea of the actual form of the pit will be obtained from a transverse section here represented. It is taken in the line of the



VERTICAL SECTION OF KILAUEA.

shorter diameter; a section through the longer diameter on the same scale (a third of an inch to a thousand feet) would not have room on the page; $m m'$ is the whole breadth of the crater; $o n, o' n'$, the black ledge; $p p'$ the bottom of the lower pit; $n p, n' p'$ the walls of the lower pit, 342 feet in height; $m o, m' o'$, the walls above the black ledge, 650 feet in height.

The walls of the crater ($m o$) are vertical, or nearly so, through the most of their circuit. There is a break with several fissures in the northeast corner, (fig. p. 173, the *upper* side of which is *north*,) the usual place of descent; and on the southeast side (at c) there are two or three sloping declivities, on which one of the famous sulphur banks is situated.

These bluff sides of the pit consist of naked rock in successive layers; and in the distance they look like cliffs of stratified limestone. The layers vary from a few inches to thirty feet in thickness, and are very nearly horizontal. They are much fissured and broken, and some have a distinctly columnar structure. Open spaces or caverns and ragged cavities often separate the adjacent layers, adding thus to the broken character of the surface, and at the same time giving greater distinctness to the stratification. The black ledge varies in width from one to three thousand feet. With such dimensions, it is no unimportant feature in the crater. The lower pit is surrounded by vertical walls, ($n p, n' p'$,) which have the same distinctly stratified character as those above, and are similar in other features. More numerous fissures intersect them, indicative of the unstable basis on which they rest. The general form of these lower regions is much like that of the whole crater, though narrower, as the ledge is widest on the longer sides of the pit. The whole length, as ascertained by the surveys, is about two and a quarter miles, and the breadth ave-

rages three-fourths of a mile. The southwest extremity (*a*, fig. p. 173,) forms a partly isolated basin, of an oval form, and contains the large boiling lake to which we have alluded. The rest of the bottom of the pit, at the time visited by the author, was a field of hardened lava, excepting two small boiling pools, one on the western side, and the other near the eastern.

On the descent, we travelled the greater part of the way between deep fissures, on narrow walls of rock, more or less covered with vegetation, and by a winding course, occasionally through clouds of steam or drafts of hot air issuing from some oven-hole or dark chasm, reached the black ledge. Here we came at once upon the scene of late fires, although the boiling pools, at the time, were three hundred and forty feet below. Various streams of hardened lava, with their tortuous windings, were traced over its surface, some spreading far and wide, and terminating in a rounded margin alongside of the precipitous walls of the crater, and some twisted into ropes or ropy lines, or reaching out in rounded knobs. Others, of still less extent, surrounded an oddly-shaped cone a few yards in height, which small worming streams, and smaller dribblings of lava, had raised. Just previous to the eruption of the June preceding (1840) the whole ledge was flooded with lava streams, and to that period all these fresh appearances are to be attributed.

The lavas crackled under foot at each tread, as if ready to break through : but this arose from a splintery scoriaceous crust, two to four inches thick, extremely cellular and brittle, and shining like greenish black glass. It is loosely attached to the more solid grayish black lava below, and may be peeled off in large pieces. Once accustomed to the scoria pavement, the explorer of Pele's pit tramps on, carelessly cracking the glassy crust, until, at another step, the lava actually gives way, and opens some concealed cavern. The layers are, in many places, swollen or expanded into hollow domes, and the fissured walls often yield to slight pressure. But the cavities are usually shallow, and such accidents are attended with little inconvenience excepting a bruise or wrench between the broken masses that may tumble with him. But besides these cavities, there are dark chasms that suddenly intercept his course, many of which open to a depth of several hundred feet, and send up torrents of hot air or suffocating fumes of sulphur. Near the walls of the lower pit, these chasms increase in number and extent, and in some places, acres of the black ledge are tottering, ready to fall. Long-continued rumbling sounds from the

falling walls twice broke the deep silence of the pit, while I was upon the verge of the precipice. Large portions of the ledge thus at times subside, or become engulfed in the abyss of fires below. There had been a most remarkable subsidence of this kind, not long previous, on the northwest side of the crater, (figure on page 173.) For about 500 yards, the inner edge of the ledge had sunk down, so that there was a sloping plain from the top of the ledge to the bottom of the pit, instead of the usual precipice of 340 feet. The area of this sloping plain was not less than 200,000 square yards. It is an example of the changes which are constantly in progress in these regions. A broad fissure separates the plain from the ledge from which it was broken off, and other deep rents intersect the sloping surface, proving a serious obstacle in the way to the bottom. The descent is, however, possible; and by winding among its deep fissures, exposed to frequent blasts of hot air and sulphur gases, the region of the boiling cauldrons is at last reached.

Though all is quiet in these lower depths, there is something fearful in treading over the streams of lava, hardened yet still hot, and hearing under foot the reverberating sounds of the hollow caverns. The very stillness of the scene impresses the mind with a sense of mighty powers only temporarily at rest. No "subterranean thunder" rolled through the depths of Pele; no "raging sea tossed its billows into fiery spray;" nor deep gulf threw up showers of stones and cinders. The dense white vapours rose gracefully from many parts of the black lava plain, and the pools boiled and boiled on without any unnecessary agitation. The jets playing over the boiling surface, darted to a height of ten or a dozen yards, and fell again into the pool, or upon its sides. At times the ebullition was more active, the cauldrons boiled over, and glowing streams flowed away to distant parts of the crater; and then they settled down again, and boiled as before, with the usual grum murmur. Thus simple and quiet was the action of Lua Pele. And this repose is, perhaps, more fearfully sublime than the fitful heavings of a Vesuvius.

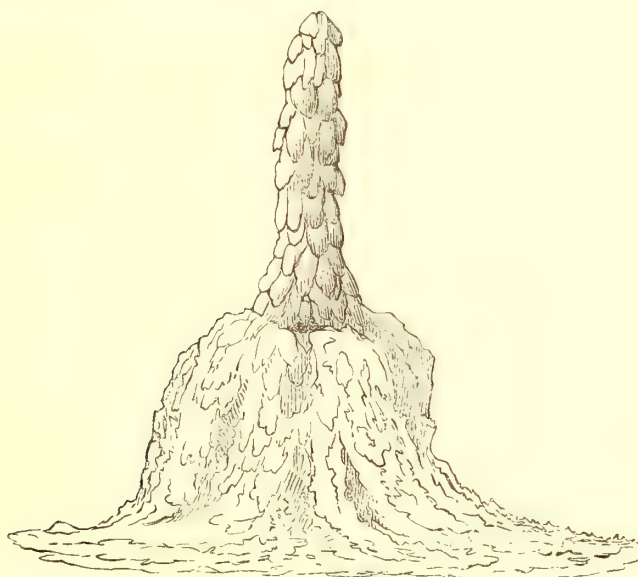
The lavas of the bottom plain resemble those of the black ledge. They have the same glassy, scoriaceous crust, covering the more compact rock beneath, though it was of more brilliant lustre, as it had not been tarnished by exposure. It had sometimes a slightly leaden hue. The hardened streams are generally cavernous, and many of them break through in walking over them. Yet there is no occasion for apprehension. The caverns are often large, and their roofs are at

times hung with black stalactites of lava. Some of these stalactites observed by the author, were as slender as a quill, and hollow, but of bent form, and were evidently a result from infiltrating waters; others were long tapering cones, or of irregular pendant shapes.

The smaller pools of boiling lava were readily approached within four or five feet. At times the large lake may be examined from alongside, though the safest place to view it is from the black ledge.

The overflowing of the pools gradually raises low cones, whose sides are usually inclined between one and ten degrees. One of these cones occupied the centre of the pit, and was about a hundred feet in height. It contained a central cavity or crater, which at the time of our visit had ceased action.

A few hundred yards from the eastern of the small pools, there stood a singular spire of lava, resembling a petrified fountain. It had a rude conical base, as here represented, and in all was about forty feet



high. It had been formed over a small vent, through which the liquid rock was tossed out in dribblets and small jets. The ejected lava falling around, gradually raised the base; the column above was then built up from successive drops, which were tossed out, and fell back on one another; being still soft, they adhered to each other, lengthening a little at the same time while cooling. This is an interesting example of a steep cone proceeding from accumulations of

lava alone, and the column is more remarkable still, as an instance of a vertical surface thus produced. Such occurrences, as was afterwards found, are not uncommon about Mount Loa. From another part of the crater I procured two specimens of the same kind on a miniature scale. One of them was not over eight inches long, and the drops of the column were but a fourth of an inch in diameter. The preceding figure nearly represents it, except that the column was much longer in proportion to the base, and the drops a little larger.

Such facts exhibit very decisively the remarkable fluidity of the lavas of Lua Pele. The small specimens last referred to consisted of the solid, stony lava, with few cellules, and not of loose scoria.*

An interval of only a few hours is sufficient to harden and cool the

* Equally remarkable structures of lava are described by the Rev. Charles S. Stewart, after his visit in 1829. There were two hollow columns tapering above nearly to a point, measuring about twenty feet in height, and not more than thirty in diameter at base. They had been formed by successive slight overflowings of lava, cooling as it rolled down into irregular flutings, ornamented with rude drops and pendants, and long tapering stalactites.—*Visit to the South Seas*, ii. 93.

Others of a similar kind are mentioned in the Narrative of the Expedition by Captain Wilkes, as occurring in an old lava stream, near the eruption of 1840. Several truncated cones, pillars, rude columns, and colossal statues of lava were met with, some twenty feet high, which were perforated at centre from top to bottom. Narrative Exp. Exp. iv. 185, and figure, p. 196.

A still more wonderful example was observed by the Rev. Mr. Coan in February 1842, as communicated by him in a letter to the author. *The large lake, at this time, was surrounded by a ridge six to fifteen feet high, raised around it by the cooling of the lavas as they boiled up.* Respecting this singular fact, Mr. Coan writes as follows: "When within four or five rods of the great lake, unaware of our near proximity to it, we saw directly before us a vast area of what we had supposed to be solid lava moving off to the right and left. We were at first a little startled, not knowing but all was about to float away beneath us, especially as the lavas for a mile back were almost insupportably hot, and gases and steam were escaping from numerous openings. On looking again, we perceived that the whole surface of the lake was from *six to fifteen feet above the level of the surrounding lava*, although, at my last visit, it was sixty to seventy feet below. Within six feet of this embankment we could see nothing of the lake, and in order to examine it we climbed the precipice some fifty feet. The explanation of this strange condition of things is this:—When the liquid contents of the lake had risen to a level with the brim, there was a constant and gradual boiling over of the viscid mass, but in quantities too small to run off far. Consequently, it solidified on the margin, and thus formed the high rim, which confined the lavas. Twice, or at two points, while we were there, the liquid flood broke through the rim, and flowed off in a broad, deep channel, which continued its flow till we left the volcano. The view was a new one, and thrilling beyond description."

surface of a stream of melted lava, so that it may be walked upon. Portions traversed while the writer was in the pit had been in fusion the night before.

At one of the pools, the formation of Pele's hair, or capillary volcanic glass, was in progress. It covered thickly the surface to leeward, and lay like mown grass, its threads being parallel, and pointing away from the pool. On watching the operation a moment it was apparent that it proceeded from the jets of liquid lava thrown up by the process of boiling. The currents of air, blowing across these jets, bore off small points, and drew out a glassy fibre, such as is produced in the common mode of working glass. The delicate fibre floated on till the heavier end brought it down, and then the wind carried over the lighter capillary extremity. Each fibre was usually ballasted with the small knob which was borne off from the lava-jet by the winds.

The large lake of lava, at the time of the descent into the crater, was boiling throughout, except on the southern side, which at this time was covered with a black crust. The banks around were fifteen or twenty feet high, and the jets appeared to rise to nearly as many yards. These jets have a constant movement to the southwest, as if the lavas were part of a stream running in that direction; but this effect is merely a result of the ebullition, the lavas thrown up by the hotter portions flowing off to the cooler side. The vapours rising from the surface are quite invisible until they have attained a certain elevation, where part become condensed from the loss of heat.

One of the most singular facts observed in the crater was met with near the place of descent, where we first reached the black ledge. High up on the walls, which were here inclined at an angle of about sixty degrees, there had been several outbreaks of lava; and now mud-black streams of hardened lava extended unbroken down the steep slope, and spread for a short distance over the ledge. They were hollow within, the fluid interior having flowed on after the crust had hardened. The vents varied in height from thirty to three or four hundred feet above the black ledge, or from four to eight hundred feet above the boiling pools of the bottom. Eruptions from points eight hundred feet above those large open vents, in the walls of the crater itself, show a singular isolation of the lines of forces in these regions. This point will come up for farther consideration.

The common lava of the crater is a heavy fine-grained rock, of a dark grayish black colour, containing usually minute particles of chry-

solite. We shall speak more particularly of its composition on a future page. It is compact, with some scattered cellules; excepting the crust already alluded to it is far from scoriaceous. The specimens usually brought from Kilauea are from this scoria, and give no idea of the ordinary rock of the daily ejections, as this scoria constitutes but a few inches out of the ten or twenty feet of which a layer may consist. Similar layers, piled upon one another, form the walls of the lower and upper pit, the rock being mostly compact, with comparatively few disseminated cellules, and seldom scoriaceous. The crust of glassy scoria disappears after every following eruption, the new overflow melting the old surface, which afterwards, on cooling, becomes rock, like the material above it: thus in the walls of the lower pit, where sections of the layers ejected during the few previous years are well exposed, we find only the compact lava, and no intervening scoria. The alternations in the walls of the lower pit show slight variations in shade of colour and in the proportion of chrysolite, which mineral is nowhere abundant. The ejected lava from different sources in the crater has, at times, been thrust out into projecting knobs, which, from rapid cooling, have a glassy exterior, and are nearly as brittle as a Prince Rupert's drop.

It is an observation, which we shall show hereafter to be of much interest, that some of the lavas within the crater are not covered with a scoriaceous crust. On the contrary, while the overflowings of the pools or lakes are of this character, the eruptions through other openings have generally a solid surface, and are either solid stone throughout, or have a *compact* glassy exterior, half an inch thick.

The walls of the upper pit we had no chance particularly to examine in the single day's ramble to which we were restricted. The inadequacy of this amount of time for anything like thorough investigation into many points that demanded attention, is obvious, and especially if it be considered that, after making a descent into the crater as far as the black ledge, there was still a walk of three miles to one of the boiling pools at the bottom; and from the same place to the sulphur banks on the southeast wall of the crater, required another walk of six miles.

In the preceding descriptions we have made only a bare allusion to the sulphur banks. Instead of being conspicuous objects about the crater, they might be passed by, unless under the direction of a guide. On the southeast side of the crater, the wall, which has

been described as a sloping declivity of earth, consists, more correctly, of two or three connected slopes. They are intersected by fissures from which steam escapes, and the whole surface of two of the slopes, to a considerable distance around, is constantly steaming. The earth has a grayish-yellow aspect, yet shows little sulphur on the exterior surface : but by turning over the crust, which is a little hardened, the under surface exposes a brilliant druse of sulphur crystals. This crust is formed again, whenever removed, and is due to the fact that the temperature at which the rising sulphur vapour condenses, is situated a little below the surface. In obtaining specimens, the feet sink to a very uncomfortable depth, and in some places the heat is intolerable. There are also fine crystallizations in the fumaroles, though they are generally too brittle to bear handling.

The other sulphur bank is outside of the crater, half a mile back from its northeast edge, where there are fissures and a depression in the plain.

The earth of the above-mentioned declivities had resulted from the action of the steam and sulphur gases on the lava rocks. Gypsum in thick fibrous plates, alum (sulphate of alumina), blue sulphate of copper, and sulphate of ammonia, were also obtained at the same banks. Besides, thin siliceous incrustations covered in some places the surface of the earth and masses of half-altered lava.

We continue this account of Kilauea with a brief statement of the observations made subsequently by officers of the *Vincennes*,* in the months of December and January. The action was in the main the same as has been described, and the general features had not altered. The descent from the ledge to the bottom was made by the same inclined plane on the northwest side.

There was but one of the smaller pools, the western, in action. On the 16th of December, Dr. Pickering describes it in his *Journal* as heaving up rounded masses of liquid lava, at nearly regular intervals, to a height of six or eight feet, while smaller jets were thrown much higher. At the same time, the large lake was boiling, and muttering in its usual style ; the brilliant surface was compared by him to "a fitful network of lightning on a dark ground." On the 31st of December the small pool was entirely inactive, and only a

* For full particulars reference may be made to the *Narrative*, by Captain Wilkes, vol. iv., chapters iv. and v.

single point of light was seen. The lake at the same time was less active than on the 16th, and the bank stood higher above the surface of the contained lavas, as if they had subsided.

On the 16th of January,* the western pool or crater still appeared almost inactive, giving out only vapours, and an occasional jet of lava at centre; the black cooled surface was depressed several feet below the edge of the little crater. Dr. Judd, then in the lower pit, deeming the quiet favourable for dipping up some of the liquid with an iron ladle, descended for the purpose to the narrow rim bordering the pool. While preparing to carry out his plans, his attention was excited by a sudden sinking of the surface; the next instant it began to rise, and then followed an explosion, throwing the lavas higher than his head. He had scarcely escaped from his dangerous situation, the moment after, by the aid of a native, before the lavas boiled up, covered the place where he stood, and flowing out over the northern side, extended in a stream a mile wide to a distance of more than a mile and a half. The large lake had been visited by Dr. Judd just before this adventure. He found that the approach to it was up a rather rapid slope produced by the overflowing lavas: but he was unable to go near enough to make any observations. It overflowed shortly after he left it. The following morning, as Captain Wilkes states, the lavas of the large lake had sunk so as to be out of sight from the north edge of the crater, where they were encamped; and the amount of subsidence was ascertained to be one hundred feet. The discharge of the large lake on the night of the 17th, is estimated, by Captain Wilkes, at fifteen million cubic feet; and that from the smaller pool, (which he designated, in commemoration of the incident related, Judd's Lake,) is supposed to have been equal to two hundred millions of cubic feet.†

On the 26th of January, Dr. Pickering found the large lake much below its banks, and remarks that a jet was rarely visible from the encampment. Yet the surface was in active ebullition. "About 9 P. M. the whole southern bank fell in at once, producing a great light, and a surging to and fro for some minutes, the surface of the fluid sometimes rising almost even with the top of the bank. Dr. Pickering approached the brink of the lake, but found it impossible to look at the dazzling surface for more than an instant, on account of the heat. He speaks of the murmuring noise of the boiling cauldron as hardly

* Ibid. iv. p. 173, 174.

† Narrative, iv. 178.

sufficient to drown the ordinary tone of conversation. While the lavas had so far subsided in the great cauldron, Judd's Lake was overflowing its banks. He observed, that during the month preceding, the whole bottom of the crater had been overflowed, rendering the surface more even and the travelling easier, and it appeared to him that the lower pit, in this period, had been raised at least fifty feet. The sides of the large lake were now the highest part of the bottom.

We follow these details by an account of the eruption which took place in June, 1840, six months before the visit of the squadron, prefacing it by a brief notice of other eruptions of previous dates. The facts will illustrate still farther the peculiar mode of action in Kilauea.

Eruptions of Kilauea.—The first eruption of this crater of which tradition gives any definite knowledge, occurred about the year 1789, during the wars and conquests of Kamehameha. It took place between Kilauea and the sea in a southeasterly direction. It is said to have been accompanied by violent earthquakes and rendings of the earth; and an eruption of cinders and stones from the open fissures. It was so violent and extensive that the heavens were completely darkened; and one hundred lives are supposed to have been lost. There are now over a large area near Kilauea, a few miles distant to the south and southeast, great quantities of a light pumice-like scoria, with stones and sand, which are believed to have been thrown out at this time.*

* The following account of this eruption is from a "History of the Sandwich Islands," by Rev. I. Dibble, published at Lahainaluna (island of Maui) in 1843. It was taken by the author from the lips of those who were part of the company, and present in the scene. The army of Keoua, a Hawaiian chief, being pursued by Kamehameha, were at the time near Kilauea. For two preceding nights, there had been eruptions, with ejections of stones and cinders. "The army of Keoua set out on their way in three different companies. The company in advance had not proceeded far before the ground began to shake and rock beneath their feet, and it became quite impossible to stand. Soon a dense cloud of darkness was seen to rise out of the crater, and, almost at the same instant, the thunder began to roar in the heavens, and the lightning to flash. It continued to ascend and spread around until the whole region was enveloped, and the light of day was entirely excluded. The darkness was the more terrific, being made visible by an awful glare from streams of red and blue light, variously combined through the action of the fires of the pit and the flashes of lightning above. Soon followed an immense volume of sand and cinders, which were thrown to a great height, and came down in a destructive shower for many miles around. A few of the forward company were burned to death by the sand, and all of them experienced a suffocating sensation. The rear company,

The famous outbreak of lavas, in 1823, and the features of the crater after it, are described by Mr. Ellis in his *Polynesian Researches*.* A large tract of country in Kau, the southern district of Hawaii, was flooded, and the stream, when it reached the sea, as I am informed by Rev. Mr. Coan, was five to eight miles wide. The earth is said to have been rent in several places, and the lavas were ejected through the fissures, commencing their course above ground some miles south of Kilauea. There was no visible communication with the lavas of this crater at the time; but the fact of their subsiding some hundred feet simultaneously with the eruption is satisfactory evidence of a connexion. The crater after the eruption, as described by Mr. Ellis,† had the same general features as when visited by the Expedition. The black ledge continued completely around the crater, and was "three or four hundred feet" above the bottom. It was, however, in a more active state: for the southwest and northern parts are represented as vast floods of lava, and there were fifty-one small cones with craters, twenty-two of which gave out vapours, and some ejected lavas. Ellis remarks that the crater appeared as if, a short time before, the lavas had been as high as the black ledge.

In June, 1832, an eruption took place both from Kilauea and the summit crater of Mount Loa. The only ejection, at this time, of the

which was nearest the volcano at the time, suffered little injury, and after the earthquake and shower of sand had passed over, hastened on, to greet their comrades ahead on their escape from so imminent peril. But what was their surprise and consternation, to find the centre company a collection of corpses. Some were lying down, and others were sitting upright, clasping with dying grasp their wives and children, and joining noses (the mode of expressing affection), as in the act of taking leave. So much like life they looked, that they at first supposed them merely at rest, and it was not until they had come up to them and handled them, that they could detect their mistake. Mr. Dibble adds, "A blast of sulphurous gas, a shower of heated embers, or a volume of heated steam, would sufficiently account for this sudden death. Some of the narrators who saw the corpses affirm, that though in no place deeply burnt, yet they were thoroughly scorched."

* *Polynesian Researches*, vol. iv., p. 211.

† Mr. Ellis, and many that have followed him in describing Kilauea, make much use of the word "flames," as though flames were actually seen. It is an excusable mistake, where the scenes are so startling and so far beyond description. An account appeared in a public print at Honolulu, about the time of the arrival of the squadron, in which "flames" are called in to give vividness to the description. It is needless to say that none were seen there by the writer, although the condition was the same as for the month previous.

lavas of Kilauea to the surface, of which we have definite account, occurred in the east wall of the crater. A deep fissure was opened in the wall, from which streams flowed out, part back into Kilauea down the steep slope, and part across into the "Old Crater," which at the time was overgrown with wood. It is important to trace out, as far as we are able, the changes which preceded it.

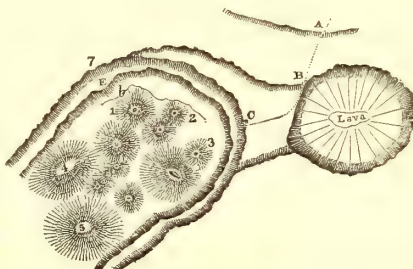
a. The first published account of the crater subsequent to Ellis's, is that of the Rev. C. S. Stewart, who visited it in the summer of 1825.* He states that it was nearly in the condition represented by Ellis in 1823. The bottom was several hundred feet below the level of the black ledge. Fifty-six conical craters were counted, and the action was violent and noisy. A plan of the crater at this time, by Lieutenant Malden, is given by Byron. The black ledge is represented as very much narrower than at present, so that the lower pit occupied nearly the whole width of the crater; the height of the ledge is stated at four hundred feet. The plan represents numerous cones over the bottom, and the two largest occupy together the whole transverse diameter of the bottom, which would give for each a diameter of three thousand feet or more at base.†

b. In December of the same year, Rev. A. Bishop observed that the crater had filled up much since the visit he made with Mr. Ellis, and he estimated the amount of change at four hundred feet. There were a great number of cones "fifty to one hundred feet high," besides lakes boiling with great agitation, "every now and then sending forth a gust of vapour and smoke, with great noise." He adds, "the natives remarked that after rising a little higher the lava will dis-

* Journal of a Voyage to the Pacific Ocean, and residence at the Sandwich Islands, in the years 1822-1825, by C. S. Stewart; 12mo. 1828. New York.—p. 355.

† A reduced copy of Lieutenant Malden's plan is annexed, as it will give increased interest to the facts observed by the Expedition.

A, is a precipice of eighty feet; B, another of one hundred and fifty feet; C, Byron's encampment; E, the point on the black ledge where they descended to the bottom; 1, the crater in action visited by Lord Byron; 2, a sulphur cone; 3, crater that broke out at the time of the visit, 29th of June; 4, crater brilliantly in action; 5, the largest crater; 6, a deep fissure; 7, deepest and most precipitous part of crater. The whole crater is not represented.



charge itself, as formerly, towards the sea *through some aperture under ground.*"*

c. In October of 1829, Rev. C. S. Stewart made a second visit to the crater, and found, as he states, that the lower pit, instead of being four or five hundred feet deep, as when he before saw it, was but two hundred feet. He remarked that it had filled up at least two hundred feet. It was more quiet than in 1825, but there were still several boiling lakes of lava, and some cones in great activity.†

d. In September of 1832, when the Rev. J. Goodrich visited Kilauea, the eruption had taken place.‡ He says that everything had changed. The lavas, which previously had increased so as to fill up to the black ledge, and fifty feet above, about nine hundred [four hundred?] feet in all, had sunk down again nearly to the same depth, leaving, as usual, a boiling cauldron at the south end. The earthquake of the *January preceding* had rent in twain the walls of the crater on the east side, from top to bottom, producing seams from a few inches to several yards in width, from which the region between the two craters was deluged with lava. About half way up the precipice there was a vent a quarter of a mile in length, from which immense quantities of lava boiled out directly underneath the hut formerly occupied by the party of Lord Byron. The position of Byron's hut is seen at C, on the figure at the foot of the preceding page, and near *n*, on the figure on page 173.

From these accounts, it is probable that in addition to the ejections from the east wall, which are insufficient to account for the subsidence in the lower pit, there must also have been a subterranean outlet beneath the sea, as the native who was with Mr. Bishop had predicted. This elevation of the lava a thousand feet above the lower pit, and discharge from the very wall of the crater, is worthy of special note.

The next eruption to that of 1832, was the one, already referred to, that commenced on the 30th of May, 1840, the lavas of which, where they reached the sea, were in some places still hot when visited by the author in the November following.

The only published accounts of the crater subsequent to that just mentioned by Mr. Goodrich, and previous to this eruption, are those

* Missionary Herald, xxiii. 53.

† Visit to the South Seas, 2 vols. 12mo. New York, 1831.—ii. 78.

‡ American Journal of Science, xxv. 199.

of Mr. Douglas,* Captain E. G. Kelley, (from statements by Captains Chase and Parker,)[†] Count Strzelecki,[‡] and Captain John Shepherd.[§]

a. Mr. Douglas was at Kilauea in January, 1834. The pit by his measurements was one thousand feet deep, and the black ledge and lower pit appear to have been in the same condition as when seen by Mr. Bishop. There was a lake of boiling lava in the north end, three hundred and nineteen yards in diameter, besides the large one in the south end. The apparent flow of lavas to the southward was estimated to have a velocity of three and one-fourth miles per hour.

b. Captains Chase and Parker visited the crater in 1838, four years after Mr. Douglas. At that time, as the sketch made on the spot indicates, the lavas had so increased that the lower pit was almost obliterated, the bottom having risen nearly to a level with the black ledge. This will be understood from the figure on page 174: all the bottom pit between *p n* and *p' n'* had become filled up, by the successive overflows, to within forty feet of the top, and over the four square miles of area, the fires were in great activity. There were six boiling lakes of lava, besides twenty-six cones from twenty to sixty feet high, and eight of the latter were throwing out cinders and red-hot lava. Standing by the side of one of the lakes, they looked down more than three hundred feet upon its agitated surface: "After a few minutes, the violent struggle ceased, and the whole surface of the lake was changed to a black mass of scoria; but the pause was only to renew its exertions; for, while they were gazing at the change, suddenly the entire crust which had been formed commenced cracking, and the burning lava soon rolled across the lake, heaving the coating on its surface like cakes of ice upon the ocean surge. Not far from the centre of the lake was an island which the lava was never seen to overflow." These interesting facts illustrate several points of special importance in volcanoes, viz. (1) the rapidity with which lava cools; (2) the frequent change of temperature that takes place even in the boiling lakes, arising from oscillations in the fountain below; (3) the formation of clinkers, well compared to the breaking up of ice. From the account of these observers, it appears that the whole bottom of the crater was not in

* Jour. of the Roy. Geog. Soc. vol. iv.

[†] American Journal of Science, xl. 117; with a drawing of the crater, which shows that the obliteration of the lower pit was nearly complete.

[‡] Hawaiian Spectator, i. 436; also, in his New South Wales and Van Diemen's Land, 8vo., London, 1845, p. 106.

[§] Athenæum, Nov. 14, 1840; Roy. Geog. Soc. of London, 1840.

fusion. On the contrary, the greater part was black lava, over which they travelled to the brink of some of the pools; yet at times floods of lava covered a large portion of the whole area. The pools were in violent agitation, and "hissing, rumbling, agonizing sounds, came from the depths of the dread abyss."

c. When seen by Count Strzelecki in the same year, it was still in the condition above described. There were six lakes, one, as he states, of 300,000 square yards area, and five of about 5,700 square yards each. The great lake was in violent action.

d. Captain Shepherd was at the crater September 16, 1839. There were "numerous small cones, twenty to thirty feet high," "lakes of molten matter in violent agitation," besides a "great lake," one mile long and half a mile broad. The party, (notwithstanding the activity, be it observed,) *descended into the crater*, and visited several of the cones and small lakes on their way to the great lake. This lake was in "violent ebullition," underwent constant changes of brightness, and in some places flowed on, "leaving ridges of scoria on the northern shore."

e. We learn from the natives, that, for a week previous to the outbreak, the whole interior was a fearful scene of fiery deluges and ejections. There was no black ledge; for the lavas, by their overflowings since 1832, had not only filled up the central pit, but accumulated over the ledge, and all was one vast theatre of intense action. The mountain was thus charged. The pressure on the sides below from the lavas and confined vapours had become immense. As a natural consequence, fissures opened and the lavas were drawn off; the centre of the great pit consequently sunk down three hundred and fifty or four hundred feet, which was its condition when visited by us.

There was no great earthquake, no shaking of Mount Loa. At Hilo not the faintest rumbling was heard or felt; and only slight quiverings to the south. It was a simple tapping of the great cauldron, Kilauea; and after it, the crater became comparatively inactive. Its black hardened surface, and the one or two boiling pools which remained over the vast area, exhibited the subdued quiet of exhaustion.

The first appearance of the lavas at the surface occurred in a small crater called *Arare*, about six miles from Kilauea, (A, map on p. 169,) as was ascertained soon after by the Rev. T. Coan.* The light was

* Missionary Herald, 1841, volume xxxviii. p. 283. The author was over the portion of the eruption towards the sea in November. Subsequently it was examined by Captain Wilkes, Mr. J. Drayton, and Dr. C. Pickering; and by means of their investigations a map of the region was made out.

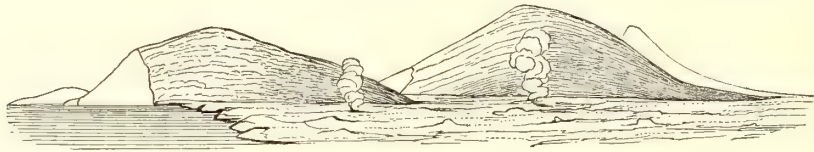
seen at a distance; but, there were no inhabitants in that vicinity, and it was set down for a jungle on fire. The next day another outbreak was distinguished farther towards the coast; and general alarm prevailed among the natives, now aware of the catastrophe in progress. Other openings followed, and by Monday, the 1st of June, the large flow had begun, which formed a continuous stream to the sea, where it reached on the 3d of June, destroying the small village of Nanawale. This flood issued from several fissures along its whole course, instead of being an overflow of lavas from a single opening; it started from an elevation of 1244 feet, as determined by Captain Wilkes, at a point twenty-seven miles distant from Kilauea, twenty-two miles from the first outbreak, and twelve from the shores. The interval between the first appearance of the lavas and this flood presents a few patches of ejections, and some steam fissures.

The extent of these patches was not accurately ascertained. Dr. Pickering mentions one small one, just before the last outbreak; and another, much larger, (*n*) covering probably three or four square miles, was observed by him a short distance above. A still larger patch, (*m*) according to a native report, exists about half way from the "Big Crater" (C) and the last outbreak; while still another, on the same authority, was seen just north of the "Big Crater." It is very remarkable, as stated by Dr. Pickering, that the line of fracture and lava patches should have cut through a high hill just north of the "Deep Crater," (B) and thus avoided this large pit, where it might have been supposed there would have been the least resistance to fracture. The natives state that the lavas rose to a height of three hundred feet in the pit-crater Arare, the first point of outbreak, and then sunk again when the next outbreak took place; and the appearance of scoria within the crater satisfied Dr. Pickering that the lavas had risen at the time to the height mentioned.

The scene of the flowing lavas, as affirmed by those who observed it, beggars description. As we learn from an eye-witness, the lavas rolled on, sometimes sluggishly, and sometimes violently, receiving at times fresh force from new accessions to the fiery stream, and then almost ceasing its motion. It swept away forests in its course, at times parting and enclosing islets of earth and shrubbery, and at other times undermining and bearing along masses of rock and vegetation on its surface. Finally it plunged into the sea with loud detonations. The burning lava, on meeting the waters, as Mr. Coan states, was shivered, like melted glass, into millions of particles, which were

thrown up in clouds that darkened the sky, and fell like a storm of hail over the surrounding country. "Vast columns of steam and vapours rolled off before the wind, whirling in ceaseless agitation, and the reflected glare of the lavas formed a fiery firmament over head. For three weeks this terrific river disgorged itself into the sea with little abatement. Night was converted into day on all eastern Hawaii. The light rose and spread like the morning upon the mountains, and its glare was seen on the opposite side of the island. It was distinctly visible for more than one hundred miles at sea; and at the distance of forty miles fine print could be read at midnight."

At three spots on the coast, probably over three opened fissures whence lavas issued, the sands continued to be thrown up, until as many rounded or nearly conical elevations were formed, the largest of which



SAND-HILLS, NANAWALE.

was found to be two hundred and fifty feet in height, and the smallest about one hundred and fifty feet. The coast is said to have been extended by the eruption nearly a quarter of a mile beyond its former limits.

The stream, as it appeared in November, consisted in its different portions of all the kinds of lava tracts we have mentioned. In some portions, especially the upper, there were fields of the smoother variety, (the pahoehoi,) with the usual ropings and twistings in the surface; and there were some miniature cones, a few yards in height, out of which the lavas spouted for a while after the rest had become quiet. Large tracts were covered with sand; and walking over them, the feet often broke through into steaming chambers, suggesting caution to the traveller. Other large portions consisted of clinkers, a fact which might have been inferred from the description given of the varying rate of the moving lavas. In some portions they were in huge angular blocks; in others in slabs laid with much regularity against one another. There were numerous caverns and fissures still sending up clouds of steam; and in many the rocks were yet glowing within a few feet of the surface. A piece of paper was instantly ignited. Small sulphur-banks, with deposits of alum and other salts, were met with in several places.

The islets of forest trees in the midst of the stream of lava were from one to fifty acres in extent, and the trees still stood and were sometimes living. Captain Wilkes describes a copse of bamboo which the lava had divided and surrounded; yet many of the stems were alive, and a part of the foliage remained uninjured.* Near the lower part of the flood, the forests were destroyed for a breadth of half a mile either side, and were loaded with the volcanic sand; but in the upper part Dr. Pickering found the line of dead trees only twenty feet wide. The lavas sometimes flowed around stumps of trees, and as the tree was gradually consumed, it left a deep cylindrical hole, sometimes two feet in diameter, either empty or filled with charcoal.† Towards the margin of the stream these stump-holes were innumerable, and in many instances the fallen top lay near by, dead but not burnt. Dr. Pickering also states that some epiphytic plants upon these fallen trees had begun again to sprout. The rapidity with which lava cools is still more remarkably shown in the fact that it was found sometimes hanging in stalactites from the branches of trees; and although so fluid when thrown off from the stream as to clasp the branch, the heat had barely scorched the bark.

The waters of the sea were so much heated that the shores for twenty miles were strewn with dead fish.

From the period, thirty-six hours, which the lavas required to reach the sea, an average velocity of four hundred feet an hour is readily deduced, as stated by Captain Wilkes. Yet, as the lavas issued from various fissures along the course,‡ the result cannot be correctly compared to an *overflow* of fluid: it is rather the rate of progress of the eruption than of the motion of a flowing liquid.

The thickness of the stream of lava here described was estimated by Dr. Pickering as averaging ten or twelve feet. In some places it was not over six feet. The whole area, judging from the surveys, covers about fifteen square statute miles; and reducing to feet and multiplying by the depth, 12 feet, gives for the amount of ejected lava 5,018,000,000 cubic feet; to which, if we add for the

* Narrative Exp. Exp., iv. 184.

† Similar facts to those here stated were observed by M. Bory de St. Vincent at the Isle of Bourbon.—*Voyage aux Isles d'Afrique*, 3 vols., 4to, Paris, 1804.

‡ On this point we cite the following passage from the Narrative by Captain Wilkes, (iv. 184):—"There are many fissures along the whole line, as will be perceived by the dark places on the map. I feel confident that from each of these an ejection had taken place, and that the lava had in some cases flowed in a contrary direction of the stream."

previous ejections of the same eruption three more square miles, it gives 6,023,000,000 of cubic feet for the whole amount of lavas which reached the surface.*

We have a still more accurate means of estimating the amount of lavas which passed from Kilauea, in the actual cubic contents of the emptied pit. The area of the lower pit, as determined by the surveys of the Expedition, is equal to 38,500,000 square feet. Multiplying this by 400 feet, the depth of the pit after the eruption,† we have 15,400,000,000 cubic feet for the solid contents of the space occupied by lavas before the eruption, and therefore the actual amount of the material which flowed from Kilauea. This is two and a half times the amount obtained from the estimated extent of the eruptions. The difference may be accounted for partly on the ground that fissures were filled as well as surfaces overflowed, and also that there may have been eruptions beneath the sea not estimated. This amount is equivalent to a triangular ridge eight hundred feet high, two miles long, and over a mile wide at base.

The lava of the eruption is remarkable for the large proportion of chrysolite, amounting in some parts to nearly one-half, and occurring in coarse grains often a fourth of an inch thick. It is consequently very brittle, slabs being easily shattered to pieces by a tap of the hammer. The sands of the seashore produced by the eruption consist largely of this mineral mixed with black grains of the comminuted lavas. In the abundance of chrysolite the lava is very unlike that formed in the crater either previous or subsequent to the eruption.

The sand-hills are examples of elevations thrown up suddenly over fissures of eruption. They consist of tufa of a rusty yellow colour, and are distinctly and finely laminated. The sea is already encroaching on them, and has exposed the regular stratification of the interior, showing a steep inclination of the layers outward. Not a trace of tilting took place in the rocks beneath. They are simple cones of eruption, formed of ejected cinders. The sands are said to have been thrown out from the centre of each hill, while in progress; yet there is now no cavity at top. It appears that the action of the molten lavas

* Allowing an average depth of but ten feet, the calculation would give for the whole amount 5,000,000,000 cubic feet.

† As the measurements of the Expedition were made eight months after the eruption, we have allowed somewhat for the increase during that time, and also for cavities emptied beneath the ledge.

as they met the sea must have been like the effect from a furnace of melted glass plunged beneath water. There was a violent explosion and eruption of fragments and steam, which fell around the centre of action; and owing to the water which ascended and descended with them, the structure became laminated like the alluvium of a river. Thus three "Monte Nuovos" instead of one were thrown up at a single eruption. The yellow colour of the tufa is owing to the action of the steam and water on the ferruginous cinders, reducing some part of the iron to a hydrate.

Since leaving the Sandwich Islands, I learn from the Rev. Mr. Coan that the crater has again been gradually filling up. In November, 1841, there was little action except in the great lake. In February, 1842, the same condition of things continued, excepting an increased state of activity. In July, 1844, Mr. Coan was near when the large lake overflowed its margin on every side, spreading out into a vast sea of fire, filling the whole southern part of the crater as far as the black ledge on either side, and obliterating the outlines of the cauldron. Two deep fissures opened, one on either side under the black ledge, and nearly encircled the whole southern area. The precipitous sides of one were two hundred feet in depth. These fissures soon became filled with the flood that was pouring over from the lake; and in one place "it fell in a cascade of fifty feet, producing a scene of terrific sublimity." In a letter dated June 25, 1846, Mr. Coan states that "the great lake is intensely active most of the time. The repeated overflowings have elevated the central parts of the crater 400 or 500 feet since 1840, so that some points are now more elevated than the black ledge." In a letter by the Rev. Mr. Lyman, written the next month to a friend, the crater is described as having the whole interior filled, and some parts of the centre to stand 100 to 150 feet above the black ledge. The large lake was still the centre of greatest activity.

It appears then at the last-mentioned date to have been nearly in the condition described by Captain Kelly, from the statements of Captains Chase and Parker, in 1839, previous to the eruption of 1840; and we may soon expect to hear of another eruption.

General conclusions.—We close our remarks on Kilauea for the present by a survey of its general characteristics and its peculiar mode of action with special reference to the geological bearing of the facts.

I. *The absence of cinder cones and fragmentary accumulations at Kilauea.*—It is almost universally the case that the centre of action in

a volcano is surrounded by an elevation composed of ejected fragments of scoria thrown from the vent. Such cones are forming constantly at Vesuvius, one being no sooner destroyed by any great eruption before another commences and enlarges till often several hundred feet in height. But at Kilauea there is no trace of a cinder cone, notwithstanding the violence of the action. The great area that forms the bottom is a clean solid floor of hardened lava. The peculiarity is not of difficult explanation. To produce cinders, fragments or masses of lava must be thrown up by ejections high enough to cool before they fall. At Vesuvius, according to Sir James Hamilton, they rise at times to a height of 10,000 feet, and a thousand feet is a common elevation during the more quiet action; the ejections take place usually every few minutes, and not continuously. At the last eruption of Teneriffe, in 1798, according to Mr. Colgan, the lavas were projected to a height of 3000 feet. Compare this with the action in the pools of Kilauea, where sixty feet is the usual height of the jets when in the greatest violence, and where, consequently, the lavas, if they fall outside of the pool, melt together, as they are still fluid, and form a solid lava cone instead of one of cinders.

But why this difference in the height of these ejections? It may be attributed principally to the greater mobility of the lavas of Kilauea. It is well known that the more free a fluid in its motions, the more freely and with the less agitation vapours or gases escape through it. In the more viscid liquid these rising gases become collected into large bubbles before sufficient force is gained to break way through,* and then the bubble bursts with a force approximately proportionate to its size. The rapidity of their formation will influence somewhat their violence. Increase of force is derived also from a narrow vent, which, by the adhesion of its sides and the liquid, retards the bursting till the bubble has attained a larger size than could form in an open pool;

* The mode of operation is well described by G. Poulett Scrope, Esq. Speaking of Stromboli, he says: "The actual aperture of this volcano, at the bottom of its semi-circular crater, is completely commanded by a neighbouring point of rock, of rather perilous access, from whence the surface of a body of melted lava, at a brilliant white heat, may be seen alternately rising and falling within the chasm which forms the event of the volcano. At its maximum of elevation one or more immense bubbles seem to form on the surface of the lava, and rapidly swelling, explode with a loud detonation. This explosion drives upwards a shower of liquid lava, that cooling rapidly in the air, falls in the form of scoria." This action in constant repetition is described as the permanent characteristic of its eruptions.—*Considerations on Volcanoes*, p. 17.

and besides, a confined space or throat above gives far greater projectile power to the imprisoned vapours, causing, as a necessary consequence, loud reports and often a trembling of the cone at each explosion. In this manner the fragments of lava at Vesuvius, Stromboli, and elsewhere, are thrown to so surprising a height, and the cinder summits of the volcanic cones are formed. The Hawaiian volcano seems a tame exhibition compared with these vents, until we consider that its quiet is a consequence of its more vivid action. That the lavas are extremely liquid is obvious from many facts stated. The size of the jets is a direct measure of its fluidity:—the smallness of the drops tossed up; the slender cones and cylinders formed by accumulation; the quiet murmuring sound, “hardly drowning ordinary conversation,” even close alongside of an active lake of lavas, $34\frac{1}{2}$ acres in area; and the resemblance of the whole process to simple ebullition,—all betoken extraordinary liquidity in the molten rock. And even in its most violent moods there is but a more active condition of the same process. We are struck with the expressions Captain Kelly uses in describing the sounds, at a time when there was remarkable violence:—“Hissing, rumbling, agonizing sounds;” and again, on another day in the pit, “large volumes of steam, hissing and cracking as it escaped.”* Without attributing perfect accuracy to the account of a scene so terrific as almost to force the mind, not especially guarded, to exaggeration in describing it, we learn from the statements at least that “deafening thunders” are rarely sounded through Pele’s realms. Instead of the viscosity which compels the vapours to accumulate before they can force their way through, the little bubbles are rising freely and bursting over the whole surface. There are pools of small size—*narrow* vents—yet the action in them is the same, except occasionally, when the lavas are stiffened and rendered more viscid by partial cooling, bubbles of larger size rise and explode with some noise. This peculiar character of Kilauea is one of great geological importance, and will be farther dwelt upon in our final conclusions on volcanic agencies.

II. *The quiet mode of eruption.*—In the several cases of eruption of which we have any definite account, the process has been the same in its progress and results as detailed on the preceding pages. The boiling pools of the lower pit have gradually filled this part of the crater by their overflowings, each stream cooling, and then, in a few hours or days, followed by another and another overflow in different parts of

* American Journal of Science, xl. 119, 121.

the vast area, till the rising bottom plain became as high as the black ledge; still the pools boiled on, and, as always happens, with increased activity, owing to the augmented pressure and the greater height of the column of lavas through which the steam and gases make their way in order to escape; the black ledge is finally flooded, and the accumulation reaches the maximum which the sides of the mountain can bear. The pressure, aided by internal forces from vapours, which had increased with the increased activity and area of action, consequently breaks a way out for the molten rock. In some cases, on the side of the island where the escape takes place, the first indication of the eruption is the approach of the flowing lavas. We would not imply that the land is proof against earthquakes, for slight shocks not unfrequently happen, and they have been of considerable force during an eruption. But earthquakes are no necessary attendant on an outbreak of Kilauea. It is a simple bursting or rupture of the mountain from pressure, and the disruptive force of vapours, in consequence of which the mountain, thus tapped, discharges itself.

The eruption of 1840, must have been small compared with that of 1823, when the stream which entered the sea was "five to eight miles wide." The plan of the crater after the eruption, made by Lieutenant Malden (page 185), gives an area for the lower pit of full 65,000,000 of square feet, nearly double the extent it had when surveyed by the Expedition; and allowing four hundred feet for the depth, as determined at the time by Lieutenant Malden, the amount of the lavas of the eruption would be 27,000,000,000 of cubic feet.

III. *Nature of the outbreak.*—The lavas, it appears, found exit by a series of rents through the sides of the mountain. It was not a single opening and an outflow, nor a single continuous fissure; but a series of fissures at intervals, through which the lavas rose to the surface. The first fissures were small, and but little lava escaped, and from some, only steam; through the last twelve miles there were several rents, two or three in some places running nearly parallel; and the tufa hills mark the position of three where they reached the sea.

The beds of sand over the stream of lava, and the sandhills of the seashore, show us that tufas, and the lavas they cover, may be, in some instances, of simultaneous formation; and also that it is possible that tufa beds may intervene between different layers of lava, and all belong to the same period of eruption.

In some descriptions of the eruption of 1840, it has been implied that the lavas, after reaching the surface, at times disappeared beneath, then broke out again, and so flowed onward to the sea. The

mistake is, perhaps, a natural inference from a successive appearance of lavas from a subterranean source. The ejected lavas in fact flowed but a comparatively short distance from the point where they were poured out, and ceased flowing as soon as the supply ceased; and the outbreak beyond was not a second outbreak of a former superficial stream, but another branch from the main lava channel below. There was an internal rupture of the mountain which reached the surface at successive points, and showed its greatest effects towards the base of the mountain.

IV. *Effect of eruptions on Kilauea.*—The settling of the bottom of the great pit, or of its middle portions, four or five hundred feet, is the immediate effect of an eruption. The walls of the lower pit exhibit a section of the layers of lava which had accumulated during the previous period; and we are struck at once with the compactness of the rock and the absence of scoria.

On the country immediately around Kilauea, the influence of these eruptions is manifest in extensive subsidences. On the *north-northeast*, there is a terrace, (*e*, page 173,) which extends nearly a mile distant from the pit, and stretches off to the eastward; it includes within its limits the northeast sulphur bank. This terrace to the west is, in some parts, sixty feet in height. The branch from it to the east, which is descended on approaching Kilauea by the usual route from Hilo, is two or three hundred feet in height. Deep fissures occur in the *northeast* corner of the crater (*m*), at the place of descent, some of which are of dark unfathomed depths; and from them steam is constantly rising and condensing in pools of pure water. They are not represented in the plan by Lieutenant Malden, (page 185,) and were formed, it is supposed, at the eruption of 1832. On the *east*, between Kilauea and the "Old Crater" (*r*), there is a plain (at *p*) bordered by walls one hundred and fifty feet high, indicating a subsidence to this extent over this isthmus. Around the southeast, south and west sides there are many fissures and some extensive terraces, but of what exact amount was not ascertained. Dr. Pickering passed the terrace on the east, near the second pit crater, or about a mile and a half from Kilauea, and at that place it was one hundred feet in height. Thus on nearly every side, the region about Kilauea has sunk, from the undermining processes at work, and the walls are in many places intersected by fissures. The greatest amount of action of this kind occurs in the line of the longer diameter of the crater, running nearly northeast and southwest. The whole

area influenced by these changes is about twice the extent of Kilauea itself, or nearly eight square miles.

V. *Frequency of eruptions.*—The last three eruptions of Kilauea have taken place in a period of nineteen years, or with intervals of eight or nine years. Between the years 1789 and 1823, there may have been a season of comparative quiet, as we learn from the natives of no great eruption. This evidence, however, is by no means decisive. They say, in general terms, that eruptions have taken place during all their kings, and assert that the crater has been in action from time immemorial. It is quite possible that in the above-mentioned interval, there were submarine eruptions, if not subaërial; and very probably, the latter also may have taken place. The statement of the native to Mr. Bishop that the lavas, after reaching a certain height, would flow out as *they had formerly done under the sea*, is evidence that they were aware of this mode of emptying Kilauea of its lavas.

VI. *Isolation of forces.*—We simply allude to the fact here, that eruptions take place from the walls of Kilauea, while the boiling pools are open many hundred feet below, and that these pools rise and fall independently, intending to recur to the subject in our general remarks on Mount Loa.

VII. *Rocks and minerals of Kilauea.*—The rocks of the walls of Kilauea, are remarkable for the distinctness and seeming regularity of their stratification. In a distant view, it was difficult to distinguish any variation from horizontality. Many minor irregularities were however apparent. In texture they were nowhere scoriaceous, though often vesicular. The larger part contained few cellules, and many of the layers were quite compact. As far as observed, in the rapid survey made, they appeared to vary in character between a ferruginous, compact basaltic rock, and graystone; and while some layers contained grains of chrysolite, in others none could be detected. The same facts, as we have stated, both as regards stratification, texture, and the absence of scoria, were presented by the walls of the lower pit.

We have described the recent lavas of the crater and their scoriaceous crust, and have mentioned also that while the crust covers the overflowings of the pools, the lavas from other openings are generally destitute of this crust, and have an obsidian-like exterior, not at all or but slightly cellular. The part of the layer below the crust is generally so solid that to the inexperienced eye it bears scarcely more evidence of having been through the fires than a piece of limestone; and yet but a few hours before it was liquid.

The scoria is mostly glassy in texture, a kind of ferruginous basaltic obsidian; and as shown by Sir James Hall, this glassy condition of a rock will fuse at less than half the temperature required to fuse the same material in its stone-like character.* It is the result, as has been often stated, of rapid cooling.

The capillary glass of Kilauea, called Pele's hair, is made from the scoria here described, or rather from lava that would have constituted scoria had it cooled upon a flowing stream.

The following are the results of analyses by Prof. B. Silliman, Jr. of Pele's hair† and lava from the crater. The last two are from the same specimen, the vitreous forming a compact exterior to the stony lava.‡

* Sir James Hall states that a stone, fusible at 38 degrees of Wedgewood, yields a glass which softened at 14°; and if again unvitriified, fused at 35°. The general results are correct, although we cannot place confidence in the Wedgewood scale. The facts show that the material is dimorphous, or assumes a difference of texture according to the rate of cooling. The same variation has been detected in more recent experiments.

† According to an analysis by Mr. J. Peabody, in the laboratory of Dr. C. T. Jackson, Pele's hair has the following constitution:

Silica,	-	-	-	-	-	-	-	50.00
Protoxyd of iron,	-	-	-	-	-	-	-	23.72
Lime,	-	-	-	-	-	-	-	7.40
Alumina,	-	-	-	-	-	-	-	6.16
Potash,	-	-	-	-	-	-	-	6.00
Soda,	-	-	-	-	-	-	-	2.00

Capillary volcanic glass is not mentioned as occurring at any other volcano except on the Isle of Bourbon, where it was found by Bory de St. Vincent.—*Voyage aux Iles d'Afrique*, iii. 50.

‡ The soluble portions of the minerals were first exhausted by digestion in repeated portions of hydrochloric acid; the insoluble residues were ignited, weighed, and the silica removed from them by the action of hydrofluoric acid, except No. 3, the insoluble portion of which was fused with carbonate of soda. The loss on this analysis may arise from the fact that a portion of soda was not extracted by the acid digestion. This was the case in Nos. 1 and 4. In the former eight per cent. and in the latter nearly two per cent. of soda were found in the part unattacked by the acid.

The solution in nitric acid, after being nearly neutralized, indicated the presence of chlorine to a small amount in all, more abundantly in Nos. 1, 2 and 3, and less so in Nos. 4 and 5.

The alkaline residue, when dissolved in water, treated with a solution of bichlorid of platinum, and evaporated to dryness, was entirely redissolved in alcohol, proving conclusively the absence of potassa.

Traces of peroxyd of iron were discovered in all the specimens, excepting the light-coloured specimen of Pele's hair.

	Pele's Hair ; dark-coloured.	Pele's Hair ; light-coloured.	Scoria, sp. gr. 2.505.	Compact vitre- ous Lava ; sp. gr. 2.91.	Compact stony Lava ; sp. gr. 2.93.
Silica,	39.74	51.19	51.93	50.67	59.80
Protoxyd of Iron,	22.29	30.26	16.91	33.62	31.33
Alumina,	10.55		14.07		
Lime,	2.74		6.20	3.66	
Magnesia,	2.40	18.16	1.73	1.13	1.71
Soda,	21.62		6.31	10.52	4.83
Water, . . . . .	.33				
Chlorine,	Trace.	Trace.	Trace.	Trace.	Trace.
	99.67	99.61	97.15	99.60	97.67
Of the above were soluble in hydro- chloric acid, . .	48.80	49.51	45.84	42.50	24.55
Insoluble in do.	51.20	50.49	54.16	57.50	75.45
	100.00	100.00	100.00	100.00	100.00

The facts which have been stated afford an explanation of the difference between the two forms of lava ejections. The layers *with a scoriaceous crust* proceed from the boiling pools by overflowing; those *with a solid exterior*, come from greater depths through fissures. The former have been in the process of ebullition, and, as would happen with any viscid fluid in this state, the surface by this action becomes blown up, we may almost say frothy, from inflation by the escaping gases. Whereas the latter come from a deeper source, where there is great pressure to prevent any such inflating cause from operating. There is the same difference that we should find between a stream poured from the surface of a frothy liquid, and another drawn off by tapping below. It is a homely comparison; but yet may give a correct idea of the subject. The remarkable absence of surface scoria from the ejections through fissures, is thus satisfactorily explained. It should be remembered that the ebullition of lava arises, not from the vaporization of the heated material, as with ordinary simple liquids, but from the escape of gases, and principally steam, through the lava.

The escape of gases, and the vesicular inflation of the crust, may continue in progress while the lava is flowing. But the process is so far impeded by the incipient cooling, that the surface cellules, instead of being enlarged and inflated are very much drawn out, becoming slender or capillary by the onward movement of the stream.

The formation of pumice is of the same general character, as it is the frothy surface from lavas which have a feldspathic constitution. No true pumice occurs about Kilauea, since feldspar is not the predominant ingredient in the lava. The material most resembling it has still the composition nearly of the ordinary scoria.

Ferruginous stalactites.—These stalactites are tubular and vermiform, and two to four inches long. They are black, with a slightly glistening lustre. Hardness 5 to 5·25. Specific gravity of the tubes, (which are cellular,) 1·656. They were collected by the writer from the roof of a cavern in the bottom of the crater, where they occurred in great numbers. The examination of Prof. Silliman, Jr., shows that they are essentially an anhydrous silicate of the protoxyd of iron. They were formed, as the mode of occurrence as well as composition shows, by the action of steam upon the roof of the cavern, decomposing the rocks and dissolving some of the silica and iron, which were afterwards deposited on evaporation.

Volcanic salts.—The sulphur banks are situated away from the main theatre of action, where the vapours rise slowly, and there is not too much heat for the sulphur to be deposited and crystallized. In the bottom of the pit the sulphur gives a yellow colour to some cracks or seams, which is usually mingled with reddish tints from the developed iron. The various minerals found about the sulphur banks are a result of the decomposition of the lavas by the ascending vapours. The sulphur vapour or sulphurous acid, changing to sulphuric acid, forms sulphate of lime or gypsum with the lime of the lava, one of the constituents of angite. It also forms alum, or sulphate of alumina, with the alumina of the feldspar. It forms sulphate of ammonia with ammonia, which is produced by the union of the nascent hydrogen (from water decomposed) and nitrogen; and sulphate of copper, the blue mineral, with oxyd of copper, or more probably by a change in some sulphuret of copper. At the same time that these changes are going on, iron is set free as an oxyd, and usually appears of a deep red colour. Silica is also liberated, and forms the siliceous incrustations met with about the banks. The

occurrence of siliceous deposits and hyalite from decomposing volcanic rocks and trachyte has often been noticed.*

The following are the results of chemical examinations made for this report by Prof. B. Silliman, Jr., with respect to several of the salts of the volcano.

1. *Sal ammoniac containing a large per-centage of iron.*

Chlorid of ammonium	-	-	-	-	-	65.53
Protochlorid of iron	-	-	-	-	-	12.14
Peroxyd of iron	-	-	-	-	-	8.10
Chlorid of aluminium	-	-	-	-	-	13.00
Insoluble matter and loss	-	-	-	-	-	1.23

This sal ammoniac becomes of a rusty colour after exposure.

2. *Blue sulphate of copper.*

Sulphuric acid	-	-	-	-	-	37.97
Soda	-	-	-	-	-	16.80
Oxyd of copper	-	-	-	-	-	10.80
Alumina and iron	-	-	-	-	-	5.00
Manganese	-	-	-	-	-	4.00
Chlorine and potash	-	-	-	-	-	Trace
Insoluble silica	-	-	-	-	-	21.00
Sulphur and loss	-	-	-	-	-	4.43

A selected sample of the purest salt yielded in a chlorid of calcium apparatus 19.99 per cent. of water. The salt analyzed was evidently a mixed sulphate of soda, alumina, and copper. Ten grains were employed in the analysis.

Green salt of copper.—This occurs as a thin incrustation with the gypsum, alum, and other salts of the sulphur bank. The quantity was too small for a complete analysis. From the examinations made, it appeared to be a simple sulphate of copper mixed with sulphate of lime.

Iron alum.—Consists principally of the sulphate of alumina, with the sulphate of peroxyd of iron, sulphate of soda, traces of chlorine, besides the usual amount of water.

* Humboldt states that M. Cordier first made known the siliceous and opal formations from the decomposition of lavas by sulphuric acid.—*Pers. Nar.*, Eng. trans., i. 175. See also Breislak, *Introd. alla Geologie*, ii. 238; Beudant, *Voyage Min.*, iii. 507; Darwin, *Volcanic Islands*, pp. 24 and 34.

Seleniferous sulphur.—This is an orange-coloured sulphur. Its colour at once suggested that it might contain selenium, which Prof. Silliman's examinations detected. A portion mixed with peroxyd of manganese and distilled, yielded a seleniferous product in water with sulphuric acid; and, after washing, it afforded strongly the odour of selenium, resembling putrid horse-radish.

The nature of the gases of Kilauea, beyond the existence of steam and sulphurous acid, has not yet been determined.

VIII. *Boiling movement in Kilauea, and its influence on the distribution of the volcanic material.*—There is nothing more interesting in all the features of Kilauea than the apparent flow of its lavas in an unceasing current to the southwest. From the black ledge opposite the great lake, the stream is seen to move on with a rate which has been estimated at three and a half miles an hour; and even from the upper walls of the crater it is very apparent in the movement of the jets over the surface. The true explanation already mentioned was first offered by Rev. T. Coan, and is published in the *Missionary Herald* for 1841. Such a flow is well compared to the motion in a boiling cauldron, for it can be nothing else. Moreover, in a confined space like the vertical conduit of a crater, or a cauldron of water, such an outward flow at the surface is necessarily connected with a complete circulation,—a descending of the material laterally, as well as a rising at the centre.

In connexion with this circulation, another fact should be considered,—that the temperature of the liquid would increase with the depth or pressure. At one of the geysers of Iceland, Descloiseaux has lately found* that at a depth of seventy-one feet, or within a foot of the bottom, the temperature at one trial was $261\frac{1}{2}^{\circ}$ F.; and from

* *Annales de Chimie et de Physique*, xix. 444, April, 1847. *Observations physiques et géologiques sur les principaux geysirs d'Islande*; par M. A. DESCLOISEAUX.—Descloiseaux obtained the first of the following results in a trial four hours before a great eruption: whole depth of the geyser at the time, 23.50 meters. The *second* three hours after a great eruption, and eleven hours before a following one: depth 22.75 meters.

Dist. from bottom in meters.	Temp.	Dist. from bottom in meters.	Temp.
22.85	85.0° C.	22.50	85.0° C.
19.55	85.2°	19.70	95.0°
14.75	106.4°	16.30	109.0°
9.85	120.4°	9.50	121.1°
5.00	133.0°	6.00	121.6°
0.30	127.0°	0.30	122.5°

M. Descloiseaux determines by calculation that in the second case the temperature of ebullition at bottom is 135.31° C.

this it diminished to the surface, where it was 185° F. Other trials corresponded in their results, though varying in the bottom temperature somewhat, according to the activity of the crater, the temperature of ebullition at that depth, about 280° F., being seldom attained.

Now as the lavas consist of different kinds of mineral material, having different temperatures of fusion, these currents, with the variations in the temperature, must influence somewhat the distribution of the ingredients, or the constitution of the lavas in the different parts of the crater. Whatever be the temperature at which any of the ingredients tend to solidify, at that temperature such ingredients will begin to thicken, and the more fusible portion, still fluid, will be carried up by the ascending vapours. In this way the superficial material of the great pools must necessarily be the most fusible part of the lava, or that which solidifies at the lowest temperature. The analyses of the scoria of the crater show that this is pre-eminently true in fact as well as theory.

Omitting for the present other considerations, we merely direct attention here to the fact that the lavas from fissures at the eruption of 1840, coming from a depth where the heat was great, abound in chrysolite in coarse grains, while in the crater, the lavas of the same period contain little chrysolite in small grains. We learn from this fact that the formation of chrysolite, a very refractory mineral, probably requires a higher temperature than exists at the surface in the crater. Consequently any chrysolite existing in the crater lavas was probably formed at some depth below, and ascended as grains in the liquid lava to the surface; and hence the rarity and minuteness of the particles of this mineral.

We likewise learn from these facts that generally in lavas issuing from a crater, a portion of the ingredients has already become partly solidified, and the liquidity is owing to a more fusible part, which remains still liquid at the surface temperature, and retains the whole in a mobile state. Lava, as is well known, cools with remarkable rapidity: we have mentioned its barely scorching the bark of a branch clasped by it while liquid. Such rapidity is a necessary consequence of the condition here described. As the temperature is nearly that which solidifies the more fusible part, and much of the lava has already lost its free liquidity, a small change will give solidity to the whole; and this change takes place with an abruptness that, in view of these explanations, cannot surprise.

The temperature of the lavas of Kilauea we were unable to ascer-

tain in the few hours at the crater; we can only mention here the common statement, derived from experiments on the surface lavas of Vesuvius, that it is between the point of fusion of silver and copper, or about 1900° F. The scoria of Kilauea melts before a blowpipe with the same ease as silver. The compact lavas have nearly the difficult fusibility of feldspar, and would require a heat for fusion far beyond 1900°. A complete series of experiments on the heat of fluid lavas is much needed, and nowhere could they be made with greater facility than at Kilauea.*

The unusual liquidity of the Kilauea lavas, implies the existence either of greater heat, or of a more fusible material. From the analysis of a feldspar from Maui, and other examinations to be detailed, we have found that the feldspathic ingredient of the lavas contains, like anorthite, twenty per cent. less of silica than albite or ordinary feldspar. It fuses with difficulty before the blowpipe on thin edges, and therefore does not help us in our explanations.

IX. *Kilauea not a Solfatara*.—Von Buch has spoken of Kilauea as a *solfatara*. The term, as is evident from the descriptions given, is wholly misapplied. A *solfatara* is an area with steaming fissures, and escaping sulphur vapours, and without proper lava ejections; while Kilauea is a vast crater, with extensive lava ejections and no sulphur except that of the sulphur banks, beyond what necessarily accompanies, as at Vesuvius, violent volcanic action. It is true, the lavas of the crater, though they flow, it may be, three miles within the pit, never rise over its sides. But this is simply because the walls are not strong enough to sustain the requisite pressure. We may here-

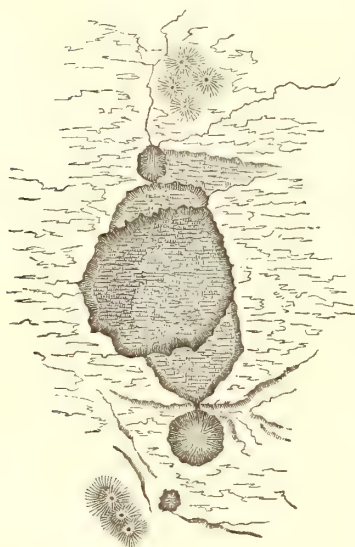
* Dr. Judd and Rev. T. Coan kindly consented, at the author's request, to make some attempts to determine the temperature of the lavas of Kilauea by means of the fusion of certain metals. The instrument was a long square iron rod, in one end of which there were cavities for receiving the metals, which were covered by plates of iron that were held in place by a ring. A long handle of wood was fitted to the rod, so that in all it was twenty-two feet long. After some unsuccessful attempts to use it, a convenient time finally offered, and at imminent hazard the rod was inserted. But they failed of their object in a manner they little expected. It was left inserted for twenty minutes, and on returning to it, with a feeling of certain success, the lavas were found to have hardened over it where it lay on the edge of the pool. These gentlemen are of the opinion that they would have been successful had they kept the rod in motion. By using different alloys, of which the fusing temperature is known, the heat of the surface lavas might in this way be obtained with much accuracy.

after show that Kilauea, in its great boiling pools, gives a more correct idea of the action of craters of ancient times than any of the volcanoes more frequently appealed to for illustrations of volcanic action.

We leave Kilauea here, to resume again the subject of volcanoes after describing the other craters of the Hawaiian Group.

b. *Summit Crater of Mount Loa.*

In the extended area, very gently sloping around, which forms the summit of the rock-built dome Mount Loa, is the deep pit crater Mokua-weo-weo.* It has a somewhat elliptical figure, as shown in



the annexed cut, with its diameters 13,000 and 8,000 feet respectively, the longer lying nearly in a north-by-west and south-by-east direction. But the deep part of the crater is nearly circular, and has the breadth of the smaller diameter; the northern and southern portions being shallow, and constituting, with reference to the central portion, a kind of terrace. The walls, through a considerable portion of their circuit, are abrupt or even vertical, and are stratified in structure like the sides of Kilauea; on the west side the height was found by Henry Eld, Jr., to be seven hundred and eighty-four feet, and on the east, four hundred and seventy feet.

The bottom of the pit, when examined by Captain Wilkes and the officers of the *Vincennes*, consisted of solidified lava, through which there were several fissures and fumaroles emitting steam and sulphur vapours in large volumes. Some parts were rough with clinkers, while in others, smoother tracts of solid lava constituted the surface. The fissures had in general a north-northwest and south-southeast

* The summit crater was examined and thoroughly explored by Captain Wilkes and the officers of the *Vincennes*, and a detailed account of it is given in the fourth volume of the *Narrative of the Expedition*. In the account presented, we have stated only the facts of special geological interest.

The name of the crater is pronounced *Mokooah-wayo-wayo*.

direction, and one near the west bank had ejected lavas at no distant period. Two cinder cones at the bottom, consisting of light scoria, were remarkably perfect in form, and one was two hundred feet high. About many of the fumaroles, there were the same salts that occur at the sulphur banks of Kilauea.

Besides the large pit, there are two others, one on the north, and another on the south, called Pohakuo-hanalei,* both of which may be looked upon as subordinate to the central one, as they are enclosed within the same general rim or outline. There is also another small pit, distinct from these, a short distance to the south.

Into Pohakuo-hanalei, a stream of lava had run from Mokuaweo; and Captain Wilkes remarks, that it looked like a cascade of iron which had become solid before reaching the bottom. There were several deep fissures in the vicinity of this pit, and every appearance of recent eruptions. "The lava at the mouth of some of the chasms appeared as though it had been thrown up and plastered on the edges in clots, which seemed of the consistency of tar or melted sealing-wax of various colours, the most predominant a dark brown."

There were several small cones about the summit, both to the north and south of Mokuaweo.

The rocks of the summit, where there was evidence in their appearance of recent origin, resembled those of modern ejections below. But the walls of the crater are described as consisting of a compact grayish rock, without cellules, and often breaking in plates. The specimens obtained were a grayish clinkstone, speckled with a white feldspar, with no trace of a cellule, and no resemblance to ordinary lavas. They consist mostly of the feldspar.

Within caverns about the crater, mammillary concretions of a hydrous silicate of alumina were obtained, which had resulted from the decomposition of the rock.

These concretions have been examined chemically by Prof. B. Siliman, Jr., who obtained the following for their composition :†

* Pronounced *Pohak-koo-o-hahnalay*.

† "*Pyrognostic Characters*.—In an open tube gives off a small quantity of water, which promptly and fugaciously reddens litmus paper. Emits, when heated, an empyreumatic odour. In thin scales, in platinum forceps, it fuses into a white transparent frit. Dissolves in carbonate of soda, and in borax forms a clear and colourless bead. With caustic soda alone, in a dry test tube, it reacts vigorously on heating, forming a complete solution. Effervesces strongly in hydrochloric acid from escape of carbonic acid, and leaves a white insoluble residue. The quantitative examination proved the presence of silica, lime, water, soda, potash, carbonic acid, alumina, and iron. A large and gritty

Silica and undecomposed silicate of alumina,	71·170
Carbonate of lime,	17·168
Water,	8·196
Alumina and oxyd of iron,	1·170
Magnesia,	0·175
Soda,	1·911
Potash,	0·115

He remarks that the mineral is probably a mechanical mixture, consisting principally of carbonate of lime and a hydrous silicate of alumina; the latter is related to the Halloysite group of minerals. Specific gravity 2·024. Hardness, 4·5—5. Structure, compact mammillary, and somewhat concentric lamellar. Colour, white to gray. Lustre, purely vitreous. When breathed on, gives a peculiar bitter odour, which is very evident when the mineral is ground beneath water in an agate mortar. It is allied to concretions from Samoa, described in the chapter on that group of islands.

But little is known with regard to the eruptions of the summit crater. Yet there is abundant evidence that, even at the present time, its fires are not entirely inactive.

An eruption is stated to have taken place on the 20th of June, 1832, and the mountain continued burning for two or three weeks; the lavas broke out in different places, and were discharged from so many vents, that the fires were seen on every side of the dome, and were visible as far as Lahaina, upwards of one hundred miles.*

The first ascent to the summit of Mount Loa by a foreigner was made by Mr. Douglas. This author describes it as far surpassing Kilauea in sublimity and violent activity. Mr. Douglas's observations are, however, received with incredulity by the residents. The

residue of silica remained after digestion in hydrochloric or nitric acid, and the mineral did not gelatinize even by prolonged and warm digestion. The inference from this examination was, that the mineral was a mechanical mixture of carbonate of lime in variable proportions with a silicate of alumina, and that no constant constitution could be assigned to it. The digestion of several distinct samples to complete exhaustion in strong acids, yielded the very variable results of 76·13, 63·72, 68·17 per centum of silica or undecomposed silicate of alumina. The amount of carbonic acid determined by the balance was 9·15 per cent. = 17·65 per cent. of carbonate of lime, while the analysis yielded 17·168. The water in this specimen varied from 7·68 to 8·196 per cent. in different trials."

* American Journal of Science and Arts, xxv. 201, in a communication from Rev. J. Goodrich, dated Nov. 17, 1832.

crater, if thus active, would have shown evidence of it, like Kilauea, in an illuminated cloud at night. But neither this nor any other proofs of its action were noticed at the time by the Hawaiians or the whites residing among them.*

An eruption took place in January, 1843, which is described by Messrs. Andrews and Coan.† It broke out at the very summit, on the 10th of January, and continued down the slopes of Mount Loa in two streams; one flowed to the westward towards Kona; the other flowed northward to the foot of Mount Kea, and then dividing, one part continued on towards Waimea northeastward, and the other towards Hilo, eastward. The branch towards Mount Kea is described as twenty-five or thirty miles long, and averaging one and a half miles in width.‡

* A comparison of the statements in the following paragraph by Mr. Douglas, with the observations by the officers of the Vincennes, will show that this incredulity is not misplaced. "This mountain (Mount Loa), with an elevation of 13,517 feet, is one of the most interesting in the world. The journey to the top took me seventeen days. On the summit is a volcano, nearly twenty-four miles in circumference, and at present in terrific activity. You must not confound this with the one situated on the flanks of Mauna Roa, and spoken of by the missionaries and Lord Byron, and which I visited also. It is difficult to attempt describing such an immense place. The spectator is lost in terror and admiration at beholding an enormous sunken pit, (for it differs from all our notions of volcanoes as possessing cone-shaped summits with terminal openings,) five miles square of which is a lake of liquid fire, in a state of ebullition, sometimes tranquil, at other times rolling its blazing waves with furious agitation, and casting them upwards in columns from thirty to one hundred and seventy feet. This volcano is 1272 feet deep; I mean down to the surface of the fire; its chasms and caverns can never be measured." Extracts from the Journal of Mr. Douglas, Magazine of Zoology and Botany, 1837, i. 582.

† Missionary Herald, xxxix. 381, 463; and xl. 44. The course of the stream and its origin were particularly examined by the Rev. T. Coan.

‡ As the Missionary Herald may be seen by few readers of this work, and the facts afford important illustrations of the mode of volcanic action on Hawaii, we cite a few paragraphs from the account by Mr. Coan.

"On the morning of January 10th, before day, we discovered a small beacon-fire near the summit of Mauna Loa. This was soon found to be a new eruption on the north-eastern slope of the mountain, at an elevation of near 13,000 feet. Subsequently the lava appeared to burst out at several different points lower down the mountain, from whence it flowed off in the direction of Mauna Kea, filling the valley between the mountains with a sea of fire. Here the stream divided, one part flowing towards Waimea, northward, and the other eastward towards Hilo. Still another great stream flowed along the base of Mauna Loa to Hualalai in Kona. For about four weeks, this scene continued without much abatement. At the present time, after six weeks, the action is much diminished, though it is still somewhat vehement at one or two points along the line of eruption."—(Miss. Herald, xxxix. 463.) Ascending the mountains, Mr. C. reached the stream of lava between Mount Loa and Mount Kea, about 7000 feet above the sea. On the

It appears from the accounts that the mountain was fissured in the two directions, and that the ejections took place from the fissures instead of from the two summit craters where it commenced.

We have remarked upon the quiet character of the eruptions of Kilauea. It is still more surprising that an outbreak of such magnitude should have taken place, at the very summit, without any warning to the islanders. The first indication of the eruption in progress

evening of the third day, "as darkness gathered around us, the lurid fires of the volcano began to glow, and to gleam upon us from the foot of Mauna Kea, over all the plain between the two mountains, and up the side of Mauna Loa and its snow-crowned summit, exhibiting the appearance of vast and innumerable furnaces, burning with intense vehemence. On this plain we spent the day traversing and surveying the immense streams of fresh scoria and slag, which lay in wild confusion, farther than the eye could reach, some cooled, some half cooled, and some still in fusion. The scoriform masses which formed the larger part of the flowings, lay piled in mounds, and extended in high ridges of from thirty to sixty feet elevation." On the ascent they passed fields of scoria, and others of smoother lavas, and regions at times that were still steaming and hot, evincing igneous action beneath. "Soon we came to an opening in the superincumbent stratum, of twenty yards long and ten wide, through which we looked, and at the depth of fifty feet, we saw a vast tunnel, or subterranean canal, lined with smooth vitrified matters, and forming the channel of a river of fire, which swept down the steep side of the mountain with amazing velocity. As we passed up the mountain, we found several similar openings into this canal, through which we cast large stones; these, instead of sinking into the viscid mass, were borne along instantly out of our sight. Mounds, ridges and cones were also thrown up along the line of the lava stream, from the latter of which, steam, gases, and hot stones were ejected. At three o'clock we reached the verge of the great crater, where the eruption first took place, near the highest point of the mountain. Here we found two immense craters close to each other, of vast depth and in terrific action." (Miss. Herald, xl. 44.) Mr. Coan writes as follows, in reply to certain queries by the author: "The angle of descent down which the lavas flowed from the summit to the northern base of Mauna Loa is 6° ; but there are many places on the side of the mountain where the inclination is 10° , 15° , or 25° , and even down these local declivities of half a mile to two miles in extent, the lava flowed in a continuous stream. This was the fact not only during the flow of several weeks upon the surface, but also in that wonderful flow in the subterranean duct, described in the Missionary Herald. There was no insurmountable barrier in the way of the flow from the summit of Mauna Loa to the base of Mauna Kea, a distance of twenty-five or thirty miles. The stream sometimes struck mounds or hillocks, which changed its course for a little space, or around which it flowed in two channels, reuniting on the lower side of the obstacle, and thus surrounding and leaving it an island in the fiery stream. Ravines, caves, valleys, and depressions were filled up by the lava as it passed down the slope of the mountain, and between the two mountains. In conclusion I remark that the stream was continuous for more than twenty-five miles, with an average breadth of one and a half miles, and flowed down a declivity varying from 25° to 1° ."

was the discovery of a small "beacon-fire" near the summit of the dome.

A still more wonderful fact is reported, that during this eruption, there was no unusual commotion, or change whatever in Kilauea, the great lateral crater of the dome, ten thousand feet below.*

c. *Subordinate Craters and Fissures of Mount Loa.*

Mount Loa has been described as abounding on all sides in craters. Its eruptions seldom end without throwing up one cone or more of lava or cinders over some parts of the opened fissures. The most remarkable region of craters, however, lies to the south and southeast, over the lower slopes of the mountain. From Kilauea, where this region commences, there is a series of craters extending along to the southeast and east, and terminating in the eastern cape Kapoho; and another by a former fissure running southwest, passing about five miles from Kapapala.

Kilauea and its eruptions have already been described: we proceed to notice briefly the other craters, deriving the facts principally from the map of Captain Wilkes and Mr. Drayton (reduced on page 169,) together with the observations of Dr. C. Pickering, as the author's limited time did not allow of his giving the region a personal examination.

Immediately adjoining Kilauea on the east there are two pit-craters,—that is, mere pits, like Kilauea, and not volcanic cones. One is situated near the northeast side, and is separated from the large crater by a wall half a mile wide, (*r*, figure on page 173.) It is circular, and about 7,000 feet in diameter, a size that in any other part of the world would be considered large. The interior is well wooded; at bottom there is a bed of lava. We have already stated that part of the eruption of 1832 flowed into it. The other crater near the southeast side of Kilauea is a much smaller pit (*s*, same figure.) It is called *Arare ororo*; according to the estimate of Dr. Pickering, it measures eight hundred feet by six hundred feet in diameter, and is three hundred feet deep:

In a line running east-southeast from the small crater just mentioned (see map, page 169), and within a distance of five miles, there are four other pit-craters, and farther to the eastward, in the course of six

* See Missionary Herald, xxxix. 382, where it is mentioned by Dr. Andrews that during the eruption, Kilauea was visited by Mr. Wilcox, and the above facts ascertained. The same has been affirmed by the Rev. T. Coan.

miles, three or more pit-craters of remarkable dimensions. The *first* of these four is properly the *second* in the line from Kilauea, and we thus number it. This *second* one is little more than half a mile from the first. Dr. Pickering estimated its diameter at one-fourth of a mile, and its depth at eight hundred feet; it was somewhat oval from east to west. The cloud over Kilauea bore from it west-by-south. There was much steam issuing from the northeast wall of this crater, and also from the plain beyond. The *third* pit-crater was a mile to a mile and a half beyond the second. It was nearly circular, and the diameter was about the same as the preceding, with a depth estimated at six hundred feet.

The *fourth* and *fifth* pit-craters were also visited by Dr. Pickering. The intermediate space between the third and fourth was not examined, and it is not certain that there may not be one or two in this space. The *fourth*, called *Varerau Kawaiki*, was estimated to be half a mile by three quarters in its diameters. It was thus oblong, and at centre was about one thousand feet deep. The ends of this oblong crater were less deep, over a large area, than the central circular portion, there being a kind of shelf on the east and west sides. At the east end, the pit was quite shallow, while at the west, it was nearly as deep as the centre. The *fifth* crater is a circular pit, and is called *Arare-iki*, or Little Arare.

The *sixth* is nearly circular, three-fourths of a mile in diameter, and about 1200 feet deep. It is called by the natives *Arare-nui*, and is the scene of the first outbreak of lavas at the eruption of 1840. There is something of a shelf on the west side. The *seventh*, called "The Deep Crater," was estimated by Dr. Pickering to be 1500 or 2000 feet in depth, exceeding much the depth of Kilauea; it is nearly a mile in diameter, and is bordered on the southeast by a depressed plain or shelf of a D shape, and as extensive as the area of the pit. The depth over this plain is about half that of the central pit. The *eighth* pit-crater, called the "*Mu*" or "Big Crater" is a mile and a half in diameter, quite regularly circular in form, but not so deep as the preceding.

These pit-craters, as it appears, are all remarkable for their depth as compared with their diameter, their nearly circular form, and the absence of any elevation about them, as well as of all decided evidence that they have ever overflowed their summit or brim. The whole series forms an arched line, and they increase in diameter almost regularly from the first to the last.

Near this line there are two cones. One on the north side of the fifth pit-crater (and called Pohi, or Puhuluhu), consists of rugged lavas, and according to the measurements of Captain Wilkes, it is eight hundred feet high above the plain on which it stands. It contains a deep conical crater, and is covered throughout with trees. The other, still larger, stands on the northern brim of the "Deep Crater," and also contains a crater. Besides these, there is a smaller elevation of similar character near the *second* pit-crater (following the above enumeration). Dr. Pickering estimated its height at one hundred feet, and the circular crater within as five hundred feet in diameter. Near the *third* pit-crater is another rugged hill seventy feet high, consisting of lavas, which appeared to be the remains of a cone of eruption.

Between the last pit-crater and Kapoho Point, there are fifteen or more lava or scoria cones, varying from two hundred to over one thousand feet in height. Kalalua, about half way, (K, map, page 169,) rises eleven hundred feet above its base, and is the highest of the number. The plain about it is twelve hundred and forty-two feet above the sea. These cones are usually covered with vegetation, and the crater of one, as Captain Wilkes states, was occupied by a garden. In another, near the sea, there is a small lake of light green water, containing fish. After an earthquake its water has frequently turned red and yellow, and smelt of sulphur. Another "is said to contain a hot spring, which the natives use as a bath."

Cape Kapoho lies nearly east of the summit of Mount Loa, and appears to owe its prominence and extent, and even its existence, to the fact that the region on this side of the mountain has been the seat of various eruptions and numerous opened fissures. These eruptions have given a greater elevation to the surface in the line of the cape; and the northeast course of the last twelve miles of the eruption of 1840 (see map, page 169) may have been determined by this fact.

The line of craters extending southwest from Kilauea lies nearly in the course of the longer diameter of this crater, and covers a former fissure. We have no particulars to add in this place beyond the facts stated on page 165.

Many cones in different parts of the mountain might be described; but the examinations made give little more than their general form and size, particulars which are of little geological interest, without further observations on their relative positions, linear arrangements (if any is apparent) and other facts illustrating the lines of fissures of eruption about the slopes of the mountain.

The characteristic features of Mount Loa consist in the absence of cones about its active vents, the large number of deep pit-craters, and the frequency of fissure-eruptions. All recent action has consisted in a rending of the mountain's sides by the forces at work, and a flowing out or ejection of the lavas by these opened fissures. This was the character of the late summit eruption, as well as of that of Kilauea. Tradition, and the knowledge of the natives, bear testimony to the same fact, and so also with equal or greater weight, the surface of the mountain itself in the numberless patches of lava which constitute it.

The many cones, of which thousands may be counted, were not the first step in an eruption; they were formed, after the first flow, from ejections at certain points in the fissure that still remained open when the rest had closed, where the lava continued for a while to rise and pour or spout out, or was ejected in fragments that cooled into "cinders." They are the indexes which remain to mark the course of a fissure, and not original centres of independent action.

b. *Mount Kea.*

Mount Kea exceeds Mount Loa in altitude about 190 feet.* It has the same gradual slopes, the average angle of inclination from the sea on the northeast being $7^{\circ} 46'$, (see figure, page 159.) Yet the mountain is peculiar in many of its features. Besides having a more pointed summit, giving it the outline of a very obtuse cone, it has no distinct terminal crater. There are at top nine cones or conical hills, consisting of cinders or scoria and fragments of lava. They are estimated by Dr. Pickering at five or six hundred feet in height.

Over the slopes of the mountain, there were observed no wide streams of lava with a ropy appearance, like those of Mount Loa. The surface consisted mostly of loose fragments or masses, and earth, and parasitic cones were very numerous. Vesicular lavas occur about the summit and the subordinate cones of the declivities, but there were no large fields of lava. The layers of rock, where exposed to view, were generally of compact texture, with rarely a cellule or none, and were mostly a gray basalt, or a dark basaltic graystone. A clinkstone, nearly like that of the summit of Mount Loa, was also met with. There were besides large deposits of coarse conglomerate, consisting

* See page 156, and note to the same. This mountain was ascended by Dr. C. Pickering and Mr. Brackenridge, from whom the facts regarding it were mostly obtained.

of material from the igneous rocks of the mountain. In the gorges which intersect the eastern and northeastern foot, the rocks appear in a succession of layers, with a very gradual dip. Just below the falls of the Wailuku, near Hilo, there is a compact graystone or gray basalt, which occurs in nearly regular prisms. Some of the prisms are eight feet in diameter; but they are mostly surmounted by others of smaller size, one to four feet in diameter. The rock is very light-coloured, and contains some chrysolite; it is compact, rarely showing a cellule. The bluff near the falls consists of an upper layer of compact basalt, nearly 100 feet thick, and in some parts having a columnar structure; below this there are twenty feet, consisting of a few layers of basalt, which are not columnar.

This mountain is an interesting example of a volcano closing its terminal crater by its own action, and finally dying out at summit in cinders or scoria eruptions. Very similar was the condition of Vesuvius in 1834, when visited by the writer; there was a summit plain and a cinder cone, and no deep gulf, such as previous and later authors have described: and had the mountain then died out, there would have been no evidence that a crater beyond that of the cinder cone had ever existed.

c. *Mount Hualalai.*

Hualalai, the western mountain-cone of Hawaii, is 10,000 feet in height. Its slopes rise from the coast near the village of Kailua. The surface has some resemblance to that of Mount Loa, and its parasitic craters are very numerous. The crater is said to smoke occasionally at the present time. In the year 1801 there was an eruption, witnessed by Turnbull, which flowed westward to the sea, and formed the present line of coast, filling up a bay of considerable extent. The crater of Hualalai was visited by Menzies.

At Kailua there is a warm cavern, in which Glauber salt is formed in large quantities. It arises obviously from the action of the sulphur gases on the sea-water. There are also warm springs at Kowaihae, farther to the north, on the same coast. They are covered at high tide by the sea. Both of these places are probably connected with the fires of Hualalai.

In concluding our remarks for the present on Hawaii, we may draw attention again to the striking fact that this island is the result of the

conjoint action of three volcanic cones, whose slopes constitute its surface. The ridge of Kohala on the north, which faces the interior with vertical cliffs, and gradually declines on the opposite side, or towards the sea, is the only example of nonconformity to this system. As the place has not been geologically examined, we cannot give the exact character of this ridge, or its relations to the other parts of the island. Mount Kea was probably the earliest vent opened, if there was any difference of age. Its lavas long since ceased to flow, and the closing scene was an ejection of scoria—a common fact with many craters. Mount Hualalai and Mount Loa are still enlarging the territory of Hawaii, by their occasional additions to its surface and shores.

d. *General Conclusions.*

We here continue our observations on the general character of volcanic action on Hawaii.

I. The absence of a cinder cone about the terminal crater of Mount Loa, or even of cinder ejections beyond a few small cones over some former fissure, is certainly a most striking feature, and one which should be well considered. We have a lofty volcanic mountain, finished off to its very top, and this top nearly 14,000 feet in elevation, without any appreciable addition at top from fragmentary eruptions. Contrast this with the lofty summits of the Andes and Mexico. The consequence is that Mount Loa has the low flat shape described, and its terminal crater is but a pit in the broad top of the dome; while the peaks of the Andes rise with steep slopes, and a narrow summit often broken in by the convulsions of the volcano.

Mount Kea is nearly as gentle in its average slope, though having a pointed summit from the character of the latest ejections; it is still very unlike a Chimborazo.

II. The quietness of the eruptions merits farther remark. How totally unlike our usual conceptions of volcanic action, that a volcano of such magnitude, should pour out a flood of lavas, reaching for twenty-five miles down its sides, and yet all take place so quietly that persons at the foot of the mountain should be unaware of it, except from the glare of light after the action has begun; and through its progress should utter no sounds to be heard below, or cause perceptible vibrations, except in the region of the outbreak, and there none of much

violence. It is perhaps difficult for the mind to dissociate from the idea of a volcano, noise and earthquake; yet there is no doubt that they are no necessary attendants. For both Kilauea and Mokuaweo-weo, neither of which is exceeded in its crater by any known volcano, have emptied out their lavas in vast eruptions, without such accompanying phenomena. We have evidence that Mount Loa has been rent through its sides for miles,—even for twenty-five miles or more at the eruption of 1843,—without a murmur reaching the residents at Hilo, on the eastern shores. It is plain that the mode of action at the summit is similar to that in Kilauea. For years there is an accumulation of lavas in progress,—a rising within and a gradual increase of pressure from this source, as is so well exhibited before the eye in Kilauea; and this increase goes on until the sides of the mountain give way, and the lavas run out. Noise need not attend such a rupture, and in many cases it does not. The mere force of pressure alone, without any unusual discharge of vapours, may cause the fracture and discharge.

The amount of this pressure is easily calculated. In the ascent of lavas, every additional twelve feet in height adds one atmosphere or fifteen pounds per square inch to the pressure exerted. Consequently every 1600 feet will make an addition of a ton or 2000 pounds to the square inch, and 13,760 feet, the height of Mount Loa, a pressure of 17,200 pounds to the square inch, or 2,500,000 pounds to the square foot. This is the amount of pressure at the level of the ocean, and also the force exerted at that level against the sides of the mountain, tending to cause a rupture. As the mountain is much narrower above, or the walls of the central cavity thinner,—and the tension in the walls of the conduit below would be communicated upward,—the resistance to external fracture, other things the same, would be least in the upper part of the mountain. The rupture actually appeared near the summit at an elevation of 13,000 feet, and the lavas consequently had risen nearly or quite to the summit before the outbreak. A crater in violent action was afterwards seen there by Mr. Coan. Whether there was anything in the nature of the mountain structure on the side of the eruption to favour its breaking there, could not of course be ascertained. On this point we can only say that the same region has been a frequent place of eruption: and moreover it is in a direction nearly transverse to the trend of the group, like the bearing of Kea and Loa, and the course of the longer diameter of Kilauea.

III. *Isolation of the lines or conduits of volcanic action.*—It is not a little surprising that summit eruptions should take place at an elevation of 13,760 feet, when on the slopes of the dome, sixteen miles distant, there is an open vent, Kilauea, three and a half miles in length, and more than 10,000 feet lower in elevation, showing no disturbance in its boiling pools, no signs whatever of sympathy. The conduits of the two vents must be separated to a great depth, in order that the force in the central one should accumulate to the amount of 2,500,000 pounds to the square foot, when elevation to the level of Kilauea requires less than a fourth of this force.* If the two channels freely intercommunicated above the point of principal action in each, (or the place of origin of the vapours that constitute the lifting force,) they would act together: but in this great syphon, filled, as is believed, with molten rock, strange to say, the fluid stands 10,000 feet higher in one leg than in the other.

We have remarked besides that the boiling pools in Kilauea move independently; for one may sink fifty or a hundred feet while the other is boiling and overflowing. Moreover, as another example of the same principle, eruptions take place through the top of the walls of Kilauea, six hundred feet above its pools. There is every reason to believe that Kilauea originated in the opening of a fissure to give exit to the lavas of Mount Loa; if so, we learn from these facts, that the lavas which filled the fissure between it and the summit and to a great depth within, have cooled, and made the mountain in this part as solid as before, leaving each conduit possibly as a separate branch of some deep-seated channel. In the same manner the smaller pools in Kilauea, though formed in a fissure that once radiated from an existing lake, soon become distinct to a considerable distance down, owing to a closing of the intermediate vent by solid lavas.

But is it possible that there is a free connexion between the legs of this great syphon? It is certainly difficult to conceive how in such a case the ordinary principles of hydrostatics could be so set aside. This, be it remembered, is no paroxysmal elevation of the lavas to the summit, but a slow and gradual result; and the difficulty therefore

* As the bottom of Kilauea, at our visit, was 990 feet below the summit of the crater, it was only 2980 feet above the level of the sea, (the summit of Kilauea being 3970 feet,) which is about two-ninths of the whole height. In 1843, the bottom was somewhat higher, but could not have equalled *a fourth* of the whole height of the crater. Even at the present period, with the lower pit filled to the black ledge, the height of the bottom is but 3320 feet above the sea level, which is less than a fourth of 13,760 feet, the whole height.

comes home to us with its full force. On this point we offer a few considerations.

It has been observed that the heat in a pool of lava increases downward with some relation to the pressure. The cooling influence of the atmosphere and surface rocks acts at the surface and would necessarily make this portion less heated than any part below. Upon this principle, were there no other cause to modify the result, the lava pools could not be smaller in diameter below than at the surface, and therefore they would continue indefinitely downward; and any two at some distance down—it may be a great distance—would be united so as to communicate freely with one another.

A sketch may help the mind to conceive of the case before us. It



MOUNT LOA.

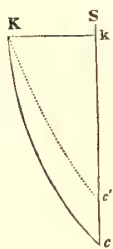
represents Mount Loa of its actual shape, and shows the diameter of the two craters, with the breadth of the conduit below, in case this conduit is as broad throughout as in its upper part. To connect such conduits, the union would of necessity be very deep, unless we suppose what is very improbable, an abrupt convergence below. The reader can make the union that seems most probable. The remarkable breadth of the craters as compared with the elevation of the mountain will be observed. The longer diameter of Kilauea is four times greater than the altitude of the mountain at the place, and that of the great lake, which is liquid throughout, is at times fully equal to this altitude.

The lava conduits, if they in fact diminish downward, must owe their contraction below to the refrigerating influence of the waters that find ingress to the fires. These waters, by which the action is kept up, must take a vast amount of heat from the lavas, the absorption of nearly 1000° F. being necessary to vaporization. Moreover, the possibility of such a contraction is enhanced by the fact that the temperature of fusion of the consolidated rock is higher than that of cooling, and the breadth once lost by the conduit, is not therefore as easily regained.

In the walls of the lower pit of Kilauea, which afford sections of the material formerly in fusion, I observed one vertical cavity, shaped somewhat like an inverted top, though more drawn out below, and apparently terminating at bottom in a small conduit. It occurred

to me at the time that this rounded, well-shaped cavity might be the site of a former boiling pool, like the small one then near me. It extended from below the upper layers of the black ledge to a depth of about one hundred and fifty or two hundred feet, and if once actually a boiling cavity, it was probably so just previous to the eruption of 1840, when the black ledge was overflowed by the lavas. This is mentioned as a probable case favouring the view that small pools may contract below. This fact, however, hardly authorizes us to infer that the same basin character may be the condition of the main pools of the craters.

If we admit a union below, (which may be considered somewhat doubtful,) the waters that gain access to the fires, and promote the action of the volcano, must operate on the conduits above the point of bifurcation, or certainly there would be a sympathy in their movements. The same is true of the conduits to separate pools in Kilauea, which also act in some degree independently. The water, in such a case, would necessarily tend to escape by ascending, and so exert its action upwards, inflating the lavas more and more as it approached the upper surface and found diminished pressure. Its influence, in giving activity to the fires, would thus gradually increase, and would be greatest above, where the pressure counteracts, in a less and less degree, its mechanical as well as any chemical effects. The lavas above, thus inflated by vapours, will therefore be lighter than those below. In order that the two legs of the syphon should not vibrate together, it is necessary that the point of junction of the legs should be at so great a depth that the difference of length between the legs would be but a fraction of their whole length. In this case, the difference of height might be as great even as between Kilauea and Mokuaweo, and still the two act without any mutual influence. From the sketch given on the preceding page, it is evident that this union must take place, if at all, at a great distance below the surface;



probable point of bifurcation, the actual difference of length will in fact be relatively small. If, in the annexed figure, *K* and *S* be the two craters (*Kilauea*, and *that at the summit*) and the lines *Kc*, *Sc*, represent the convergence of the conduits, the point *c* will be forty-four miles below the surface, and *Sk* the difference in the height of the two craters above the sea, will be about one twenty-third *Sc*; or if *c'* be the point of convergence, the distance *Sc* is thirty-three miles, and one leg of the syphon is one-eighteenth

longer than the other. We may therefore comprehend that the two legs of the syphon may differ as much in length as at Mount Loa, and the lavas, owing to unequal inflation, still balance one another.

IV. *Volcanoes fed by the fresh waters of the Island.*—If, then, the conduits are separately operated on, as must be admitted, whatever be our conclusions with regard to their union or disconnexion below, we see additional reason for attributing a large part, if not the whole of the action of water to points near the surface, and we may also say, to the fresh waters of the land. The difference of action in the pools of Kilauea, can have no other cause, as far as we can understand; and the explanation of the relative phases of Kilauea and Mokuaweo requires none other. Salt water may have some influence. But when we consider the facts, that borings, directly on a sea-shore, even one comparatively flat, will always bring fresh water; and on a coral island, ten feet is sufficient depth for pure water a hundred yards from the beach, we must admit that only deep in the sea will the ocean's pressure force its waters into the volcanic mountain—a depth greater, it is believed, than is consistent with the facts above explained. The rains that fall over the island, and the waters from the melting snows, are, to a very great extent, absorbed by the cavernous rocks, and they must make their way down to the fires. If we keep in view the area of Mount Loa (at least 3000 square miles), and also its height, and consider the great amount of water that flows ordinarily in numberless streams from the surface of such a mountain, we may conceive of the extent of the contribution received by the fires below.

V. *Volcanoes no Safety-Valves.*—From these considerations we may doubt whether volcanoes are ever "*safety-valves*," as they have been often called, and are almost universally considered by writers on these subjects. We may strongly doubt whether action so deep-seated as that of the earthquake must be, can often find relief in the narrow channels of a volcano, miles in length. The conduit of Mokuaweo is almost three miles long, down to the level of the sea. Assuredly if while Kilauea is open on the flanks of Mount Loa,—a vast gulf three and a quarter miles in diameter,—lavas still rise and are poured out at an elevation more than 10,000 feet above it, Kilauea is no safety-valve, even to the area covered by the single mountain alone. If lavas may be ejected from the very lip of Kilauea 1000 feet above its bottom, while the pools are still boiling below, Kilauea, notwithstanding its extent, the size of its great lakes of lava, and the freedom of the incessant ebullition, is not a safety-valve that can protect even its own im-

mediate vicinity. How then, with so limited a protecting influence, can it relieve from danger a neighbouring island? Nothing can be farther from the truth, however popular the opinion, or however supported by authority. Volcanoes are in fact indexes of danger, and the absence of them is the best security. They point out those portions of the globe which are most subject to earthquakes, and are results of the same causes that render a country liable to such convulsions.

We also understand, from this study of volcanic action, why it is that earthquakes in volcanic regions are so seldom attended by pulsations or any increased action in the active vents.

VI. *Phases of Volcanic Action.*—Moreover there can be no truth, at least as regards Mount Loa, in the principle reasoned out at length, in an able article on volcanoes, by Bischof,* that the phases of volcanic action depend on water gaining access to the central fires of the globe; for the evidence is certainly conclusive that the main action of waters is comparatively near the surface.

The phases of volcanic action at Kilauea are simply as follows:—

1. The centres of action, when most quiet, are reduced to a single one, which occasionally overflows. This overflowing raises the bottom of the crater; the lavas continue to boil over, and go on accumulating, and elevating the area of action; the pressure is consequently gradually increasing; the action becomes after a while more intense, from the increasing pressure, and increasing height to which vapours ascend before escaping; new centres of ebullition add to the effect; finally, after the bottom is raised 400 feet above its lower level, these centres are numerous, the ebullition is violent, the overflowings almost incessant;—at last the increased pressure, in addition to the force of rising vapours proceeding from the increased action, cause a rupture through the mountain's sides and the liquid rock flows out.

This is the history from a period of quiet to one of greatest activity. If the larger pool, after an eruption, should become crusted over, as happens with the smaller pools, the lavas sinking far below the surface, there would seem to be a state of inactivity. But the same process going on, the surface would be gradually reached, and the work would be continued as above explained. This is all a simple result of the passage of vapours from below, inflating the lavas as they ascend, producing the appearance of ebullition, and occasioning thus

* *Natural History of Volcanoes* by G. Bischof, Jameson's Edinburgh Journal, xxvi., 1839; American Journal of Science, xxxvi., 249, 250.

the rising of the molten material, and the overflowings. The scoria is the froth of the surface still more inflated, like the scum on the surface of a boiling syrup.

To compare Kilauea with other craters, we must keep in mind this important point, proved by the absence of cinders in the crater, and the free ebullition there, that the lavas are remarkably liquid, while those of other craters are comparatively viscid. The ejections of the great lake of Kilauea are 60 feet in height, while those of Vesuvius during an eruption may be 10,000 feet; and this, though not a direct measure of their relative liquidity, is a consequence of it. With this principle in view, we may translate the language of Kilauea into that of Vesuvius or Etna. The phases of their craters may be of the same general nature, and be due to a similar mode of action, varied only by the simple fact of the greater or less viscosity of the lavas. There may be the same succession of effects with the same results; and periods of quiet and violent action may have the same mutual relations and dependence. We need look to no extraordinary influx of waters to occasion an eruption, as the eruption is a result of a progressive state of things, perhaps long in action. I do not here deny that such a paroxysmal influx of waters may at times take place, and has produced results. I urge only that they are exceptions; and that phases of quiet and violent activity would necessarily succeed one another without such intervention.

The same gradually acting cause will also produce occasional violent ruptures. For where the waters for a period find slow access to any centre of heat within the volcanic mountain beneath its cover of rocks, the vapours will gradually accumulate till the pressure breaks a way through the mountain, to give exit to the vapours, together with the compressed lavas. The starting of a cork from a bottle of soda-water and the escape of the liquid, as well as carbonic acid gas, though a familiar incident, depends on a general principle, with regard to pressure, to which even the lavas of a volcano must be obedient. The sudden outburst of lavas through fissures in the summit of the walls about Kilauea may be of this character. In many cases even violent earthquakes might attend this mode of action.

VII. *Kinds of Craters on Hawaii.*—The craters on Hawaii are of four kinds, according to their mode of formation; yet these kinds are not always distinct, owing to the combination of different effects in their origin. These kinds are as follows:—1. *Lava cones or domes*; 2. *Cinder or scoria cones*; 3. *Tufa cones*; 4. *Pit-craters*. We omit

our general remarks on these kinds of craters for the present, and consider in this place

VIII. *The Origin of Kilauea and the Pit-Craters of Mount Loa.*— Leaving out of view for the present Mokuaweoweo, and counting from Kilauea, the pit-craters of Mount Loa are ten in number, within a distance of fourteen miles. Their several peculiarities, especially the abrupt walls free from scoria, favour the view that they are simply the results of subsidence. Yet it would be surprising that areas of subsidence, from undermining, should, in so great a number of instances, have a nearly circular form. Moreover, the absence of scoria from the walls is in fact no proof that they were not once filled with lava; for there is the same absence of scoria from the walls of the lower pit of Kilauea, although the whole black ledge was covered before the eruption of 1840; and so perfectly clean are these bluff fronts, that the facts, were they not beyond doubt, would hardly be credited. There is the same reason, therefore, for believing that the lavas never filled this lower pit, as that they never filled the whole crater of Kilauea, or any of the other pit-craters mentioned.

We deem it more consonant with the mode of operation in these volcanic regions to suppose that all these pits were once boiling lakes, like those now in the bottom of Kilauea; and that, like the small cones, they occur upon former fissures, on this part of the dome; that they are the points in these fissures, where, after ejections from fissures had partially subsided, the lavas continued to boil up, and remained for a while in active ebullition. The facts in Kilauea itself point to this conclusion. New pools are opened from time to time in this crater; and the steps are the same as just pointed out,—a rending of the surface and an overflow, after which the wider part of the opening remains as an active boiling pool. Captain Chase witnessed the formation of one of these boiling lakes, and describes the fissures, succeeded by a flood of lava, which soon became “a great lake of fire.” We perceive, moreover, that this is the natural course of things. Lavas do not melt their way to the surface; for if so active in any point as to threaten this result, their vapours will break the crust for their escape, and thus open the way for the outflow of the lava. After the opening is made, the constant ebullition of the lavas will necessarily give at last a circular form to the boiling pool, whatever the shape with which it commenced, unless action within the fissure on which it was formed, causes it to become oblong. We thus comprehend the very regular circular outline of some of these pits, and at the same time the

elongate form of Kilauea and others. We have in Kilauea a complete exemplification of this subject. When the lakes in this crater subside one or two hundred feet, as sometimes happens, they are actual pit-craters. The crater, Kilauea, it should be noted, is itself one-fourth as long as the whole line of pit-craters to the eastward, and the large lake within it is as broad as many of the pit-craters themselves.

We may, therefore, believe that from Kilauea towards the east-south-east, at some period of eruption, there was opened a series of deep rents accompanied by ejections of lava, which drained Mount Loa as now lower openings drain off the lavas of Kilauea. At certain points the lava continued in active ebullition, and perhaps for a while flowed over. Kilauea stands at the intersection between the line of fissures here pointed out, and another line extending to the southwest; and while its own length has the direction of the latter, the many pit-craters are in the former. The two were probably, therefore, of simultaneous origin; and the rending of Mount Loa, which opened this vast gulf and the other vents, consisted in the starting of a great triangular segment of the dome. It must have been a deep rent, different from any ordinary eruption, to have opened a perpetual fountain of boiling lavas—a fissure that reached down to the source of the central fires of the dome; the starting, therefore, of such a segment, is not only a probable result, but may be considered as almost a necessary one. The island of Maui will afford us an example of a like result, established by facts which cannot be doubted. We have before remarked that Kilauea is nearly in the line of the Loa range of heights in the group, and constitutes the southeast extremity of this long northwest and southeast chain. We observe, moreover, that its longer diameter and the southwest fissure correspond in direction to the *transverse* trend pointed out, in which lie the two summits Kea and Loa, and the two islands at the west end of the group, Niihau and Kauai.

Kilauea, when first opened, may have been occupied with lavas to its summit; and for a while they may have overflowed. The natives have a tradition to this effect; and the slight elevation of the plain about it seems to support it. But subsequently, an opening in the mountain's sides below emptied it of its lavas, as well also as the smaller pits. After this, Kilauea boiled and steamed away at a lower level, and was the only vent that remained in action.

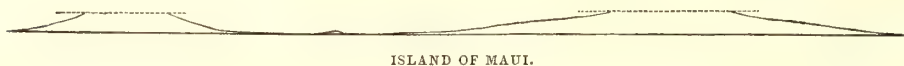
In another place we have observed that the fires of the Hawaiian Islands have become extinct seriatim from the northwest towards the southeast; and in this transfer of a large part of the force of Mount Loa

to the crater of Kilauea, the same general principle is exemplified. This consideration explains to us the opening of these pit-craters on this part of Hawaii, and for their absence from other parts. Had the sides of the mountain below been able to stand the vast pressure of the lavas which once rose to the summit of this pit, Kilauea might have been the centre of another rising dome or volcanic cone like Mount Loa.

From the calculations, it appears that the slopes of Mount Loa from the summit to Kilauea, to the nearest point on the south coast, and to the nearest point on the west coast, are severally approximately equal; and that these same declivities continued, would have finished off the dome within five miles southeast of Kilauea. We therefore see that these craters and this great scene of action, is situated just over the proper limits of the main dome; and that eruptions in that region and beyond have been the means of the extension of the base of the mountain twenty miles to the eastward. It is by no means very improbable that the outbreak which produced Kilauea may have been an early step in the progress towards this result.

II. ISLAND OF MAUI.

Maui* lies about twenty miles northwest from Hawaii, and is the next largest as well as the next highest island in the group. Its length is fifty-four miles, greatest breadth twenty-five miles; and area six hundred and fifty square miles. It consists of two peninsulas, which are distinct in their slopes and elevations, and are connected by so low a neck of land that vessels have at night made the fatal attempt to pass across. The annexed sketch of its outline, as seen from the southward, is imperfect, yet too instructive to be rejected. Clouds concealed



ISLAND OF MAUI.

at the time the rest of the view. It shows the double character of the island, and its slopes as seen in the distance at sea.

The eastern peninsula resembles one of the mountains of Hawaii.

* The author only had views of the island when passing in the Peacock and Flying-Fish. It was visited and examined by Dr. C. Pickering and Mr. J. Drayton, from whom the facts stated are mostly derived.

The elevation, poetically styled Hale-a-kala, "House of the Sun," has the general form of Mount Kea, with nearly the recent appearances of Mount Loa, and its height, as determined by the Expedition, is 10,217 feet. The western peninsula consists of a mass of peaks and ridges, apparently without order or system; yet all evidently belong to a single region of igneous action. The highest point, Eeka, is 6130 feet in altitude.

The shores of the island differ as strikingly on the windward and leeward sides, as those of Hawaii. Where exposed to the trades between the north and south of east there is abundant vegetation, as the rains are frequent and streams numerous. This is described as the best region for potatoes on the islands, and good for wheat. Deep valleys cut into the mountains, which at the shores are six to eight hundred feet deep, and gradually diminish upward, corresponding thus in size with the force of the descending torrents at different elevations. But on the leeward sides, the country is dry, and vegetation scanty. "At Lahaina," on the southwest shores, "it scarcely ever rains, and seldom more than half a dozen times a year." The consequent sterility presents a strong contrast to the appearance of the Koolau coast. Irrigation has long been resorted to on the shore plain, and it is said to have been a custom of former times that each farmer should have the use of the water every fifth day.*

East Maui.—Hale-a-kala is quite regular in its slopes in different directions, with the exception already stated that its windward side is interrupted by gorges. It has the general form of an obtuse cone, and contains at summit the remains of one of the most remarkable craters in the group. By a simple calculation we ascertain that the average inclination of its sides is eight to ten degrees, thus exceeding a little the steepness of Kea and Loa. There are many parasitic cones over its sides, and fresh-looking fields of lava. But the deep valleys to windward indicate a long cessation of its fires. The natives have a tradition that *Pele*, the goddess of Kilauea, once lived there, until frightened by the sea coming too near, when she fled to Hawaii. Such a tradition may be only an inference of the people from a resemblance in features and the appearance of the rocks, to the Hawaiian volcano, but we are inclined to consider it a relation of an actual fact, inasmuch as the same fact is deeply imprinted on the mountain itself.

* Rev. C. S. Stewart, *Missionary Herald*, xxi. 40.

We may therefore believe that its extinction took place since the natives arrived at the islands, or within the past two thousand years. The natives also point to a certain field of lavas which dates back only two or three centuries.

The crater of Hale-a-kala, according to the measurements of Mr. Drayton, is *one to two thousand feet* deep, and thus surpasses the more famous Kilauea. In diameter, also, it is greater, the circuit being stated at fifteen miles. A sketch of it is here given, copied and reduced from Mr. Drayton's drawing, as published in the Narrative of



CRATER OF HALE-A-KALA.

the Expedition. The walls are steep, but may be descended, with some difficulty, in any part. On two sides, the east and north, they are broken down, and a gorge commences, one to two miles wide, which continues down the slopes towards the sea, though gradually diminishing in depth. These are the grand openings which were made at the last summit-eruption, and gave passage to its lavas. The eastern gorge of the crater is floored with the solidified stream, and the surface in many parts has all the tortuous ropings

and plaitings of a recent flood from Mount Loa; while in others there are large clinker fields. Over the bottom of the crater, towards the commencement of the eastern gorge, sixteen cones were counted by Mr. Drayton, besides thirty or more sand hillocks. Dr. Pickering remarks, that along the middle of the stream, which is no where less than two miles wide, as far down as he examined, (about three miles,) there was a line of small conical hills. Like those of the crater, they consisted of scoria or cinders, and varied from one to five hundred feet in height. The scoria was generally light, and had a reddish tinge; in other parts it was black, and resembled comminuted pitchstone. This great lava stream continued of nearly uniform width, confined by its lofty precipitous walls, about half way to the foot of the mountain. It then expanded to the southward, as shown in the following sketch: the lower part, as seen from the sea, had the form of an immense delta. Several ravines in the upper declivities terminate abruptly against that part of the stream which stretches south, showing that they were

formed before the eruption, and that the continuation of them below was filled up and obliterated by the lava. The slope of the stream from the sea to the summit is nine and a half degrees in average inclination. (Part of the view was obscured by clouds, when seen by the author.)



PART OF SOUTH-SOUTHEAST SIDE OF MAUI.

The *north* gorge takes nearly a straight course to the sea. From the account of it, given me by Dr. Pickering, it contains evidence of recent action in its ropy lavas and cinder cones, like the eastern, though less striking; and they evidently belong to the same eruption.

If these gorges are the result of the convulsions attending the last summit-eruption, as seems most probable, they tell of violence beyond conception. The forces ruptured the mountain in two directions, opening a deep cut from its top to its very base, and separating a segment nearly equal to a fourth of the whole cone. The eastern opening was evidently the course of a series of fissures, as its line of small cones indicates; and its lavas, therefore, though flowing in part from the crater itself, were also ejected along its whole course, or through a considerable portion of it. What has become of the material that once filled these immense gaps in the mountain? We can only say, that it is gone. The valleys left, 2000 feet deep and one to two miles wide, extending towards the sea, may well compare with the famous Val-del-Bove of Etna.

Evidences of other eruptions over Hale-a-kala are in many places apparent. But the only one of which we have any distinct mention

is indicated by a line of small cones extending down the slope on the southwest side, and near the base of the mountain, in the same line, by a stream of lava. This is the region where, according to the natives, an outbreak took place about two centuries since.

The rocks of Hale-a-kala resemble those of Hawaii. The scoria and pitchstone cinders of the crater have been mentioned. There are also the usual gray and black basaltic rocks or lavas; there are, besides, feldspathic rocks, allied to clinkstone, and resembling a similar rock on Mount Loa. Loose tabular crystals of a glassy feldspar were obtained in the crater, which were nearly transparent, and about half an inch in breadth. They prove, on analysis, to be a new mineral species, for which we propose the name

Mauilite. Crystals tabular. Cleavage in one direction perfect, in a second less perfect; angle between the two $93^{\circ} 15'$. Specific gravity 2.887. Hardness 6. Transparent and colourless, with a highly vitreous lustre. Streak white. An analysis by Prof. Silliman, Jr., afforded—

Silica,	-	-	-	-	-	-	41.56
Alumina,	-	-	-	-	-	-	45.07
Soda,	-	-	-	-	-	-	12.74
Magnesia,	-	-	-	-	-	-	0.52

which corresponds to the formula $\overset{\cdot\cdot\cdot}{\text{Al}}^3 \overset{\cdot\cdot\cdot}{\text{Si}} + \overset{\cdot\cdot\cdot}{\text{Na}} \overset{\cdot\cdot\cdot}{\text{Si}}$.*

Dividing Plain or Isthmus.—The plain between the two mountains of Maui, in its lowest part, is but a few feet above the level of the sea at high tide. The breadth is about ten miles and the length fifteen. It slopes gradually, in some parts almost imperceptibly, into the acclivities of Hale-a-kala, and is properly the foot of this mountain, uniting it to the western mountains. The surface consists mostly of loose sand, with clayey or even marshy land in some portions. The sands are in part of coral origin, and appear as if of beach accumulation. The surface is arid, bearing scarcely any verdure.

* "The crystals subjected to analysis weighed less than a gramme. They were finely pulverised with the aid of water, and .8036 gramme was decomposed by means of hydrofluoric acid gas in a suitable apparatus of platinum. By this means, the silica was removed, and the whole was rendered soluble in dilute hydrochloric acid. The alumina was separated as usual, and the process of Berzelius was employed to separate the magnesia from the alkalies, i. e. by addition of oxyd of mercury and the dense solution of the mixed chlorids. The formula given requires the following proportions:—Silica, 40.78, Alumina, 45.41, Soda, 13.88, which rejects the magnesia as an unessential constituent."
—B. S., JR.

In some places Dr. C. Pickering found the sand penetrated by tubular concretions, standing upright or variously bent, consisting of sand compactly cemented. They "look as if formed by large Annelids; but the interior surface was too irregular to be other than the result of mineral concretion." The exterior is also quite rough. They occur at an elevation of fifty to one hundred feet above the sea.

West Maui.—The general features of West Maui are much like those of Madeira, the valleys being deep, the declivities very abrupt, and the ridges sharp and broken. Every portion bears evidence that the fires long ages since ceased their action, and left the land to the wearing action of running water and decomposition. There are high cliffs on some parts of the northern coast, but in general the sea is bordered by low land. Lahaina on the west shore is situated upon a plain, half to three-fourths of a mile wide, and beyond it there are mountains "gloomy with ravines and frightful precipices of black rock and lava." Some small lateral cones occur on the declivities, one of which stands just back of Lahaina-luna. But there is no great central crater, and none of its peaks are of this nature.

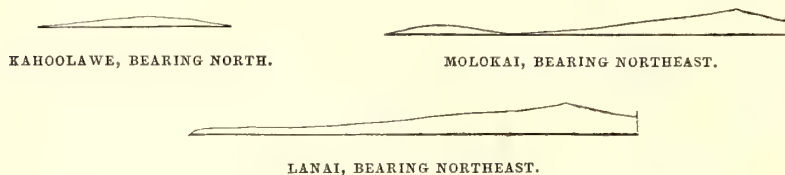
The rocks consist of compact and cellular basalt or basaltic lavas, besides the feldspathic clinkstone. On the northeast shore there are cliffs of conglomerate three or four hundred feet high; and along the pass through the mountains Dr. Pickering observed this conglomerate 2000 feet above the sea, consisting of half-rounded fragments.

Coral borders the shore on some parts of West Maui, though the reefs are not as extensive as on Oahu. It is also said to be found at a height of 500 or even 800 feet above the sea. It is described by Rev. Mr. Andrews as occurring adhering to the rock and in crevices, besides in loose masses; and in some places the stones look as if they had a thick coating of whitewash. No distinct ledge has, however, been met with, and there may be some doubt if the facts prove an elevation of the island. We shall recur to this subject again.

III. KAHOOLAWE, LANAI, MOLOKAI.

But little information with regard to the structure of the islands Kahoolawe, Lanai, and Molokai was obtained by the Expedition, beyond that, generally known, of their igneous origin and resemblance to others of the Hawaiian Group. The gentleness of their slopes in

a distant sea view are shown in the following cuts, which, though unfinished sketches, illustrate a point of geological interest.



Kahoolawe is a low nearly level island, lying seven miles south of Maui. It is but twelve miles long and five broad, and has an area not exceeding fifty square miles, with the highest part about five hundred feet above the sea. The surface is barren, and there is no fresh water, excepting a brackish pool; facts which are explained by its little elevation, and its situation under the lee of Hale-a-kala. Cliffs two hundred feet high nearly encircle the island, and are distinctly stratified; and the layers of basaltic rock, as seen from ship-



ISLAND OF KAHOO LAWE.

board, have a slight but perceptible dip away from the centre. There is an extinct crater upon the highest part of the island, which, like Moku-a-weo-weo, is not surrounded by a prominent cone. Besides this central pit, I was informed that there are two extinct cones resembling Diamond Hill of Oahu, though smaller: one of them, Canapo, is near the northeast side, and the other, Lipi-lipi, is towards the northwest.

The island resembles the summit of a flat dome. Calculating from the extent and height, allowing two hundred feet for the cliff, we obtain for the inclination of the surface only fifty to a hundred feet to the mile.

Lanai lies eighteen miles north of west of Kahoolawe, and but eight miles from the southwest shores of Maui. It is twenty miles long, about nine broad, and has an area of one hundred and fifty square miles; its longer side ranges with the general course of the group. A sloping mountain about 1800 feet high, intersected by valleys running in the direction of the slopes, forms its southeastern end; while

northwestward the declivities lengthen out into a long dry plain, without forests, having a scarcely perceptible inclination, and terminating in a cliff of one to two hundred feet.

Molokai is nine miles north of Lanai, and about the same distance north of west of Maui. It is a narrow island, thirty-five statute miles long and averaging seven in breadth, with an area of about two hundred and twenty square miles. It trends east and west. In a distant view from the south it appears like two unequal islands united by a strip of low land,—in this respect resembling Maui, though much less lofty in its heights. The western elevation is quite low, and the surface very dry. The eastern mountain rises to a height of 1500 feet, and is called Mount Olokui. On the north side there is a long range of vertical cliffs 1500 to 2000 feet in height; but in the opposite direction the slopes are gradual, and are traversed by many valleys running seaward. In the sides of these valleys the stratified structure was distinctly seen from the vessel as we passed by the southern shores, and the layers were observed to slope at a small angle away from the interior. There are many lateral cones, some of which were visible from the ship.

Coral has been obtained on this island, as we were informed by Rev. Mr. Andrews, at a height of three or four hundred feet above the sea, which still exhibits the structure of recent specimens. It extends over a surface of more than twenty acres on the acclivity of the eastern mountain, two or three miles from the sea; and descending from the locality, it was traced almost to the sea.

IV. ISLAND OF OAHU.

I. GENERAL FEATURES.

Oahu is twenty-eight statute miles west of Molokai, and trends west-northwest. It has the shape of a trapezium (see map), with the parallel sides facing northeast and southwest. The length of the trapezium is thirty-five miles, the breadth twenty-one, and the area six hundred square miles. The two parallel lines of coast, the northeast and southwest, are faced by ranges of mountains, and between them lies a large tract of low, nearly level land. The island is thus a twin of mountains like Maui, and the intermediate plain is properly the foot of the eastern range. We designate the mountains

on the northeast, the Eastern Range, and those of the southwest the Western Range. These mountains have an irregular serrated outline, and are intersected by deep valleys. Two peaks in the former, adjoining the valley of Nuuanu, called Konahuanui and Waolani, are about 4000 feet high; and the peak Kaala in the latter, as ascertained by Dr. Gairdner, is 3850 feet in altitude.

There are no mountain craters and no distinct cones among the summits of the range. Yet there is a general regularity of structure, which enables us to trace out the relations of these heights to those of more simple outline. The *dividing plain*, as we call the intermediate low land, slopes into both ranges of high land, and gradually declines on opposite sides to the sea. Its height, where greatest, is about six hundred feet.

The mountain declivities, for the lower six to ten hundred feet, are mostly covered with a growth of grass; beyond this, they are enveloped in forests. The shore plains on the southern or leeward side are dry, and the dusty soil of Honolulu is scarcely laid by a day's rain.

The shores of the island are deeply indented on the south side, where the dividing plain reaches the sea, and there is here a delta-like area of shallow waters or lagoons seven miles in breadth. There is another bay of larger size, more open to the sea on the northeast side, called Kaneohe Bay.

Through a large part of the circuit of the island, as shown on the map, there are extensive coral reefs, and to this feature, Oahu is indebted for its principal harbour,—the one at Honolulu. The elevated reefs, the extent of which is shown by the yellow tint on the map, give increased interest to the geology of Oahu.

The island is well watered, even on the leeward side, owing to the peculiar character of the mountains. The largest stream empties near Wailua on the northwest, after having cut a deep course through the dividing plain. It rises in the northwestern declivities of the Eastern Range, and in rainy seasons receives additions from the Waianae Mountains. Till within half a mile of the coast it is but a rivulet; here it is enlarged from some subterranean springs and from the influx of the sea, and becomes a river sixty or seventy feet wide and six feet deep. From the same region, two or three streams flow southward into Pearl River lagoon. There is another stream worthy of mention on the northeast side of the island in the Koolau district, which flows from the mountains over the plains of Kailua, passing through some pretty lakes; it has a width towards its mouth of eighty feet.

The streams of the mountains occasionally become subterranean, and several appear again at the shores, gushing up in copious springs or fountains. One spring of this kind near Ewa has sufficient force in its waters to turn a mill.

In the farther account of Oahu we may speak separately of the two divisions, the eastern and western, and afterward take up the subject of the coral reefs and reef rocks.

2. EASTERN DIVISION.

The ridge which forms the backbone of the eastern division of Oahu has a jagged outline, presenting many angular peaks, and some towering summits. It commences rather abruptly at the east point of the island, called Makapuu, and seesaws along at an elevation of one thousand to two thousand five hundred feet, till near its centre, where it rises into the two massy elevations Kónahúanúi and Wáoláni, between which there is the deep break which forms the head of the valley of Nuuanu. This wide valley commences on the south near Honolulu, and at the precipice at its head—the *Pali* of the natives—the ridge is but twelve hundred feet in height, or nearly three thousand feet lower than the lofty peaks that overlook the pass.

The opposite declivities of this range are totally unlike. In a view from the southward, we observe that the land rises gently from a shore plain to the summit, and the declivities are cut through by a great number of valleys leading toward the shores. These valleys are large and extensive, so that the whole country, as shown on the map of the island, is a succession of narrow ridges and deep gorges, which widen as they open towards the sea. This is the prevailing character of the surface on this side from Makapuu to the dividing plain; and further west and north the features are still the same, except that the slopes decline into this plain and the valleys take the same course.

But in a northern view, a long mural precipice is presented, extending the whole distance from Makapuu to the west cape of Kaneohe, twenty miles. It is nearly vertical throughout, and the crest of the range is the brink of this precipice. The height is, therefore, from one to four thousand feet.

The general features are exhibited in the following sketch, taken near Kaneohe. It includes the peak Konahuanui, and a portion of the wall either side, with the Nuuanu pass or Pali, near the middle of the

view. The precipitous front is vertically fluted by narrow gorges, some of which are abrupt winding ravines of great depth. Below the preci-



VIEW OF PART OF THE KOOLAU PRECIPICE.

pice, there is only a narrow strip of land, varying in width from half a mile to two and a half miles,—a small extent compared with the length of the southern slopes. The view of this mountain wall is one of the most remarkable in the Pacific. Its lofty front might in other regions be cliffs of bare rock, but in these tropical climes, the rocks are only here and there distinguished through the dark verdure, and no talus of fallen fragments lies at its base. From the Pali, the mural heights, the almost inaccessible pass below, and the plantations, villages, and bay of Kaneohe, make a scene of unusual grandeur and beauty.

We may add a few more particulars respecting the valleys and ridges of this mountain range. The valleys seem to the explorer like passages to the very heart of the mountain. They are entered not far from the shore, and are at first of considerable breadth; but, a short distance in, they become narrow gorges; the stream has barely room to leap and dash along its rocky bed, while the ridges on either side are several hundred feet in elevation. Continuing on, many a cascade appears in view playing amid the verdure of the declivities, and the shifting scenes afford constant delight and surprise. At last the valley is suddenly closed to farther progress, for it ceases abruptly against a bluff wall, the very midrib of the mountain. On the north coast, near Laiée, there is a narrow gorge which has already become a place of much resort for the grandeur of its scenery, its shaded recesses, its lofty walls, and the cascade that pours down the precipice at its head. A few valleys are broad expanded plains even

to their head. Of this character is the Nuuanu Valley, back of Honolulu; and another a few miles farther west is said to be similar.

Still another kind of valley occurs where the general surface of the country is nearly level, as in the dividing plain of the island, or where the slopes are very gradual. They are deep channels cut out of the rocks, with vertical walls of two to four hundred feet, and a narrow riband of land at bottom through which the stream takes a serpentine course.

The ridges separating the valleys have broad flat slopes where they first rise from the shore plain, or after the first one or two hundred feet of ascent; but beyond, they become narrow and irregular. Many terminate in a thin ridge running up to the crest; others break off abruptly before reaching it, and precipitous depths of great extent intervene. The sides of these ridges are occasionally abrupt and lofty, and some portions appear as if formed of rounded buttresses or clustered columns, constituting a sublime style of mountain architecture. Just west of Kaneohe Bay there is a spur of this kind, fifteen hundred feet in height. It stands by itself like a temple cut from the hills, and we look almost unconsciously for an entrance to the solemn grandeur of its interior.

A remarkable feature of the country gradually opens to view, as the voyager approaches the shores of Oahu. Besides the hills and valleys of the interior, there are at several places along the coast isolated elevations of a broad conical shape. They have an earthy stratified appearance, and are much gullied down the slopes. In certain views, a glimpse is obtained of a large cup-shaped cavity at top. These are tufa craters, singularly fresh in their appearance, although they have evidently been long extinct. Some of them form the prominent capes of the island. One of these tufa craters stands against the side of the hills, just back of Honolulu, significantly called the Punch-bowl: it is a capacious bowl, five hundred feet in height. Diamond Hill is another, still larger, forming the southernmost point of the island. At Koko Head, near Makapuu Point, and east of Kaneohe Bay, are similar subordinate cones.

A. *Geological Structure and Constitution of the Eastern Mountains and Lateral Craters.*

a. *Mountains.*

Structure.—The many valleys of the south and west are deep sections exhibiting the interior structure of the mountains. Yet the declivities are so enveloped in foliage and earth, even where steepest, that only general facts are open to view. The stratified structure of the whole is, however, apparent in every part, from the foot of the hills to the summit, black stripes of rock in many places showing themselves through the verdure. The dip of the layers is uniformly away from the crest to the shores, until approaching the dividing plain, where it becomes more southwesterly, and beyond this to the northward, it is even westerly. In other words, the layers have the slope that characterizes the mountain as a whole, declining towards the circumference of a circle that might be described through Koko Head, Diamond Hill and the dividing plain. Farther to the northwest, the layers slope northwest, following in this way nearly the points of the compass. In the lofty wall which faces the north, only the edges of layers are exposed.

The dip is small, being but five to eight or ten degrees: and it is as uniform in amount as in direction; for there are no tiltings—no anticlinal and synclinal valleys. Every gorge is alike on its opposite sides as far as they can be studied. Such simplicity of arrangement affords little material for particular description.

Rocks.—The material of the layers is mostly a black or brownish-black basaltic lava, containing chrysolite. It is a heavy rock, more or less cellular, like much of the basaltic lava of Hawaii and Maui, and sometimes has the ropy surface of a recent eruption. When the cellules are few, as is commonly the case, it breaks with a nearly smooth or splintery surface, and a slightly glistening lustre. Excepting the chrysolite, no crystals or grains of any kind are to be detected.

This black variety passes also into grayish or bluish rocks of similar constitution, but containing less iron. They vary in compactness and in the proportion of chrysolite.

These again graduate into a clinkstone like that of Hawaii. At a locality about three miles east of Honolulu, a variety of this rock has

a light gray colour, and is speckled with a white soda feldspar which constitutes the greater part of the whole: but besides, there are dark green points of impure augite. The rock is exceedingly compact, without a trace of a cellule, and it breaks into coarse plates or slabs owing to a lamellar structure.

These solid layers alternate at times with *conglomerates* and *tufas*.

Many of the conglomerates are beds of rounded stones and gravel, of the same material as the mountain. Others are compacted beds of basaltic earth, and have a tufa character. The material in a few places consists of true volcanic scoria and cinders, the former twisted and ropy, and the latter looking like comminuted pitchstone; and the whole is so loosely aggregated as to crumble in the hands.

The alternation of the solid and conglomerate layers may be seen in many places. At the Pali, it is well exhibited, and in some portions of this mountain wall the latter constitute a large proportion of the height. In many of the gorges near Ewa the same is shown. A section exposed near the Ewa church, contains a series of layers composed of rounded stones and earth, loosely compacted. There are twelve feet of basaltic earth between two layers of the loose conglomerate, and another tufa layer overlies the upper conglomerate, about sixty feet above the sea. The conglomerate layers are very irregular, graduating frequently into the finer kinds, and forming isolated beds.

At Waipeo, where is presented another section of the same plain, there is a clayey deposit of a tufa character, three or four feet thick. It lies thirty-five feet above the sea, and below twenty-five feet of the soft layers of basaltic earth and pebbles.

At the foot of the mountains near Honolulu, and farther east, the layers are mostly basaltic lava, with rarely any of the conglomerate intervening. They have in general nearly the ragged appearance of recent lava, though not scoriaceous. The under surface of the black layers is rough and uneven. Many a cavern opens upon the sides of the valleys, some of which are the habitations of the natives, and others their burial places. Like those of Hawaii, they are merely vacant spaces left beneath the streams of rock as they flowed along at some former period. In one of them, I made my way over scattered bones and skulls for one hundred yards, through which distance it varied in height from six feet to three and a half. Beyond, it became too low for farther exploration. The roof was rough, and in some parts had a thin calcareous coating.

The basaltic rocks present frequent traces of a columnar struc-

ture, though well-formed prisms are not common. The size of the prisms had an obvious relation to the depth of the bed.

A columnar structure is finely displayed in a *baked tufa* east of Diamond Hill. The bed of tufa lies beneath a layer of the black basaltic lava, from which the heat was derived which produced the change in the tufa. The texture had been rendered quite firm and hard, and the colour, in other parts dirt brown, is changed to a deep red. The prisms are very neatly regular, and mostly hexagonal; they are one to two inches in diameter, and three or four long. The effects of the heat are not apparent below six inches.

Lateral Craters of the Eastern Division of Oahu.—The lateral or shore-craters have many points of interest, and merit particular description. On the south side of the island, they form four distinct regions, in some of which there are several craters. *Koko Head*, near the east cape, is one of these regions:—*Diamond Hill*, eight miles west of Koko Head, along with other craters east of Honolulu, constitute a second;—*Punchbowl*, behind Honolulu, is a third;—and the *salt lake* region, seven miles west of Honolulu, is a fourth. To the north of the Pali, there is a single district, constituting the east cape of Kaneohe Bay. About the Pali itself, there are indications which appear to deserve notice in connexion with these lateral points of eruption.

Diamond Hill.—Diamond Hill is one of the largest and most remarkable of these secondary cones. Its height varies in different parts from five to eight hundred feet, and it is full a mile in diameter at top. The bowl or crater has nearly the curve of a saucer, and is neatly smooth, without a loose stone to deface it. There are a few blades of grass about the centre, where the waters collect and remain for a while during the rains.



DIAMOND HILL, AS SEEN FROM THE WEST.

The sides are deeply gullied by the rains, or rather by rills of water caused by the rains; which have reduced the once smooth and gradual slopes to steep declivities, presenting, on a small scale, the

features of the mountain range, with its valleys and ridges. The top is also broken into miniature peaks, which are highest on the southern side. In consequence of this degradation of the sides, the stratification is distinctly seen far at sea. In the first distant view the lines appear to indicate different streams of lava, but on closer inspection they prove to arise from layers of tufa. The tufa is very friable, yielding easily to the fingers. It consists of thin laminæ, as distinct as many alluvial deposits, and often separable. The layers vary in texture from a fine earth to a bed of pebbles, and have a brownish colour. They are often incrustated by a chalky coating of carbonate of lime, or are interlaminated with thin calcareous seams or plates.*

The extent of degradation over the sides of Diamond Hill is very apparent in the fact that the layers constituting it present exposed edges on nearly every side of the cone. It is on this account a less satisfactory place for ascertaining the dip of the tufa than at some others of the tufa cones. Where best exhibited the angle appeared to be about thirty degrees. But the dip of the exterior and interior are in a reverse direction, the latter sloping *towards* the centre, instead of outward. The rim of the crater is in the dividing plain between the opposite slopes of the layers. In appearance there is an anticlinal axis; but it is obvious that the ejected earth and cinders, as it formed a rising barrier around the opened vent, would fall on two declivities,—the *inner* or that within the crater, and the *outer* or exterior of the cone. The layers resulting would have this double slope, as is exemplified by most tufa cones.

Although no lavas can be traced from this crater, large streams lie near its eastern foot. Between Diamond Hill and the mountains, a distance of a mile, there is a slight elevation of the country, and about half way there are remains of a crater; yet it is so low as to be barely traceable in a distant view, and is only a hundred feet above the



sea. The crater is nearly circular, about three hundred yards in diameter, and fifty feet deep. This vent appears to have been the source of the lavas alluded to that now cover the plain near Diamond

* A somewhat similar occurrence of lime at the Cape Verdes, is mentioned by Mr. Darwin in his *Volcanic Islands*, p. 13.

Hill; they extended either side to a distance of half a mile to a mile, and the surface consists mostly of loose blocks of the black rock, with a little reddish earth between them. The interior of the crater is covered with similar blocks and fragments of lava, with much scoria. The scoria is very cellular, and occurs in twisted pieces of brownish-red and purplish shades.

There is still another cone in this Diamond Hill region, standing at the foot of the mountain declivities, nearly in a continuous line with the preceding two. It is a small and steep hill, about two hundred and fifty feet high, consisting wholly of blocks of black basaltic rock, one or more cubic feet in size. The cone is broken down on the south side, and there are two rounded eminences on the north and northwest; and below these an uneven plain slopes away to the lower grounds around. The tracts of lava blocks around this hill are continuous with those of the crater just described, and extend westward about a mile.

As Diamond Hill and these two craters are upon the same line, they may have originated in the opening of a single fissure, and have been cotemporaneous in their ejections.

Punchbowl.—Punchbowl is much smaller than Diamond Hill, yet resembles it in general character. It has the same arid aspect and brownish tufa sides. The height of its summit above the sea is about five hundred feet, and the diameter at top not far from six hundred yards. The cavity of the crater is very shallow; and the side to the south and southwest is about two hundred feet higher than the opposite. Nearly the whole cone consists of thin layers of tufa, which, as in Diamond Hill, lap over the rim of the crater, and slope both inward towards the centre, and outward to the plain around.

The tufa is very neatly laminated, and seams and incrustations of carbonate of lime whiten it in all parts of the crater, having the chalky appearance already described. The dip inward and outward is about thirty degrees.

This crater does not consist solely of tufa. Ascending from Honolulu towards the fortress at top, we passed over two dikes of basaltic lava intersecting the tufa, which are respectively three and twelve feet wide. They appear in sight for a few rods only, and the tufa on each side is hardened and fissured parallel with the walls. The rock is a dark gray basalt containing some grains of chrysolite and a few particles of augite; that of the smaller is compact, excepting the centre which is cellular for about a foot in width.

Besides these dikes, there is a rocky crest at summit, which consists of cellular lava and scoria, having every appearance of recent fusion in its twisted, ropy, and stalactitic forms. The lava appears to have been thrown out in successive jets, which became partly fused together as they fell. On the east side of the Punchbowl there is a gap through which the waters of the rains drain off; and near by, there has been another outbreak of lavas, and a jetting of scoria, which has formed a pseudo-conglomerate. The gap was probably opened by the eruption which ejected these lavas. There are several vertical seams in the tufa sides of this gap, which are filled with uncrystallized carbonate of lime, like the white incrustations of other parts of the crater.

The eruptions of the Punchbowl have covered the plain between it and the sea—a mile distant—with tufa deposits. For the outer half mile, the deposits are thin, and form alternations with coral sand. We see no evidence around the crater that extensive lava streams have ever flowed from it.

About a mile east of Punchbowl, at the entrance of one of the valleys, there is a low elevation, which appears to be the remains of another crater. The lava stands out in peaks and ledges of solid rock, among which are large masses of scoria and twisted fragments half melted together. Four hundred yards to the east, there is still another hill, consisting of compact black basaltic lava, which is much fissured and broken into subcolumnar forms. It is surrounded by a tract of black lava, which appears to have been ejected from two or more fissures.

Koko Head Craters.—Koko Head is a narrow point of land, extending south or southeast from Makapuu Point. Its position may be seen on the general map of Oahu; but its topography will be better understood from the accompanying plan. It is occupied by two tufa eminences, about a mile distant, one of which contains a large crater, and the other is the remains of two or three craters.

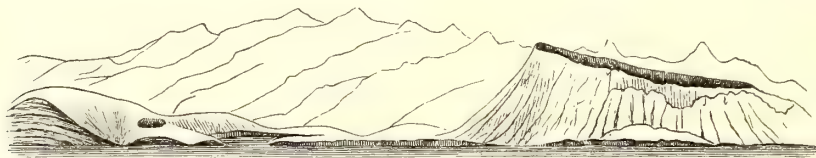
The northern, which is the more perfect, (on the right, in the figure,)



KOKO HEAD.

It is very

obliquely truncate at top, owing to the action of the trade-winds attending its formation, and not to degradation. The southwestern side



VIEW OF KOKO HEAD CRATERS, FROM THE EAST.

is the highest, being by my estimate seven hundred feet in elevation. The cavity within is nearly as deep as the height of the cone, the interior having apparently been worn out by water, for which there is an exit by a deep gap on the northern side.

The southern hill is about three hundred and fifty feet high. It forms a segment of a circle around a small circular cove, towards which the slopes incline. This cove has evidently been a centre of eruption; but it was possibly subordinate to a larger vent, which has disappeared beneath the waves, as may be inferred from the extent and position of the ridge, and the cliff which exhibits a section of this ridge. The north side is much the lowest, (but eighty feet,) for the same reason as in the case of the crater above mentioned.

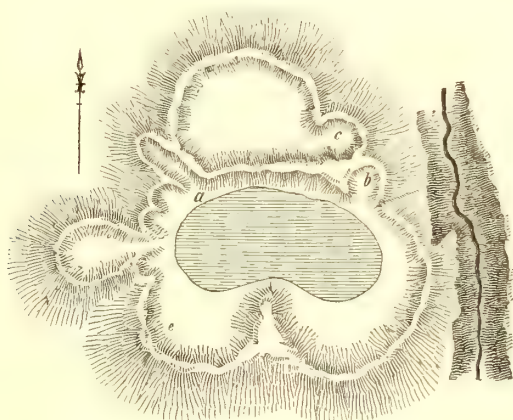
Upon the inner slopes of this hill, not far above the cove, there is a more recently formed crater, about two hundred and fifty yards across.

The layers of tufa dip in various directions, owing to the number of combined vents which have here been in action. In the highest part of the ridge they lap over it, dipping outward towards the west, and inward towards the east, as in the other cones examined. But near the subordinate vents, the dip corresponds, according to the same principle, with the position of these vents. The layers around the small crater in the side of the ridge lie over the others, and are of most recent date. About half way up the ascent to this small crater, there is the only bed of lava I saw about this region; and it was evident that it had flowed from this vent.

The tufa is very similar to that of Diamond Hill, and like that is interlaminated with lime. The layers are often less than a line thick and very distinct. One hundred and fifty feet above the sea, I found fragments of coral limestone and shells imbedded in the tufa. In some parts large fragments of rock were also included. Some varieties of the tufa have a greenish tint from the proportion of chrysolite, and the

sands of the seashore at the foot of the hill often consisted half of chrysolite.

Salt Lake Region.—The salt lake of Oahu is one of its principal curiosities. It occupies a depression surrounded by a low ridge, and is situated about three-fourths of a mile from the sea, and eight miles west of Honolulu. It is not at first apparent that its site was once a region of hot water and tufa eruptions. Yet, from the character of the tufa, and the direction of its dip, such was the case. There were evidently several vents of considerable lateral extent, but of small force, and they resulted in producing a plain a mile and a half in its longest or east-and-west diameter, bounded by the low ridge referred to. The general character of the region is shown in the annexed topographical sketch, which includes, besides the basins, part of the valley on the east. Two circles united form the larger part of the plain, in



which the lake is situated; but there are three or four others of smaller size farther to the west, in immediate connexion; and one to the northeast (*b*), which is quite deep, and regularly bowl-shape. The ridge on the south is but fifty feet high; while on the north (near *a*) it is two hundred feet. It consists of tufas similar to those described.

Ascending the north side, or that away from the sea, we look down on still another flat plain, surrounded by a low ridge, which, on the north and west, is but forty feet high. In its western corner (*c*) there is a deep bowl-like crater, with a high circular wall of stratified tufa. In structure and composition, the walls resemble those of the other tufa cones. The following view, taken from the harbour of Honolulu,

shows, on the left, the bluff *a*, fronting the lower basin; and to the right, part of the prominent walls of the crater *c*, just referred to.



Fragments of chrysolite are sometimes found in the tufa of this region, half an inch in diameter, resembling the large crystals observed occasionally in some of the compact gray basalts of the mountains. I observed no lavas which had flowed from any of these vents.

There is still a third basin, which is situated to the west of the first, near the borders of Pearl River lagoons. It is a flat plain, nearly circular, surrounded by a low ridge, and in area about half the size of the last.

These three basins occupy together a region about twelve square miles in extent. The more northerly is about forty feet above the lake; and the lake was found by the Expedition to be near the level of the sea at half tide.

The *salt lake* (called by the natives *Alia paakai*), when visited by the author, was nearly a mile wide in its longest diameter, and half a mile in the transverse, and occupied about half the area of the basin in which it lies. The shores are flat, and a rise of a foot would extend it to the enclosing ridge. It was formerly supposed to be fifty fathoms deep, but the long line prepared for sounding it descended only sixteen inches. This was in November, 1840, at which time it was surveyed by officers from the Expedition. In the November of the year following, when examined a second time by the writer, there were but *six inches* of water; and instead of finding salt only about the shores, or on some planted twigs, the whole bottom was covered with a crust of salt, averaging three inches thick and hard enough to support a team of horses. The surface of the crust was beautifully crystallized, consisting of brilliant cubes, mostly a third of an inch in their dimensions. In some places the salt stood up in knobs, as large as the fist, consisting of clustered crystals; and there were columnar or finger-shaped aggregations, made up of a series of these large cubical crystals, which had formed horizontally from the knobs, or parallel with the surface of the water, instead of erect,—a position evi-

dently due to currents in the water produced by the winds, as they point to leeward. They were quite pure, and had no nucleus, excepting a few granules of dirt along the centre. There were narrow fissures through the crust, forming a kind of network over the pond, and showing the muddy bottom of the lake below; the edges of them were somewhat turned up, and the crystals were here larger than elsewhere. A cane penetrated four feet into the mud, without meeting with any resistance. The water of the lake was extremely dense, and had an oily feeling.* Over the flats, on the south side of the lake, the earth or mud was strongly impregnated with the brine, and the salt crystallizing, raised the hardened surface in small blisters, one to three inches in diameter, apparently owing to a fibrous crystallization, radiating from a centre. There were also thin seams of salt intersecting the soil.

In the rainy season, the lake is said by the natives to rise four feet above the above-mentioned level, making in all a depth of five or six feet: and it is then simply a pond of salt water, navigable, and often navigated, by canoes.

At the centre of the lake there is said to be a deep hole, through which the salt water of the ocean, with which it is supposed to communicate, boils up. The object of the author, in crossing the lake, was to examine this salt-water fountain. But, although the spot was found, and the hole seen, there was no flow of water. My native guide said that it did not operate much in dry weather, but when the rains set in, the water boiled up in large volumes. The statement shows some connexion with the streams of the mountains; and this is probably one of those springs that are so frequent along the coasts of the Pacific islands,—a place of exit of some subterranean torrent from the adjoining mountains. Such springs become most copious during the rains, and often entirely fail in dry weather. Along the eastern shores of the lake basin, there are several fresh-water springs, opening at the surface, from one of which I drank; and I have no where found purer water: besides, on the same side, there is a large taro patch, a collection of shallow fresh-water ponds covering several acres,

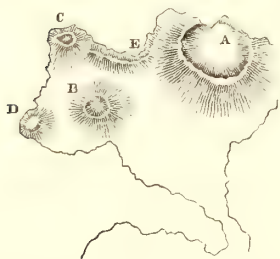
* To protect the feet from the sharp crystals, while wading across the lake, I put on a pair of moccasins, forgetting the action that might be expected from brine. They soon began to tighten on the feet, and before half way over, they became so painful from contraction, that I was compelled to cut them off, when they immediately shrunk to three or four inches in length.

and separated from the lake only by a dam built for the purpose. These waters rise from springs, as just explained.

There have been no satisfactory observations made upon the lake, to ascertain whether the tides of the ocean cause an oscillation. The author spent seven and a half hours on the ground during one day (from 9 A. M. to 4h. 30' P. M.) at the time just alluded to, in order to observe the tides. It was high tide that day on the coast at 12h. 30'. Between 9 A. M. and 10h. 30' A. M., there appeared to be a fall of half an inch. But after this, there were only slight irregular oscillations, depending on the winds, and no evidence whatever of any connexion with the sea.

Incrustations of salt were observed by Dr. Pickering, and afterwards by the author, high up on the bluff in the small gorge at the northwest corner of the basin, one hundred feet above the level of the lake, and half a mile distant. They occurred under a projecting ledge, and were an eighth of an inch thick and less. Dr. Pickering also detected salt plants, a species of *Sesuvium*, in all the three basins, the northern and western, as well as the *Alia paakai* basin; the last two are many feet above the level of the sea.*

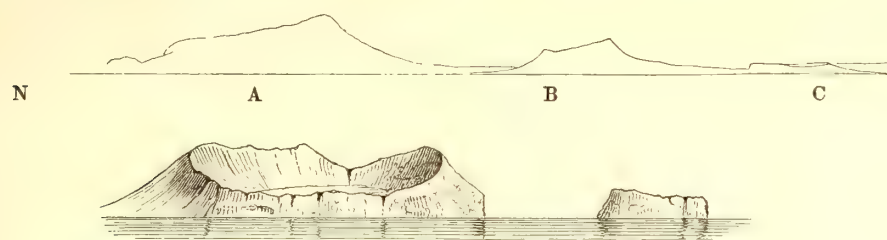
Previous to the rising of the island indicated by the elevated coral reef, this lake must have been many feet beneath the sea; and there is interesting evidence of this in a ledge of coral reef, on the southern ridge of the basin, at a point marked *e* on the topographical sketch of the lake region, page 245.



Kaneohe Point.—The east point of Kaneohe Bay is a small peninsula, eight or nine square miles in extent. Excepting the volcanic hills, the surface is nearly flat, and is formed of coral limestone, elevated a few feet above high water level. There are four of these hills, of which three have remains of craters, more or less distinct. The largest of the craters, A, occupies the outer extremity of the peninsula. Its walls are broken away on the western side, exposing to view the bowl-shaped cavity within. It is like Diamond Hill, except that the inner walls are more furrowed. The sea washes its foot, and the broken condition is owing to the action of its waters. The following sketches show the outline

* Craters containing salt lakes are described by Mr. Darwin as occurring on the Galapagos.—*Volcanic Islands*, pp. 105, 108.

of the point in a view from the northwest, and the general appearance of the largest crater A, and an island N, off the point to the northward, as seen from the northeast.



CRATER A, AND THE ISLAND N.

The crater B, next in size to A, stands back about three-fourths of a mile from the sea, near the western side of the peninsula. In a distant view, this crater has a high conical form, and is obliquely truncated at top. It is mostly a lava cone; and black rocks form a large portion of its northern walls, besides half filling the shallow crater. The outer surface is mostly loose soil. The lava of the eruption flowed off to the northward towards the sea, but is concealed, to a great extent, by the coral sandhills that have accumulated on this side of the peninsula. The rock is extremely compact and heavy, containing but few cellules, and has a black or brownish-black colour, resembling that near Diamond Hill. There are some minute particles of chrysolite. It breaks with a clinking sound and a smooth conchoidal fracture. Externally, the masses exhibit a laminated structure; but when broken, the lamination is not apparent. There are some loose masses of scoria lying in and around the crater.

The crater C, is also a lava crater. It is broken down nearly to the level of the sea, excepting the eastern and western sides, which stand like two rocky hills sixty or eighty feet high. The lava is like that just described, and much of it is broken into large blocks, which lie in confusion together.

There is also a small rounded elevation at D, half a mile to the southeast, which consists of the same basaltic rocks, although there is no distinct crater at the present time. They are not connected with those of the vents just described, and must have been ejected at the spot where they now lie. This is, therefore, a fourth vent.

The small island of rock (N) standing off Kaneohe Point, must be a remnant of a fifth cone: it was not visited.

This closes the review of the subordinate craters or vents of Eastern

Oahu. We barely allude to the scoria beds or deposits of the Pali, at the head of the Nuuanu Valley, as apparently among the most recent indications of eruption in Oahu, though no distinct crater or centre of eruption was made out. The scoria and pitchstone cinders are loosely aggregated, and form a deposit of large extent.

3. WESTERN DIVISION OF OAHU.

The mountains of the western division of the island, are broken irregularly into ridges and peaks, with deep valleys and steep slopes. The outline is not strikingly uneven, yet runs up into several elevated summits, of which Kaala is the highest. As seen from the westward, this peak appears to have a table summit; but from other directions it is pointed. To the south of Kaala, there is a gap in the ridge, where a path crosses to the plains of Waianae, only fourteen hundred feet above the sea; farther south, there is another pass, at an elevation of about sixteen hundred feet.

These mountains are very abrupt towards the southwest. They have, in general, a bold mural front, around the Waianae plains, and are deeply furrowed or fluted, and shouldered up by narrow buttresses, much like the Kaneohe side of the eastern range. But to the eastward and northward of east, the slopes are gradual, and they pass into the gentle declivities of the dividing plain.

The rocks of these western mountains are mostly a gray basalt or graystone, and are often somewhat cellular. They are frequently much porphyritic, small tabular feldspathic crystals being thickly disseminated. Some of the isolated ridges on the Waianae plains (see map), consist of a kind of clinkstone porphyry, allied to the clinkstone of Hawaii and Maui. The colours presented are various, as dull brownish-black, purplish, bluish-gray, and grayish-white; and the compact base is finely speckled, in most parts, with points of feldspar. On decomposition it becomes white, and so soft that it may be used like chalk. Conglomerate layers are abundant in these mountains. Some hills at the foot of the precipice, at the pass south of Kaala, consist of a coarse volcanic breccia, firmly cemented, in which some of the masses of scoria and lava are several feet through. The hills are three to six hundred feet high, and are imperfectly divided into thick layers. They appear to have been formed soon after an eruption of lava, of the angular masses of volcanic rock then ejected, and

they probably lie near or about the vent from which they were thrown out, now so obliterated that it cannot be distinctly traced.

At the same pass several dikes intersect the ridge. There are eleven within a space of fifty yards, and some of them stand out like artificial walls. In other instances the rock of the dike is removed, leaving a deep channel in the declivities. There is a narrow fissure through the mountains at the gap; and the formation of this fissure may have been the origin of the gap, which was subsequently enlarged by degradation. The mountain rises to a height of a thousand feet either side of the pass.

There is a region of small cones and comparatively recent appearances of eruption, near the southwest angle of the island, at the base of the mountains. The craters are three in number, and half a mile to a mile apart. They consist mostly of black compact lava or basaltic rock, and are surrounded by immense quantities of loose blocks, from one to twenty cubic feet in size, resembling the regions near Diamond Hill and on Kaneohe Point. There are remains of a crater in each hill, and in two of them the rock stands up in irregular columnar forms.

The largest of the three may be three hundred feet high; and the lowest is but little raised above the plain.

4. CORAL FORMATIONS OF OAHU.

In the remarks on Molokai, we have alluded to some instances of coral rock found at a considerable height above the sea. About Oahu the elevation of the once submerged reef has not been carried so far; but its extent is much greater, the evidence of elevation is beyond doubt, and the circumstances connected with it are peculiarly interesting.

Coral reef rock.—The elevated reef forms a plain at the foot of the mountain declivities, from five to twenty-five feet above the level of the sea. It occurs along the whole southern shores, a distance of thirty miles, forming also the large flats in the Pearl River lagoon. On the northeastern side, it continues, with few interruptions, from Makapuu to Kahuku Point, the north cape; on the northwestern, it is met with for several miles about Waialua; on the southwestern, along by Waianae and the southwestern cape.*

* On the map of Oahu the surface covered by it is indicated by a yellow colour.

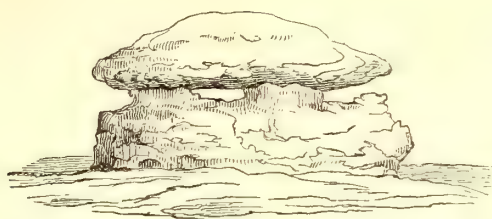
The elevated coral reef is, therefore, not a doubtful heap of corals, but extensive tables of calcareous rock, in many places a mile in width. The whole island is fringed by it to the same extent as now by a growing reef. It has been mentioned that a ledge of reef rock occurs also on the south bank of the salt lake basin, which is now shut off from the sea by a barrier forty or fifty feet in height.

The reef rock is a white compact rock, quite various in structure, as we have described when speaking of coral reefs and islands. Some portions contain the corals imbedded as they grew; but a larger part is a solid homogeneous rock, with only here and there a coral or shell distinguishable; it gives a clinking sound under the hammer, and breaks with a splintery fracture, throwing off, at the same time, sharp fragments. Other varieties consist of aggregated shells, or shells imbedded in a compact calcareous base, and are generally as firm in texture as any secondary limestone. A still more remarkable variety resembles chalk, having its colour, its earthy fracture, and soft, homogeneous texture, and being an equally good writing material, as has been mentioned in the account of coral reefs.

The growing reefs of the island have the same structure as here described for the elevated reef. But, while *Astræas* appear to have been abundant during former times, at present they are comparatively rare, and the corals belong now, to a very large extent, to the genera *Porites* and *Pocillopora*, especially the former. The building material of Honolulu comes from the harbour reef, and consists of a closely branched *Porites* with intermingled fragments of shells and smaller fragments of corals and coral sand; and very frequently the *Porites* is *in place*, with the interstices filled more or less completely with shells and coral fragments.

The elevated reef rock appears to form one, two, or three layers, five to ten feet thick. In some places, it is full thirty feet above the sea; but the average height is from ten to eighteen feet. At Honolulu, it has been frequently penetrated to some depth in making wells; but it has not been bored through. In excavations of this kind, it is usual to find first, two to five feet of soil; then two to three feet of volcanic sand; and below this, the coral reef rock, the depth of which has not been ascertained. At Waialua, on the northwest side of the island, the limestone stands twenty to twenty-five feet above the sea in some parts of the plain, varying from this height to ten feet. There is here an isolated block, which stands on the lower flat of reef rock, elevated upon a kind of rude pedestal, to which it is cemented by large

stalagmites. Off Kaneohe, the islands of coral are six to eight feet above high tide. At the southwest corner of the island, the reef



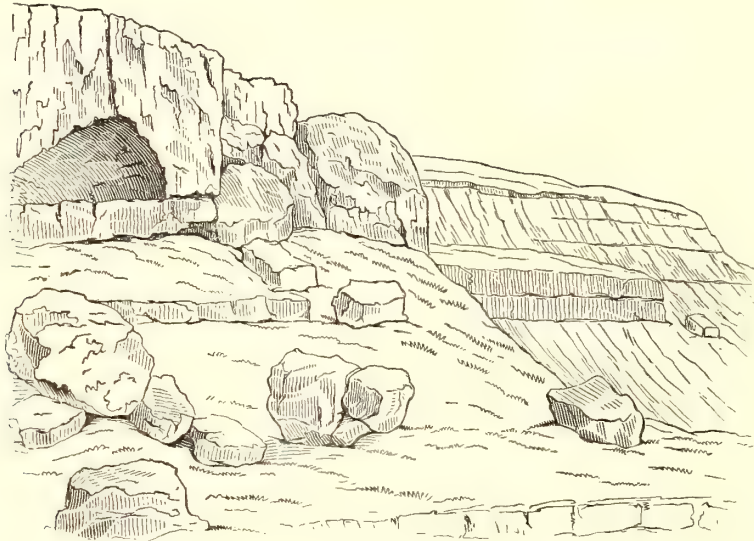
rock faces the sea in a bluff twenty to twenty-five feet high, and large masses, some of which are thirty feet in length, have been undermined, and now lie at the foot of the bluff. On this point there are some places where its elevation is thirty feet above the sea.

The height of the rock thus varies, much like the surface of the submerged reefs. A large part of the bay of Kaneohe is now filled with reefs, which are rarely less than two feet below the surface, while, in many parts, they are ten to twenty feet.

The reef rock contains many caverns, some of which are extensive. There are several of these caverns a short distance to the eastward of Diamond Hill, which are long winding horizontal chambers. Many of the subterranean streams between Koko Head and Honolulu make their appearance on the shores between the layers of this rock, or at the mouths of the caverns; and to the action of these running waters, and others trickling from above, we must attribute the origin of the limestone caves. The limestone plains are, in general, the most barren parts of the island.

Coral Sand-rock.—In some parts of Oahu, the elevated reef is surmounted or backed by hills of coral sand-rock, formed of the beach-sands which were accumulated on the shores when this reef was beneath the water. They occur, like the existing drift-heaps, on the windward sides of the island, from Diamond Hill, where there are some accumulations, around by the east point to the northeast as far as Kahuku Point. On the Kailua plains, and between Laiée and Kahuku, they form prominent bluffs, fifty to eighty feet above the sea and over three-fourths of a mile back from the coast, giving a singular aspect to the scenery. One of these bluffs has been already mentioned in our remarks on coral formations. The front has been broken down, (probably the result of degradations following its elevation,) so as to present a face of limestone, in most parts finely laminated. The

bluff side of the different hills either fronts the sea, or a valley which, at a former period, must have been an arm of the sea. There are many excavations in some of these hills, besides fissures, caused, in some instances, by a previous undermining from the action of water.



One hill of this sand-rock near Laiée is broken into large masses, twenty, thirty, or forty feet in their several dimensions, some of which stand three or four feet apart, leaving deep passages between; it appears as if it had been shattered by an earthquake. The vertical surface, and the cavities below, are covered with a thick stalagmitic crust, illustrating the important agency of the rains towards producing these effects by undermining portions of the hill, and preparing it to be fissured either by its own weight or by earthquakes.

This sand-rock has been described on page 45. Though generally consisting of fine sand, it contains, in some places, pebbles of basalt, especially in the lower layers, as should be expected from the character of the shores on which the heaps were accumulated. Many portions of the present coast afford examples of the agglutination of basaltic pebbles by calcareous incrustations and depositions among them. (See page 44.) The thin laminated structure is interesting, as illustrating its formation from successive driftings, and also the effect of the winds in producing such a structure, even when there is no variation in the quality of the material. The complex character of the lamination is such as would proceed from the causes

at work, which the drift-heaps of all beaches illustrate. It is a correct registry of the various fortunes of the rising ridge; for the gale that swept off the summit, and the winds that laboured again in completing it, have their effects here indicated in the solid rock.

The following cuts represent sections from part of the Kahuku bluff.

Fig. 1.

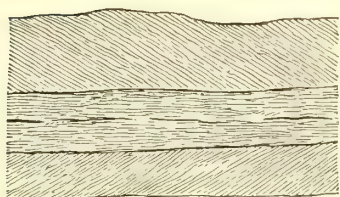
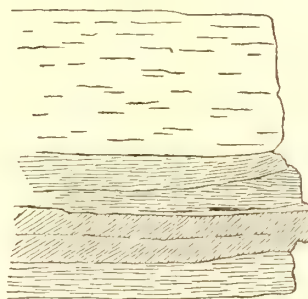


Fig. 2.



a. In the section figure 1, there are three distinct divisions. The upper ten feet are laminated obliquely to the left; the next eight feet are horizontal, but not distinctly laminated; and the lower seven have an oblique lamination sloping to the right.

b. In figure 2, the upper four feet are horizontal; the following ten consist of several subordinate layers, dipping in different directions; and near the middle there are two separate layers, composed each of thin laminae inclined at an angle of thirty degrees.

Fig. 3.



c. In figure 3, representing the upper layer of the Kahuku bluff, the laminae of the lower portion to the left are straight, and incline twenty-five degrees to the left; these are covered with horizontal layers, curving downwards on the left; next above follow several layers, which, to the left, curve downward, and terminate against the surface of the layer below; and so the irregularities continue to the top.

We may easily trace out the steps in the formation of the rock represented in this last figure. *a'* was once near the limit of the bank. It was swept over by a gale or a wave from the sea, and reduced to the outline *a a'*. A series of driftings parallel with the surface followed, during more quiet weather, raising it to the line *b b'*; and afterwards, by a lighter breeze still, the sands were wafted but part way over, producing the shorter layers *c*. Then, by an increase of the winds, the whole surface was again covered, increasing the hillock both in breadth and height. Thus we might pursue it through its recorded history. Some minor irregularities may have been caused by eddies around twigs growing in the sand.

The same shores that now present us with these coral sand-rock ridges or hills, present also *recent* sand-hills near the beaches. At Laiée these recent drift-heaps are twenty-five feet high, and extend back over a surface one hundred yards in width. They have an uneven curving surface above, which is continually varying with the force or direction of the wind. They do not form a continuous ridge parallel with the shore, but a series of hills, with valleys between, trending about east-by-south and west-by-north, while the coast-line faces northeast. One of the long sand-drifts had been cut through by the winds, and the gully formed had a vertical front on the south side; it was again slowly filling up.

This irregular subdivision into hills, elucidates the features of the ridges of sand-rock. Before studying this example offered near by, the occurrence of so many isolated hills instead of a continuous ridge, seemed to be the greatest difficulty in the way of accounting for their formation. We farther learn from the recent drifts, that shells are of very rare occurrence in them. Grass is growing thinly over them, and the surface is often scratched in interrupted lines by the fleet *ocypod*.

The character of the lamination illustrates the formation of siliceous sand-rocks, and all rocks that have proceeded from material drifted by winds. The frequent changes in the direction of the lamination well exemplifies the structure of the Sydney sandstone of New South Wales.

5. GENERAL REMARKS UPON THE GEOLOGICAL HISTORY OF OAHU.

There are several facts in the structure of Oahu pointing towards one and the same theory of its origin, urging us to conclusions which, at the first glance, may appear incredible.

In Hawaii, as has been shown, we have an instance of an island formed by the action of three great vents or centres of eruption, Kea, Loa, and Hualalai. From the features of Maui, it is as evident that the origin of this island must be attributed to two centres of eruption, its two insulated peaks standing apart, and coalescent only at base, like the two great summits of Hawaii. What then follows for Oahu? Is not this double-headed island another example of the conjoined eruptions of two vents, one the eastern, and the other, the western?

The rocks of the two parts have flowed from distinct openings, for they both slope gently towards the dividing plain, precisely as on Maui and Hawaii. In the eastern division, the inclination of the layers follows the points of the compass, the southern side sloping south, the southwestern, southwest, the western, west, exactly as with Mount Loa. Although the inclination is much obscured by the many valleys, we may distinguish a sloping plain along the tops of the ridges which rise from the coast, and from ridge to ridge it is so even in its height, and the layers composing them are so regular and uniform, that we cannot doubt the whole to have been continuous, and subordinated to a single elevation of volcanic origin. On the side of the dividing plain, we may distinctly follow this sloping surface up the declivities, see it become more and more cut up by valleys, yet retaining a uniform angle of declivity.

It is reasonable to infer that the beds of lava, (which must have flowed from some direction,) have flowed from that towards which they rise: and when we find them all pointing upward towards a single central area, can we hesitate with regard to their origin, any more than we can with reference to the lavas over the dome, Mount Loa? The inclination of the layers is small—only three to ten degrees, and the flowing of lavas, at such inclinations, is abundantly exemplified among the forming cones of Hawaii. There are no upturnings of strata, no irregular tiltings in any part of the island; the only tilt, is this gentle slope away from a central area.

These remarks with regard to the nature of the eastern division, apply also to the western range. The only difference is, that, in the latter, the original slopes have been more completely obliterated by valleys, and both the heights and declivities are more irregular.

It is obvious, therefore, that Oahu, although now consisting of two nearly straight and narrow ranges of mountains, one thirty, and the other fifteen miles long, must, at some former period, have been a

twin of volcanic summits like the peninsulas of Maui, or like Loa and Kea on the island of Hawaii.

The question next arises, where were the centres of these mountains situated?—what remains can be found of the great craters?—How was the volcanic dome changed into a narrow mountain ridge? Whether these points admit of explanation or not, the fact that such summits existed, cannot be doubted. Examples have so frequently been observed of volcanic summits without distinct craters, owing to the peculiarity of the closing eruption, or its final phase, that they are no longer considered a necessary feature. Moreover, the degradation which has made the many valleys, each vastly more extensive than the great pit of Mount Loa, was sufficient to obliterate any trace of a mountain crater. But we are led by the facts to another important consideration bearing upon this point.

The sloping layers of basaltic lava, whose accumulation raised the eastern mountains, rise gently from the south and west, and terminate abruptly in the face of the great Pali or precipice. Instead of a mountain, with opposite declivities on opposite sides, as in Kea, Loa, and the summits of Maui, there are only the declivities of *one* side; these are cut short by a section upwards of twenty miles long, which is at the present time, notwithstanding all the extensive degradation that the valleys indicate, from two to four thousand feet in height,—a mountain wall of an extent seldom witnessed, even among the more famous Alps and Andes. Can this wall have been a part of the outline of the great crater? Its twenty miles of length, with so small a curve, would indicate that the crater had been more than sixty miles in circuit. We have no warrant for such an extravagant conjecture in any observed facts.

The only plausible hypothesis, the reader has probably anticipated: that this wall was the course of a rupture in the former volcanic cone,—a fissure along which the mountain was rent asunder. A section through Mount Loa, across its southern slopes, in the same direction, would give us almost a fac simile of the effect here supposed to have taken place. The plains at the foot of the precipice have been described as very narrow; and Kaneohe Bay is a deep indentation in the coast, situated not far from the axis of the original vent.

With regard to the extent of the whole dome before the rupture took place, we may obtain some data from the size of the segment remaining, and by comparison with Loa, Kea, and Hale-a-kala. It might be thence inferred that the fissure passed through the cone two-thirds of

the distance from the summit to the base. When entire, the mountain may have been six or eight thousand feet in height, with a diameter at base of twenty to thirty miles. Konahuanui and Waiolani are, therefore, but fragments of the once lofty mountain. The portion of the great volcano cut off at the rupture has disappeared beneath the ocean.

A similar train of facts and comparisons guide us to a like conclusion for the western mountains, although the data afford less satisfactory grounds for definite computation. It is important to observe that the lines of the Waianae or western coast and mountains are exactly parallel with those of the Koolau coast and the adjacent mountains.

Catastrophes of the grandeur and extent here supposed, though beyond the comprehension of the uninformed mind, have been of frequent occurrence in the history of our globe. The observer of nature is early taught that the forces employed by creative power are not to be measured by the ordinary experience of man any more than the extent of their influence is limited by the field of his vision; the universe is the vast arena, where the majesty and wisdom of God's operations are displayed, and the agencies are commensurate with this extent. Evidences of many facts of the kind above described, have been brought to light by recent investigation; and occurrences at the present time evince that the same forces are still at work. We need not look for examples beyond the islands described in the preceding pages. The recent rending of Mount Loa for a distance of twenty-five or thirty miles, with the ejection of streams of lava, has been mentioned, and what is most remarkable, it happened quietly, with none of the terrific signs of violence often attending such phenomena. It was simple, irresistible force, without noise. The rupture of the summit of Maui at its last eruption, as explained, cut from the mountain a segment ten thousand feet in elevation: and although the segment was not dislodged from its place, it opened valleys one to two miles wide, poured out floods of lavas, and left precipices of one to two thousand feet. Such are occurrences attending the action of single volcanoes; and if thus great, where shall we limit the disrupting forces of the globe, by which continents are made to vibrate? The views here presented are familiar to the geologist; but there are many general readers who shrink from unfamiliar facts, and measure what *may* be, by what they themselves know, and for such we have added these remarks.*

* Lisiansky, in his *Voyage Round the World*, states that a lofty precipice near Ihack, island of Kodiak, is said to have been formed during an earthquake that tumbled part

The eruptions of the eastern mountain continued long subsequent to the extinction of the western vent. The two mountains, as the extent of valley-degradation and other facts show, had nearly the relation in age of the two which constituted Maui, or the two, Loa and Kea, of Hawaii. The lavas of the former, as now with those of Mount Loa, flowed over the foot of the other cone, and raised the intervening plain by accumulations of layers of compact rock and tufa or conglomerate. The features of the eastern slopes of the Waianae ridge exhibit distinctly this half-buried character.

Subsequent to the convulsion that rent the island of Oahu, the eruptions of Kaneohe Bay, now not far from the centre of former action, must have taken place, and they may have been one of the immediate effects. The scoria and cinders about the Pali, at the head of Nuuanu Valley, were also ejected after this event. Nuuanu Valley itself may have been the course of an earlier outbreak, like that which we have alluded to on Hale-a-kala. The several tufa cones and the lava eruptions associated, occur over fissures. Respecting their age we can arrive at no very definite conclusions, though we may infer with probability, that they were the last extinguished fires. That corals had already begun to grow, is apparent both from the fragments of coral imbedded in the tufa, and the incrustations of lime.

The nature of the eruptions producing these tufa cones is evident from their position and structure. Previous to the rise of twenty-five or thirty feet, which the island has experienced since its fires became extinct, their bases were below the level of the sea. The cones of Koko Head, which constitute a peninsula, even now rise from the water's edge, and must have commenced beneath the sea; and Diamond Hill and Kaneohe Point are other regions *made* into dry land by the eruptions, and enlarged by the subsequent elevation of the island.

The finely laminated character of the tufas, so much like some alluvial deposits, would, alone, prove the same fact as regards their semi-submarine, or, at least, maritime origin; for large quantities of water and steam must have ascended and descended with the showers

of the conical mountain into the sea.—p. 185. Humboldt mentions, (see *Researches*, i. 238; also *Cosmos*,) that the volcano of the Andes, Capac-Urca, was once more lofty than Chimborazo; but suddenly fell in. Carguairazo, eighteen thousand feet in height, crumbled together on the night of the 19th of July, 1698, leaving only two enormous rocky horns of the crater. On Timoa, one of the Moluccas, in 1638, a mountain entirely disappeared, and a lake took its place; previous to the catastrophe it had served as a prodigious watch-light, and was seen at a distance of more than three hundred miles. See farther, *Scrope on Volcanoes*, p. 163.

of cinders. The tufa hills of the eruption in 1840, at Nanawale, are an exact representation of these cones in most respects, though of less extent, and of more rapid formation. The occurrence of the coral and interlamination or incrustations of lime correspond well with these facts. About the Salt Lake region, there were evidently numerous pools of boiling water in operation, forming, perhaps, a scene of geyser eruptions during some part of their action. It will be remembered that there are several coalescent basins, with circular bays on the east and west sides, appearing as if there had been a great number of active centres; and from the size of some, the hot waters of a single area may have been a mile or more in circuit. The lower flat basins are now at low-tide level, and the coral ledge pointed out, is proof of their former submergence. A farther study of the Alia-paakai region, may give sufficient evidence for believing that the salt of the lake, instead of being derived through the tides from the sea, arises from salt in the earth or tufa below, boiled down by these fires. The existence of salt plants on the upper salt basin, now forty feet above the sea, would be thus explained. Other facts, with regard to the fountain of waters playing most copiously in wet weather, and not appreciably in dry weather, all harmonize with this mode of explanation.

In pointing out the characters of the two lofty cones of Oahu which originated the islands, tracing their history to their rupture and partial subversion, and indicating other subordinate eruptions and boiling springs upon the coast, Geology looks far back into the earth's past history. The facts are not, however, hypothetical, but worthy of full confidence. The language in which the events are recorded, is not of doubtful character; for it is the same in which the operations of passing events are journalized on the earth's surface. The interpretation is but a necessary conclusion based on the principle that *like produces like*. We have called in no new powers, nor taxed known powers beyond their limits. The forces that have buried mountains, or raised their heads to the clouds, are not of speculative origin; for the lofty summits and the submerged lands bear their own evidence to the changes which the surface of the earth has undergone. And to these effects, the merest tyro in geological science can bring forward abundant testimony.

V. ISLAND OF KAUI.

GENERAL FEATURES.

Kauai* is nearly circular in form, and has an average diameter of twenty-nine statute miles, with an area of six hundred and forty square miles. The land rises very gradually from the coast, except on the western side, where there is a precipice fronting the sea, of a thousand feet or more in height. Elsewhere, there are usually cliffs of two or three hundred feet, above which commences a gently sloping shore plain, two to five miles wide, and one to five degrees in inclination. This cliff occasionally retreats inward, leaving a sea-coast plain surrounded by an amphitheatre of steep hillsides. The surface of the interior is broken into ridges and valleys, many of great extent. The loftier summits tower up with steep, unbroken sides three or four thousand feet above the other heights around them, and some of the gorges are one to two thousand feet deep. The altitude of Waialeale, the highest peak, is estimated at eight thousand feet.

Towards the west side of the island, there is a mountain plain about four thousand feet above the sea.

Among the lofty summits of the interior there is no trace of a crater. The ridges, as they reach towards the sea, are very distinctly seen to decline gradually into the shore plain, this plain being, in fact, but the base or foot of the mountains, and continuing the slope of the ridges to the sea. Moreover, the plain and the ridges show not merely a continuity of surface, but also of internal structure. The river channels which intersect it, like those of the dividing plain of Oahu, often three hundred feet deep, have a uniform stratification, which extends, without changing essentially its inclination or general character, far towards the centre of the island. This uniformity of structure affords more decided evidence of continuity than might be gathered from the nature of the surface, which is, sometimes, quite undulating. We may, therefore, distinguish in the topography of the island, notwithstanding the great irregularity in the arrangement of the heights and ridges, a seeming conformity to a system, pointing to a unity of origin.

* The observations on this island by the author were made during four days, to which time he was limited by definite orders.

Besides the interior mountains, there are some ridges near the eastern shores which appear to be distinct from the others, as they lie between the border plain and the sea, or partly intersect this plain. One of these ridges extends along the southeast corner of the island, and passes inward towards Koloa. It has a broken summit with remarkably bold features ; and, from the appearance of the highest peak, has been called the *Hoary Head* ridge.

The valleys of Kauai are as much more extensive than those of other islands of the group, as its peaks are more irregular, abrupt and broken. Hanalei Valley, which opens on the northern coast, is a wide plain for many miles, though becoming a narrow gorge above : it separates a ridge on the east from the mass of mountains on the west. Hanapepe Valley opens on the opposite or southern shore, and is one of the most extensive in the island. Its waters, like those of Hanalei, rise in part from the lofty peak Waialeale, the highest on the island.

The valley of Hanapepe was visited by the author, and well deserves some few words by way of description. We reached its enclosing walls, about four miles from the sea, where the sloping plain of the coast was just losing its smooth, undulating surface, and changing into the broken and wooded declivities of the interior. The valley, which had been a channel through the grassy plain, a few hundred feet in depth, was becoming a narrow defile through the mountains. A strip of land lay below, between the rocky walls, covered with deep-green garden-like patches of taro, through which a small stream was hastening on to the sea.

We found a place of descent, and three hundred feet down, reached the banks of the stream, along which we pursued our course. The mountains, as we proceeded, closed rapidly upon us, and we were soon in a narrow gorge, between walls one thousand feet in height, and with a mere line of sky over head. The stream dashed along by us, now on this side of the green strip of land, and then on that ; occasionally compelling us to climb up, and cling among the crevices of the walls to avoid its waters, where too deep or rapid to be conveniently forded. Its bed was often rocky, but there was no slope of debris at the base of the walls on either side, and for the greater part of the distance it was bordered by plantations of taro. The style of mountain architecture, mentioned when speaking of Oahu, was exhibited in this shaded defile on a still grander scale. The mural surfaces enclosing it had been wrought, in some places, into a series

of semicircular alcoves or recesses, which extended to the distant summits over head : more commonly, they were formed of a series of semicircular columns of vast size, collected together like the clustered shafts of a Gothic structure, and terminating several hundred feet above, in low conical summits; and though the sides were erect or nearly so, there was a profuse decoration of vines and flowers, ferns and shrubbery; and where more inclined, forests covered densely the slopes, which were greatly enriched by the intermingling of a species of tree, with massy grayish-green foliage. The architectural features proceed from the wear of rills of water, streaming down the bold sides of the gorge. They channel the surface, leaving the intermediate parts prominent. The rock is uniformly stratified, and the layers consist of gray basalt, alternating with basaltic conglomerate.

Cascades were frequently met with; at one place, a dozen were playing around us at the same time, pouring down the high walls, appearing and disappearing, at intervals, amid the foliage, some in white, foamy threads, and others in parted strands imperfectly concealing the black surface of rock beneath.

A rough ramble of four miles brought us to the *falls* of the Hana-pepe. The lofty precipice, sweeping around with a curve, abruptly closed the defile, and all farther progress was therefore intercepted. We were in an amphitheatre of surpassing grandeur, to which the long defile, with its fluted or Gothic walls, decorated with leaves and flowers and living cascades, seemed a fit porch or entrance-way. The sides around were lofty, and the profuse vegetation was almost as varied in its tints of green as in its forms. On the left stood apart from the walls an inclined columnar peak or leaning tower, overhanging the valley. Its abrupt sides were bare, excepting some tufts of ferns and mosses, while the top was crowned with a clump of bushes. To complete the decorations of the place,—from a gorge on the right, in the verdant mountains above, where the basaltic rocks stood out in curved ascending columns on either side, as if about to meet in a Gothic arch, a stream leaped the precipice and fell in dripping foam to the depths below; where, gathering its strength again, it went on its shaded way down the gorge.

The few particulars which have here been stated, illustrate many scenes on the Pacific islands, exhibiting faithfully the features of numerous valleys. The only peculiarity worthy of mention is this,—that the gorge terminated without becoming the rocky bed of a rapidly de-

scending torrent, the usual character higher up among the mountains: still it may have these precipitous features above the precipice.

There is a fall of a much greater volume of water, though of far inferior beauty, on the Wailua River, which empties on the east side of Kauai. The fall is within two miles and a half of the sea. The river is making its course through the shore plain, and is about thirty yards wide. It divides into several streams on reaching the edge, and plunges down a precipice one hundred and sixty feet in height into a foaming basin, and thence flows on, dashing for a while over a rocky bed between high enclosing walls. For the last two miles of its course, the river averages fifty yards in width, and through the last half mile, it is two to three fathoms deep. The valley is a beautiful one, and well worthy of a visit for its picturesque scenery. Above the fall, the river bed makes but a slight depression in the plain; but the channel continues increasing in depth as it recedes towards the mountains, and, not far distant, it becomes a narrow gorge, like that below.

The principal rivers of Kauai have already been mentioned: they are the Hanalei, the Wailua, and the Hanapepe; and there is another, of nearly equal importance, emptying at Waimea. The Hanalei is navigable for canoes about three miles: for this distance, the width varies from fifty to one hundred and fifty feet, and the depth from three to ten feet. The Wailua is the second in magnitude, and is navigable for canoes nearly to the falls. The river is almost closed at mouth by a sand-bar, which has reduced the fifty yards, its width above, to three or four yards, and has also rendered it very shallow. Otherwise it would afford safe anchorage for vessels drawing less than fifteen feet water. Nearly all the smaller streams are closed in the same manner by sand-bars, and so completely, that they may generally be crossed at mouth on dry land. These sands are mostly from the coral reefs, and are thrown up by the sea.

Kauai is considered the garden of the Hawaiian Group. The island has a peculiarly verdant appearance to one who has just left the arid shores of Southern Oahu. The mountains and the valleys are covered with forests; and the high shore plain, which forms a broad border to the island on the southern, eastern, and northern sides, is mostly a region of grass and shrubbery, shaded with occasional groves of pandanus and kukui. The lower lands of the island lie all to *windward* of its mountains, and this is a sufficient cause of the prevailing fertility. The lofty summits, and the mountain plain of the west, are in

a region of frequent mists and rains, and the declivities are often marked with white, thready cascades, streaming down their almost vertical surface, sometimes through one, two, or even three thousand feet, in uninterrupted lines. The island is, consequently, well watered, and the lower country seldom fails in its productions. The district of Waimea, to the southwest, is the only exception to these remarks, and this is owing to its leeward situation.

The soil of the island has the ordinary character of that derived from the basaltic material of these islands. It is usually of a deep red colour, from the iron contained, except where altered by vegetable growth and decomposition. The depth over the shore plain is from three to eight feet, and the rock below is altered in colour and compactness to a much greater depth. Near Koloa the brown surface soil was a foot or two deep; and below this, it had the usual red or brownish-red colour, derived from uncombined oxyd of iron. The rocks of the walls of the valleys are generally so decomposed that it is difficult to obtain fresh specimens. The soil of the mountain declivities, where the moisture is constant, is rarely in any part red, as the iron from decomposition seldom appears in its condition of dry red oxyd, but is either a hydrate, or is united with carbonic acid, and certain organic acids, crenic, apocrenic, and others.

GEOLOGICAL STRUCTURE OF KAUAI.

Besides the mountains which compose the mass of the island of Kauai, we have mentioned the occurrence of an independent ridge along the eastern shores. There is also a region of small craters, as perfect as many of the lateral cones of Hawaii, situated near Koloa. In addition, there are coral formations in progress on the shores, and others that have undergone a change of level. These different points may be separately considered, as follows:—I., the structure of the interior elevations, and the shore plains subordinate; II., the eastern shore ridge; III., the lateral craters of Koloa; IV., the coral formations; and after this may follow general deductions with regard to the origin of the island.

1. *Structure of Central Kauai and the Shore Plains subordinate.*

As far towards the interior as the island was examined by the author, it consisted of a series of layers, like the mountains of Oahu. We have already alluded to the regularity of stratification presented in the valley sections of the shore plain, and have stated farther that the same structure continues to characterize the walls of the gorges beyond this plain. The layers are remarkably regular in direction, and dip with the slope of the plain, at an angle of one to five degrees; they are so nearly horizontal, that the inclination is often hardly apparent.

The dip, as in Oahu, corresponds in direction with the points of the compass, the surface rising gradually towards the interior from the southern, eastern, and northern shores.

The layers differ much in thickness, and enlarge as we approach the interior. Within five miles of the sea, they vary from ten to one hundred feet: twenty to twenty-five feet is the average thickness. Each layer stands out distinct on the bluff, owing either to decomposition or removal between, or to open spaces left by the flowing rock. The under surface of the layers is frequently very jagged, and some small caverns or deep cavities may be seen among its protuberant points.

These layers consist of the same compact and conglomerate rocks which have been described in the account of Oahu and the other islands.

They often have the appearance of a recent lava, though generally nearly compact, with irregular cells. Some grayish layers are very cellular, though not scoriaceous; the under surface of many layers, as just stated, strikingly resembles the recent formations of Hawaii. The rock is usually of a grayish-black or grayish-blue colour, with a slightly glistening lustre when broken: some ferruginous varieties are black and heavy. Grains of chrysolite are commonly disseminated through the texture, and, among the glistening points, particles of magnetic iron may sometimes be detected. Other than this, it is rare to find imbedded crystals in the rock, or any trace of crystallization. Porphyritic varieties are, however, met with: in those seen, the feldspathic crystals were small and imperfect. Augite is seldom found in distinct forms.

Though generally somewhat cellular within five miles of the coast,

there are also compact layers, without a trace of a cell. Some of the boulders, in the Hanapepe Valley, consisted of grayish-blue basalt, containing crystals of chrysolite an inch or more in their several dimensions. The clinkstone varieties were not met with in the course of our rapid jaunt over the island.

The conglomerates are very various in structure. Some are a coarse tufa; others consist of large, rounded masses, many thirty cubic feet in size, lying together, with earth and pebbles filling the interstices. They contain all the rocks of the mountains, the most cellular as well as the compact. Near the descent into the Hanapepe Valley, not far from the bottom, there were masses of scoria in the conglomerate, looking as if there had been ejections of scoria in the vicinity while the island structure was in progress, and before the superincumbent two hundred feet of layers had been formed.

There is often a tendency to prismatic structure in the basaltic rocks, and distinct columns were occasionally met with. Towards the interior of the island, the prisms are most perfect and extensive. At the falls of the Hanapepe, they were well defined, and could be traced for a height of one hundred and twenty feet, though less distinct below; and above, they were a little curved on each side of the falling water, so that, if continued, they would span it with a Gothic arch. On the side of the valley opposite the fall, the steep sides of the slender peak overhanging the valley, show a columnar structure. This structure was met with, in many places in this valley, before reaching the falls: but we observed no examples of much interest near the bottom of the gorge, and could see only at a distance the columns which occur in the inaccessible heights above. In some thin layers, the columns were but six feet long, and ten inches in diameter. Where we first reached the bottom on the descent, we left a high precipice on our right, which was distinctly columnar throughout its upper half: the following section was there presented.

Eighty feet coarse basalt, with a columnar structure, the upper thirty feet imperfectly so; columns irregularly curved in some parts.

Twenty-five feet;—a second layer, but not distinctly columnar.

Twenty feet;—a third layer, not columnar.

Twenty feet, or to the bottom; coarse conglomerate.

The layers of basaltic lava were black and ragged. The conglomerate is the same bed which has been described as containing scoria and light cellular lava. The place was, probably, a lateral vent at some period in the history of the island.

In the Wailua Valley, similar examples of columnar fracture and curved columns occur in some of the layers which compose the walls; but symmetrical columns are not common. Near the banks of the stream, up three-fourths of a mile from the sea, a layer is convex for a short distance, leaving a large cavern underneath with a concave roof. It is evidently an instance of a layer bulged by vapours beneath, while cooling, such as are common on Hawaii. The rock was sub-columnar, the fractures following nearly the course of radii drawn from the centre of the sphere of curvature.

Curved columns often occur in places where, at first, it seems difficult to account for them by reference to the position of the cooling surfaces. The *middle* or *interior* of a layer, which, in other parts, is vertically columnar, presents, at times, singular examples of contorted columns; the straight columns curve to the right or left for a short distance, and then gradually resume their original direction. In explanation, we remark, that over streams of cooling lava, steam-holes remain for many months, and often continue for a year or more after the eruption has ceased, emitting hot air and vapours; and under such circumstances, the cooling of the interior must take place very unequally; curvatures of various forms might, therefore, be produced, and still derive their peculiarities from the position of the cooling surfaces, or, what is equivalent, the direction in which the heat is drawn off.

A spherical structure is exhibited in the rocks on many parts of the island. On the descent to the valley of the Nawiliwili, not far from the eastern shores, and also ascending from it, there appeared to be a pavement of cobble-stones along the steep declivities. The stones were concretionary nodules of the basaltic rock, and were three to twelve inches in diameter. They had been brought out in relief by the superficial decomposition of the rock, which gave it a dirt-brown colour, and assisted in the deception. The layers of the nodules were gradually peeling off, exposing a harder interior, which did not exhibit a concentric structure.

The mountains of Kauai are intersected by numerous dikes, which may be seen in many of the valleys where the walls are too steep for continuous vegetation. In the Hanapepe, about six miles from the sea, or two miles from the place of descent, the wall, which is not less than one thousand feet high, is cut through from top to bottom, by a dike but four feet wide. It was inclined on the face of the bluff 60° to the southward, and had a west-southwest course, as nearly as could

be judged. Cross fractures indicated an imperfectly columnar structure; and, in some places, the dike was faulted. Two other dikes were seen near by, but, on account of the vegetation, they were traceable only for a short distance. Scarcely any effect of heat in the walls of the dike could be detected; there was a slight change of colour to brown, and the rock was a little more cellular. But much alteration is seldom seen, when the rock of the dike is similar to that it traverses.

In the Wailua Valley, about a mile from the sea, several dikes intersect the high walls on the south side of the gorge. They are from three to six feet wide, and have a southeast and northwest direction. Three of these follow a nearly parallel course, diverging a little above, and they are all inclined to the westward. They are occasionally faulted, a common characteristic of dikes intersecting other basaltic rocks, owing to the many fractures in basaltic layers, and their tendency to break irregularly.

Other dikes were observed on the island, but nothing of special importance was distinguished in the distant view we had of them.

b. *Eastern Shore Ridge.*

The range along the eastern coast, either borders the sea or extends along within half a mile of it; and the shore plain between it and the mountains, is from two to three miles wide. It is not continuous, but forms several isolated ridges, among which, the thin crest called Hoary Head, is one of the most prominent. The range faces the interior with an abrupt front, and has an uneven serrated outline. The declivities were mostly enveloped in a dense wood, excepting at base, where the ridge was often quite vertical. Some spots to leeward about the higher summits were covered with grass. In a few places columnar rocks were distinguished. Wailua River intersects one of the ridges about half a mile from the sea. Near this place, parallel layers were distinct to the very summit of each of the rugged peaks. The dip amounted to eight or ten degrees, and in direction was north-eastward, or nearly towards the sea. The same dip was observed in summits near Nawiliwili, a few miles south of Wailua. In the course of one hundred and fifty feet in height, there were ten layers of basaltic rock, the thickness of each varying from ten to thirty feet.

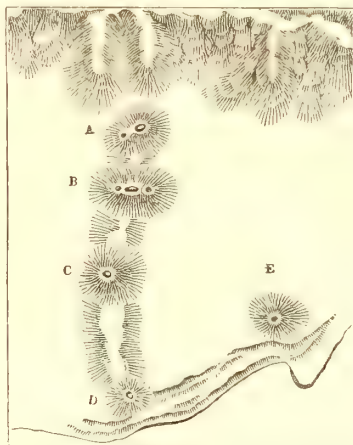
Back of Anahola, on the northeast shore of the island, eight or nine

miles north of Wailua, there is a high broken ridge with needle summits, in which the usual stratification is apparent. At this place there is a hole quite through the ridge, near the base of one of the summit needles: when first seen, the light shining through, appeared like a star in the horizon. Beyond Anahola to the northward there are other ridges which extend towards the mountains.

The features of these ranges were only cursorily examined on a rapid walk from Koloa to Hanalei. Their abrupt sides, thin and sharp summits, craggy peaks,—the stratified structure, arising from basaltic layers often more or less columnar,—and the dip seaward, of eight or ten degrees,—are the points of prominent interest which were ascertained.

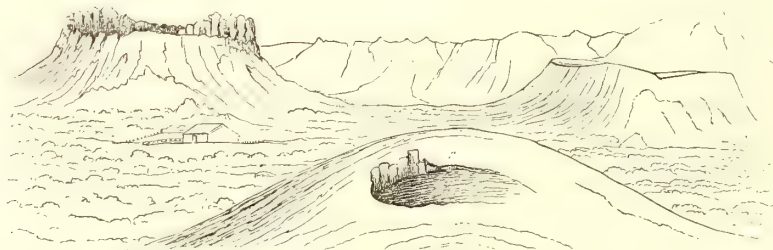
c. *Lateral Craters of Koloa.*

The region east of the village of Koloa and south of Hoary Head ridge, is occupied by several craters and their ejecta, having much resemblance in character and condition to those of Oahu, and appearing to be of more recent origin than any other portion of the island. This volcanic tract covers a space of eight or ten square miles. The craters are eight in number, and are confined to a single square mile (represented in the annexed cut), near the easternmost extremity of the tract, or the southeast corner of the island. Black layers of lava, as bare as many of the lava fields of Mount Loa, form the surface of a large part of the region, especially near the village of Koloa; while other portions, commencing about two miles from Koloa, consist of large blocks lying loosely together, as near Diamond Hill, with scarcely a single shrub over the surface; and still others, including a part of the craters themselves, consist of red earth. The solid layers of lava have, in many places, a ropy surface, and they are bulged up into domes and ridges, covering ovens and subterranean chambers, like the modern eruptions of Hawaii. These caverns are often of



large size: one, the first entered by the author, not far from Koloa, was ten feet high, twenty feet broad, and fifty long. The layer which covered the cavity was about five feet thick, both over the cavity and elsewhere. The roof was very rough, though not stalactitic. Caverns of this kind, upon the coast, afford water-scenes of a striking character. The waves of the wide Pacific driving over the black rocks, into dark recesses, and rising in copious jets or dashing into foam, afford majestic sights wherever seen about these volcanic islands; and some of the spout-holes of Koloa are unusually grand.

The rock of the region is a ferruginous basalt of a black or brownish-black colour, and generally has a glistening lustre. Excepting sparsely disseminated grains of chrysolite, there are no traces of crystallization. In other words, the rock is the same as that of Kaneohe Point, the craters near Diamond Hill, and other parts of the islands. The lava is more or less cellular, but is very compact between the cellules. In some places it is columnar. Along the banks of a small stream that runs through the village of Koloa, there are well-defined prisms of five, six, or seven sides, and they form a neat polygonal pavement, or stand in columnar walls. The columns seldom exceed eighteen inches in diameter. Horizontal fractures occur at regular intervals, but the plane of fracture is flat instead of convex. In these pavements, the rock immediately adjoining the fissures or lines of fracture, is often harder than that within, and gradual abrasion wears the inner parts, leaving an elevated line along the fissures. This superior hardness has probably arisen from infiltration subsequent to the formation of the fissures; gases from below, usually decompose instead of giving increased hardness.



The number of volcanic hills is five, and among them, one contains two craters, and another three craters, as shown in the preceding map. With one exception, they are low, with a rounded contour and barren earthy sides, looking as if made of dark-coloured brickdust. The one exception, called the *Old Crater*, is represented to the left in the above sketch.

a. The Old Crater has a steep and ragged summit, consisting of dark brown lavas and scoria. The cone stands about one hundred and fifty feet above the plain. The bare sides are smooth till near the summit, where the lava breaks out in columns, so rude and jagged as scarcely to justify the term, yet appearing columnar from below. It forms a narrow wall, or crest, broken by numerous rents, and is mostly wanting on the east-southeast and west-northwest sides. The crater is about one hundred and fifty yards wide at top, and has a depth of thirty or forty yards. The surface within is smooth, and consists of red earth, like the lower slopes of the exterior.

The lava of the crest owes its roughness, in part, to a thin laminated structure and numerous vertical fractures. The laminæ are from half an inch to two inches thick, and although not easily separated, they stand out prominent over the worn or decomposed surface. The rock has been rendered very irregular from disintegration, and, at top, the columns are sometimes unevenly tapering. Besides these sources of its rough features, the walls within are covered with lava in twisted shapes, forming patches plastered on the surface, or hanging in stalactites. The rock of the crest is very cellular, and much of it is scoriaceous.

b. To seaward from the Old Crater, the observer looks down upon a low, broad elevation (D), with a shallow crater at top. Its smooth surface, covered with scanty vegetation, at first suggested that the lava had not flowed from it. But the crater proved to be half filled with black basaltic rock, lying in huge blocks, averaging more than a cubic foot in size. There was no scoria about the crater. The lavas were ejected, and subsequently erupted cinders, with decomposition, covered the exterior with earth. The rock resembles that about Koloa.

c. A little to the east of north from the Old Crater, there are two hills, of oblong form, and about one hundred and eighty feet high. The near one, B, (see preceding map, and also the crater on the right side of the foregoing sketch,) contains three craters, and the other, A, two. These are alike in their red, earth-covered declivities, unfurrowed by a single ravine or depression. The central crater in B, has a diameter of a hundred yards. On one side the lava is piled up in columns, somewhat as in the Old Crater; the bottom of the cavity is very evenly concave, and covered with red earth, like the exterior. The western crater is about half the diameter of the central, and has

an earthy margin around the shallow cup-shaped cavity. The rock crops out in one place, and shows the same features as above described. Ejected cinders probably covered the lavas, as in other instances; the red colour is the result of decomposition setting free the iron in the state of red oxyd.

d. In number A, the larger crater of the summit is nearly two hundred feet across. The same red earth characterizes it inside and out. The smaller crater lies adjoining, and is forty feet across and twelve deep. The walls around consist of cellular lava in layers which appear to have flowed from the larger crater; the rock is the same as that of the plains below. On one side of this small crater there is an entrance to a cavern which appeared to run down the hill: it could not be traced beyond thirty feet, on account of the rocks that had fallen in from above. The entrance is eight feet high and fifteen wide, and the walls are, in part, incrustated with lava stalactites. The cavity appears to indicate that a stream of lava had flowed from the small crater. There is still another depression on the western slope of this volcanic hill, that may have been a third crater.

e. To the eastward of the Old Crater, about three-fourths of a mile, there is a small hill (E), with evenly rounded top, as represented in the foreground of the preceding sketch. It has a shallow cavity, about one hundred feet in diameter, broken down on one side, with walls of semi-columnar lava on the other. The lava is lamellar in structure, like that of the Old Crater, and the surface is covered with ropy and twisted slag-like scoria. This is the last of the eight craters. There is another small elevation near the Old Crater, about one hundred feet across, and twenty high, which formerly may have had an opening, though now there is no satisfactory evidence of it. It is covered with blocks of lava like the plain adjoining.

The lavas of the Koloa district probably issued from some or all of these craters, and from fissures in the plain. All the hills but E, lie nearly in the same line; and, probably, a large fissure was opened in the direction of this line, from which the eruptions took place, certain points along the fissure becoming vents for continued eruption and giving origin to the cones,—the usual mode of action on Hawaii and in other volcanic regions. In the Old Crater, the lavas appear to have boiled up to the top, and thus formed the crest, as a ridge is formed around a lake in Kilauea, and then subsided again, leaving the sides covered with pendent masses of scoria.

The red soil of the Koloa district resembles that in other parts of the

island. The effect of the growth of vegetation upon it, in bringing the iron into new combinations with organic acids, is seen about Koloa, where there is a foot or so of dark loam. The cavernous surface of the lavas appears to soak up whatever waters fall, and the region is mostly barren, except in the immediate vicinity of Koloa, where there is a fine stream and some marshy soil.

Other lateral cones were said to exist near Wailua, in the southwest part of the island; but they were not examined by the author.

d. *Coral Formations.*

The shores of Kauai are bordered by a narrow growing reef of coral excepting on the side of the mountain cliff, where the shore is too abrupt. The most important effects derived from these reefs, are, the accumulation of coral sand on the beaches, the protection of the coast from degradation, and the enlargement of the island through the stoppage of the detritus brought down by the rivers, as well as by beach accumulations.

The beaches of coral sand are quite extensive on the eastern or windward shores, and a low ridge continues along, seldom interrupted, except by an occasional jutting point of black rock. This ridge is raised from ten to twenty feet above high tide, and, in some places, where drifted by the winds, the height is thirty to thirty-five feet. There are remarkable hills of this extent on the southwest coast.

About the mouths of the streams, the sands are often thrown up so as to close the stream entirely, as far as appears at the surface, and deltas of small extent are sometimes formed. At the opening of the Hanalei Valley, which forms a small bay, a tract nearly four square miles in extent has been made through the agency of the sea, winds, river, and reefs, and upon this plain the fine village and rich lands of Waioli are now situated. The land, through the gradual extension of the beach, has advanced about a mile to seaward. The river banks, which vary from two to ten feet in height, expose the stratified coral sand in numerous sections, and they present often a thin lamination, with all those irregularities of dip and direction which may be found in a beach, and with a slope, in general, to seaward. This slope, though, at times, nearly horizontal, more commonly amounts to eight or ten degrees. The sands are either loose, or aggregated into brittle

plates, and many of the laminæ are but an eighth of an inch thick : though firmly cemented, they still hardly bear handling. They frequently alternate with thicker layers of loose and coarser sand, giving a distinctly stratified appearance to the sections. Some of the cemented layers were four or five inches thick, but they were not of equal firmness throughout.

The plain formed by these accumulations is from four to ten feet above the sea, which is not higher than the sands are thrown upon the present beach of the bay, where the formation is still in progress. We have no data for determining the rate of increase. This rate must be less now than formerly, as the shores are longer and rise from deeper water, and the reef is comparatively of less extent.

These deposits contain, in some parts, the shells and corals of the present shores but little altered, and resembling beachworn specimens. There is a small bank of this kind near the mouth of the river, four or five feet above the existing level of the sea. But such beds of shells are not common, and by far the greater part is without a fragment larger than a grain of sand. It occasioned some surprise, also, that these sand deposits, formed at the mouth of a river fifty yards wide, should be nearly pure from mountain detritus. The hills, two to three miles back, are covered with loose soil, and the banks of the stream, beyond the termination of the coral sand deposit, consist of soft earth from the adjoining declivities : yet it is rare to find a basaltic pebble in the layers, and there is but a trace of earthy material. A few scattered points, of a brown colour, and some of chrysolite, may be detected. Facts of this kind have been noticed on a former page, and they show how uncertain the evidence which a particular deposit may present with regard to the nature of the surface of the country adjoining, or the amount of life in the waters. The fact stated is actually no more remarkable than the freedom of the present beach from basaltic material, for all these accumulations have had a beach origin. The detritus of the rivers is mostly carried off to sea ; and that thrown up on the beach, is so light as either to be washed away again, or is driven far back of the beach by the winds. The plain is covered with eight to thirty inches of black earth, arising in part, perhaps, from this source, and from the dust which the currents of air bring in from the high country around. In the shores of the river, for a mile from the mouth, there were ten or twelve inches of black earth, six or eight inches of brownish earth containing an occasional shell, and, below this, several feet of grayish-white coral sand or sand-

rock, with some broken shells and corals. Two miles back, the black earth of the surface has twice the thickness here stated.

At Anahola, Kalihiwai, and other places on the coast, the shores have been extended nearly in the same manner as at Hanalei, though not to so great an extent.

There are also solidified beach deposits analogous to the drift sand-rock of Oahu, and as remarkable in character. The only instance examined by the author occurs on the shores of the Koloa volcanic district. The ridge has the features here represented. It forms a



cliff of thirty-five feet, which appears to be undergoing degradation from the action of the sea, and masses of large size are now lying at its foot. The ridge consists of a laminated calcareous rock, the thin layers of which lap over the ridge, and incline in opposite directions on the two opposite sides, exhibiting full proof of its drift origin. The dip, where greatest, amounts to twenty-five degrees. In some parts, the rock is compact and impalpable; but generally it has a sandy texture, though seldom friable. The colour is white or grayish-white. The rains have worn or eroded the surface quite largely; but in some places, where the waters have stood in cavities, the interior of the cavities has become hardened by infiltrating lime, and bowl-shaped depressions have been formed, lined with a crust of compact limestone three-fourths of an inch thick, and having no trace of a sandy structure.

This ridge is evidence of a change of level in the island of Kauai, though to what extent cannot be inferred. The recent sand-drifts of the same shore are extensive, and are still in progress, and no evidence of cementation was observed about them; while, in the solidified ridge, owing to some change in condition, there are no sands thrown upon the surface, and the sea is making slow encroachments.

Conclusions relating to the Geological History of Kauai.

The facts which have been presented in the preceding pages, at once suggest that the island of Kauai is another volcanic mountain like those of Hawaii or Maui, which different agents have altered, and degraded, till the original features have been obliterated. The whole island is not larger than either of the mountains Loa, Kea, or Hale-a-kala, as may be seen by making the comparison on the map of the group. Mount Kea has all the necessary material, therefore, for a Kauai, and it is only requisite to isolate it, and intersect it with gorges, to turn it actually into a Kauai.

It is natural, landing upon an island of peaks and ridges, without order or apparent system, to look for separate volcanic cones in the several summits. But the steepness of these heights, as well as their structure, is evidence against such a view. It requires but little study of the other islands to ascertain that steep and lofty cones are not among the results of volcanic accumulation in the Hawaiian Group; for the great slopes of the volcanic mountains are always gradual, not exceeding fifteen degrees. Moreover, there are the same facts in support of the hypothesis of a single volcanic summit, as in the eastern division of Oahu.

The shore plain, and its layers of rock beneath, have a gentle inclination away from the centre of the island, and this inclination is very uniform, being undisturbed by tiltings or irregularities of any kind. As we ascend, three to five miles from the coast, the plain begins to form the backs of the ridges; and we trace it on, till, towards the interior, the whole structure is so altered by degradation, that nothing appears to represent it, except the stratification of the rocks. These rocks, moreover, appear in much thicker layers, and, as near as could be judged from distant views, the stratified structure was as much wanting in the interior peaks as in those of Tahiti. This important point will be remarked upon in our account of the Society Islands. What relation the high mountain plain of the western part of the island had to the crater or summit of the original volcanic cone or dome, we are not prepared to say. The cliff of two thousand feet, on the northwest, is, beyond doubt, another example of fracture, like that of Oahu, with a disappearance of the part broken off, beneath the sea.

By no other process could it have been formed. This precipice is in the same line with a similar one forming the eastern coast of the island Niihau. The direction is transverse to the general trend of the group.

The shore cliff or declivity, of two or three hundred feet, which prevails around the island on the south, east, and north, may have been formed by the sea before the coral reefs were sufficiently extensive to afford protection.

The craters of the Koloa district appear as if they had been in action more recently than any other part of the island.

With regard to the origin of the eastern shore ridge, there remains much doubt. It may be the result of a faulting and uplifting of the strata: yet this is not probable. The shore plain, inside of it, is evidence that no extensive degradation has taken place over the surface of this plain since it was formed. It may be that we must look far back into the history of Kauai for its explanation, to a period before the material of the present mountains was ejected, when an earlier cone was broken down, and this ridge was left, as Somma now stands on the side of Vesuvius. In this case, the shore plain must have derived its lavas from the volcanic mountain which subsequently rose.

VI. GENERAL REMARKS ON THE ORIGIN OF THE HAWAIIAN GROUP.

A frequent effect of change of level in the earth's surface, is a breaking of the crust by the action of forces within. The linear arrangement of the volcanic islands of the Pacific is thus explained; and there is no more instructive example of it presented us, than is afforded by the Hawaiian Group.* The Kea and the Loa ranges of mountain heights were pointed out in our introductory remarks. The facts since brought forward show us that these several islands are not merely regions of general volcanic action proceeding from many vents of eruption, but that each is the simple result of one, two, or three centres. As Hawaii consists of three mountain domes, each a distinct

* This fact, with regard to the Hawaiian Group, is recognised by von Buch in his work on the Canary Islands; and the general principle has long been admitted in the science of Geology. Some circumstances attending this rupturing, and certain characteristics not hitherto pointed out, come up in the following pages.

centre, so Maui, Molokai, and Oahu, were made by two centres: pouring out their lavas in near proximity, they overflowed one another at base, and thus their twin character resulted. This series of islands, therefore, is not only a series of volcanic regions, but of volcanoes;—volcanoes, too, of great magnitude. Hualalai and Hale-a-kala, still distinct cones in form, are scarcely less lofty than the far-famed Sicilian mountain. Loa and Kea exceed Etna nearly one-third in altitude; and if we compare their actual size, Loa contains material for two and a half Etnas. Kauai, and one, if not both, of the ranges of Oahu, were other lofty summits. The Hawaiian Group forms a noble range of heights, from Kauai, which bears deep marks of age upon its features, to Mount Loa, which has not yet passed from the period of growth.

We shall in another place present reasons for believing that the commencement of the eruptions of Hawaii may date as far back as the early carboniferous or Silurian epoch. We naturally conclude from the facts which have been considered, that on the first rupture of the crust, which determined the position of the islands, lavas were poured out, as now at an eruption of Mount Loa. This was followed by continued ejections from certain points in the line, which went on building up volcanic mountains—whether submerged or not we may hereafter consider. From Kauai to Mount Loa all may thus have simultaneously commenced their ejections, and have continued in operation during the same epoch till one after another became extinct. Now, the only burning summits out of the thirteen which were once in action from Niihau to Hawaii, are those of Loa and Hualalai: we might say farther that these are all out of a number unknown, which stretched along for fifteen hundred miles, the length of the whole range. This appears to be a correct view of the origin of the Hawaiian Islands.

No facts can be pointed to, which render it even probable that Hawaii is of more recent origin than Kauai, though more recent in its latest eruptions. The rocks of Mount Loa, exposed upon some of its sides, indicate as great an age, as far as lithological evidence goes, as any beds in the group. We may conclude, from the facts exhibited to view, that the eruptions of Mount Loa have continued to a later period: an assertion of anything beyond, is unwarranted by the structure of the islands, and should be received only as an improbable conjecture. This will appear more clearly after reviewing

the Geology of the other Pacific Islands, and considering the conclusions to which we are thereby led.

To comprehend fully the nature of the action alluded to above, we must keep in mind the facts already sufficiently illustrated, that fissures formed by subterranean forces are not long uninterrupted rents, but a *series* of linear ruptures, approximately regular, separated by longer or shorter intervals, sometimes two or more being in parallel series, or one starting to the right or left of the point where another ceases; also, as is elsewhere remarked upon, that transverse fissures at right angles with the main line are a natural result of the same causes; also, the common fact, that fissures, after the first ejection, often remain open for a while, wherever widest or deepest, and continue the ejections. These principles fully explain the *double* line of islands, which we have denominated the Loa and Kea ranges. They explain any irregularities in the lines; for perfect rectilinear courses would be highly improbable. They explain the existence of volcanic vents over the fissures, from which the several islands have been built up. They explain the transverse trend of Niihau and Kauai,* and of Kea and Loa. And to this we add, that the principle here referred to gives us a reason for the great prolongation of the shores of Hawaii to the south, in the line of Kea and Loa; for this region, like that beyond Kilauea to the east, appears to have been lengthened out, by lateral eruptions, beyond the proper limits of the dome Mount Loa.

But this is not all. It is another common fact that a range of fissures has its maximum size at one of its extremities; and the subordinate rents of the series may have the same characteristic. If we may take as evidence of the extent of a fissure, the length of time which it subsequently pours forth lavas,—for plainly the deeper or wider it is, the more probability of its long continuing open,—we shall arrive at some interesting results respecting the Hawaiian Group.

We observe in the first place that the southeastern extremity alone

* This transverse direction is more nearly rectangular than it appears on the map; the precipice of Niihau cuts off an eastern portion which, if present, would give this island a position more to the south of Kauai than it has on the map. As the two precipices, that of Niihau and that of Kauai are nearly in a single line, they afford another example in addition to that deduced from the relative positions of the two islands, of the rectangularity in the intersections between the transverse system of fissures, and the main line of the group.

has continued in action to the present time, and here, therefore, if we may infer any difference in the line, must have been the place of maximum intensity in the erupting force, and the widest rupture.

Moreover, not only does the southeast extremity of the whole line of rupture bear evidence of having been the place of maximum effect, but in exact correspondence with the principle stated, the southeast end of each subordinate rupture in the line was likewise the maximum point in each. For example, we have stated that on Hawaii, Maui, and Oahu, the southeast summit of each was the last to become extinct. The proof is beyond doubt, both from tradition and topographical features, that on Maui, Hale-a-kala was in action long after Eeka, as already shown; and the same topographical evidence convinces us that the eastern mountain of Oahu was burning long subsequently to the western mountain.

From the facts we deduce—

1. That there were as many separate rents in the origin of the Hawaiian Islands as there are islands.

2. That each rent was widest in the southeast portion.

3. That the southeasternmost rent was the largest, the fires continuing there longest to burn.

4. That the correct order of extinction of the great volcanoes is, therefore, nearly as follows (leaving out Molokai and Lanai, which were not visited by the author, and whose correspondence was not ascertained):—

1. Kauai.

2. Western Oahu.

3. Western Maui, Mount Eeka.

4. Eastern Oahu.

5. Northwestern Hawaii, Mount Kea.

6. Southeast Maui, Mount Hale-a-kala.

7. Southeast Hawaii, Mount Loa.—

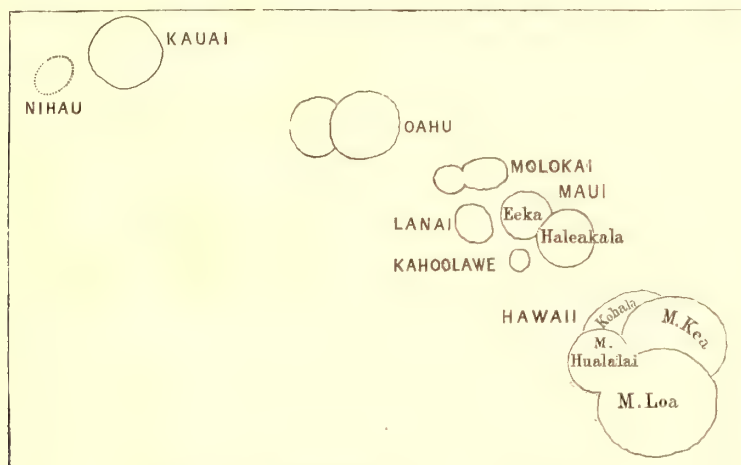
Or, if we substitute numbers for the summits in succession, passing from the northwest, 1, for Kauai; 2, 3, for the two of Oahu; 4, 5, for the two of Maui; 6 and 7 for Kea and Loa of Hawaii,—the order will be as follows:—1, 2, 4, 3, 6, 5, 7—the last still burning.*

* Since this report was first written, I have received a manuscript from Mr. Couthouy, in which views, somewhat similar to the above, are expressed; and as far as we coincide, they afford to the science the independent judgment of another observer. Mr. Couthouy, however, only recognises the general fact, that the progress of extinction was from the west to the southeast; and supposes that the vents were formed in this succession. In

This order is that shown by the extent of degradation on the surface. Each successive year since the finishing of the mountain has carried on this work of degradation; and the amount of it is therefore a mark of time, and affords evidence of the most decisive character. On this point we shall dwell more at length when speaking of the formation of valleys in the Pacific islands.

We are thus sustained in our deductions, not only with regard to the general group, but particular parts of the group. The facts find a ready explanation in the view presented that the islands have proceeded from a series of ruptures of the earth's crust, each of which was largest at its southeast extremity, and the largest of the whole, the southeasternmost of the series.

After the above explanations, the map of the group here annexed will not be deemed hypothetical. The origin of the islands from one,



two, or three vents, and their consisting of as many distinct volcanic mountains, though now much altered by degradation, fully accord

his concluding remarks he says, "The foregoing observations are applied to the course of volcanic action at the islands taken separately, with a view to show that it has been successive in each, from the western to the southeastern extremity of the group, and the possibility that they were also forced up in regular succession by the subterranean fire. The phenomena they present seem to point to such an origin, unless we adopt the hypothesis that they were formed in a continuous chain, which has been shattered by some great convulsion, and partially submerged, leaving them in their present relative position.

with every fact observed ; and in this view, we have all the simplicity and completeness which a satisfactory theory can afford.

We have added a curved line for Kohala, on the north of Hawaii, as it is quite probable that this ridge is a section of a volcanic mountain, which suffered early changes from convulsions, and was finally overtopped by Mount Kea. We have mentioned that the eastern shore ridge of Kauai may have the same relation to that island.

CHAPTER IV.

SOCIETY ISLANDS.

THE Society Group consists of ten islands, ranging in a line 250 miles long, trending N. 62° W. Commencing from the northwest they are as follows:—Tubuai, Maurúa, Bórabóra, Taháa, Raiatéa, Huahine, Tapuaemanu, Eimeo, Tetuaroa, Tahiti. To this number Osnaburgh or Metia may properly be added, as it lies in the same range, about one hundred miles to the westward of Tahiti. With the exception of Tubuai and Tetuaroa, they are all basaltic or high islands. The area of the whole together does not exceed twenty-five miles square, or 600 square miles, and of this about one half, or three hundred square miles, belong to the single island of Tahiti.*

These basaltic islands are characterized by high mountains, deep precipitous gorges, and that rich livery of green with which the mild airs of a perpetual summer clothe the tropical islands of the Pacific. Coral reefs in some instances border their shores, forming a circle around dotted with verdant islets.

The broken character of the surface is most striking on Eimeo, yet all the islands afford scenes of grandeur unsurpassed in the Pacific. In the distant view, Eimeo seems to be a mass of mountain towers,



ISLAND OF EIMEO, FROM THE EASTWARD.

crags, and peaks, rising abruptly to great elevations,† and in one lofty summit, resembling a rudely-shaped cone, there is a hole opening through, a few hundred feet from the top.

* The coral islands, Lord Howe's and Scilly to the westward, are sometimes united to the Society Group. They, however, belong to a separate range.

† See also a sketch by Mr. Agate, in the Narrative of the Expedition, ii. 56.

On Tahiti, still loftier summits, with crowns and crests and jagged ridges constitute the surface: the eye follows up one precipitous slope to plunge at once one or two thousand feet to the bottom of another.

The islands to the northwestward are described as exceeding Tahiti in their bold features, and in the indentations of their shores, which form deep bays, penetrating far among the mountains; they are, for their size, the most remarkable in the Pacific.

There is great luxuriance of verdure over the Society Islands, and good soil. But owing to the mountainous character of the lands, and especially the remarkably steep declivities, but little of the surface, comparatively, can be brought under cultivation. Yet there are many fine valleys besides the level areas along the shores which might be tilled to great advantage. The sugar-cane and many tropical fruits are already grown in abundance, and to these the coffee plant and other productions of the East Indies might be added.

ISLAND OF TAHITI.

The Island of Tahiti consists of two unequal peninsulas, united by a long, narrow isthmus, and has some resemblance, in outline, to the figure 8. The trend corresponds with that of the group. The larger, or northern peninsula, is nearly circular, and measures about twenty miles across. The smaller is twenty-five miles long, with a breadth varying from five to nine miles.

1. GENERAL FEATURES.

With the exception of a narrow plain bordering the sea, the whole surface of Tahiti is a succession of lofty ridges and deep valleys. The mountains of the two peninsulas belong to separate systems, entirely disconnected by the isthmus, and as distinct in the inclinations of the rocks and slopes which constitute them.

In the northern peninsula, they commence their ascent from the sea or the seashore plain, and gradually rise, on all sides, toward the central peaks, the ridges of the north and west terminating in the towering summits of Oróhená* and Aorái,† while the eastern and southern, though reaching toward the same peaks, are partly interrupted by the

* Pronounced Oróhenáh.

† Pronounced Owry.

valley of Pápenóo.* Amid many irregularities, we readily distinguish that the general course of the ridges corresponds nearly to radiating lines from the centre toward the shores.

Bold precipices, or inaccessible slopes, form the sides of these ridges, and a narrow edge, scarcely affording a safe pathway for man, their summits. This is especially the case beyond four or five miles from the shores. The lower declivities are more gradual and less broken.

The valleys enclosed between the precipitous ridges are usually as narrow and rugged as the ridges themselves, affording at bottom barely room for the streamlet which comes dashing down its rocky bed. Within two or three miles from the shore, they are five hundred to a thousand feet in depth, and from this they continue increasing in abruptness, till they finally abut against the face of the central peak, in a precipice of two or three thousand feet. Owing to this peculiarity, it is useless to attempt the ascent of the mountains along the valleys. For if not stopped by impassable rocks in the bed of the torrent, the explorer, when in full hope of success, soon finds himself suddenly checked by lofty precipices, the sought-for peak still rearing its head several thousand feet above him.

A few of the valleys enclose, at bottom, a slip of land, through which a stream winds its way to the sea. Yet to these there are the same abrupt sides, often a thousand feet in height; and far toward the interior they assume the character above described: the stream becomes a mountain torrent, and the bottom of the valley its rocky bed.

The island is thus a succession of ridges and valleys, the former, in height and boldness, scarcely rivalling the depth of the latter. But to conceive of Tahitian scenery, it should be borne in mind, that the declivities throughout the island are mostly buried in foliage; for there is hardly a bluff which is not faced with ferns or shrubbery, or hung above with vines, and the steepest slope is concealed beneath dense forests. The backs of the ridges, ten or fifteen hundred feet above the level of the sea, are generally covered with grass, and look dry in a view from shipboard, disappointing the voyager, who is ready to expect groves from the shores to the summit.

To give a more definite idea of the topography of the island, we dwell for a moment upon the features of a few of the valleys.

On the north and west sides of the island, there are five of the larger valleys of Tahiti:—the Papenoo, Matavai, Papaua, Papiete, and

* Pronounced Páhpayno.

Punaavia* valleys. The first and last are quite broad, and contain the largest streams of the island; while, in the others, the including slopes continue converging to the very bed of the stream that runs between them.

Papenoo Valley has a southerly course from the shore, and passes to the southward and eastward of the peak Orohena. For five miles the enclosing hills, though steep, have a partially rounded contour, but, beyond this, they stand with mural fronts, scarcely broken for six hundred or a thousand feet, except where some branch valley opens through them. Eight miles from the sea, we passed up one of these lateral valleys, and, after a while, reached a mountain amphitheatre, such as we have described. Precipices of eight hundred feet rose before us and on either side, exuberantly covered with foliage, from amid which, at top, the rocks occasionally exposed a rugged summit. The torrent we had followed up was traced to a waterfall a thousand feet in perpendicular descent.

The Matavai Valley, the next to the west, extends southerly, and is enclosed throughout by steep and lofty slopes. It is a vast cut through the mountains. At its upper limits, the observer sees above him, on one side, the summit of Aorai, three thousand feet up, and, on the other, the still loftier Orohena: both with precipitous fronts, varying in inclination from sixty to ninety degrees. These two mountains are united below by a ridge or wall of rock, elevated less than half their height, which wall constitutes the head of the valley, and separates it from the great Punaavia Valley.†

* Pronounced *Mättavy*, *Pappówah*, *Papáytay*, *Pohnáhveah*. We have named the valleys from the towns on the coast at their entrance. The Punaavia appears to be the Bunaro of Tyerman and Bennett.

† There is an appearance of exaggeration even in the calmest statement with regard to the height and boldness of the ridges of Tahiti. We cite here, for additional information, a description of a view in the Matavai Valley, from Tyerman and Bennett, vol. i. p. 101: "The mountains, on either hand, rise abruptly, and to a considerable altitude; their sides are generally clothed with trees and bushes, which overhung our heads as we went, and closing or opening the scene of sky and valley, frequently presented the most singular and pleasing pictures. In several places, the crags towered perpendicularly from the bed of the torrent, five hundred feet or more, decorated with trees and shrubs, which, starting out of the fissures in their bold faces, seemed to grow in air, suspended and supported of themselves. From the tops of these huge masses, the upper eminences sloped to a fearful elevation beyond, and appeared to hold their sunny peaks in the deep blue firmament. Throughout the whole valley, there are objects of grandeur and awe that overwhelm the beholder, and defy description."

The *Papaua* Valley, which commences from the shores between Taunoa and Papaua, extends, with some irregular flexures, in a south-southeast direction, to the northern foot of Aorai, and presents similar features to the Matavai Valley.

The Papiete Valley is a little more easterly in its course, but terminates alongside of the Papaua, separated from it only by a narrow ridge or wall. Mount Aorai rises from each, with a bold front, sloping at an inclination of from sixty to eighty degrees, yet covered with forests nearly to the summit. A part of the western ridge of the Papiete Valley, just under Aorai, bears the name of the Crown. It is a wall of rock, six or eight hundred feet high, worn above into jagged points or needles. Beyond it lies the Punaavia Valley. It is a striking object, in a view from the sea, a little to the eastward of Papiete harbour.

West of Papiete, the slopes of the mountains are much broken into minor valleys and ridges, but there is no large valley opening on the shore corresponding to those described till we reach Punaavia.

The Punaavia Valley has some general resemblance to the Papenoo Valley in the breadth of the enclosed strip of land, yet assumes a very different character toward the interior. It has a course to the south-eastward, and continues to the very foot of all the loftiest peaks of the island. About a league and a half from the sea, there is a steep acclivity, in many parts quite perpendicular. Making this ascent, we reach a broad, irregular plain, three or four miles wide, around which stretch precipitous ridges a thousand feet or more in height; far above these ridges rise, with erect, majestic front, the lofty Orohena and Aorai, with the Crown and other crested summits at their foot. These peaks, at top, are not over two miles apart; and thus they stand side by side, Orohena full four thousand feet above the plain at its foot, and Aorai but a few hundred feet lower. Aorai is seen in profile, and narrows upward to a mere edge, though appearing massive from the north. A low ridge of rock connects the two mountains at base; it is the same that heads the Matavai Valley. The Crown is just to the north of Aorai. The extent of the plain I had no time to ascertain: a circuit of twelve miles is not an over estimate.*

* We cite again, from Tyerman and Bennett, a passage describing the scene above alluded to. The views on these islands are so extraordinary, so unlike any thing in our own country, that we believe a second account may be needed to give an idea of the Tahitian mountains. It is condensed from page 101, vol. i. "Far in the distance to the southeast, Orohena appeared, but only half revealed below the cloud that compassed its mysterious top. While we gazed, the vapours shifted, and gave us, glimpse by

These descriptions of valleys and ridges are not given as mere landscape sketches. The geologist sees, in these lofty heights or mountain walls, and the profound gorges that divide them, evidence with regard to the agents that have been engaged in producing these results. Probably, no twenty miles square, on any continent, can present effects of either denudation or volcanic subsidence, or of both combined, more wonderful and instructive. We shall not be accused of degrading scientific reports by mere journalising, if we continue our description of the ridges, by mentioning a few incidents connected with the ascent of Mount Aorai by the author.

We commenced the ascent by the ridge on the west side of the Matavai Valley, and, by the skilfulness of our guide, were generally able to keep the elevated parts of the ridge without descending into the deep valleys which bordered our path.* An occasional descent,

glimpse, now one, and then another, section of the upper regions. The summit, which we repeatedly caught, as it stood immovable among the shifting clouds, seemed, on the western quarter, perpendicular, on the north, making an angle of 60° and then 50° . On our left, we particularly remarked a solitary range of black rocks, high and inaccessible, shutting out the sky beyond, and so terminating the view that imagination itself, however active amid such scenes as surrounded us, would hardly have dreamed of an object beyond it. Yet, while we took our refreshment under a shady recess, and were still contemplating, with an eye 'not satisfied with seeing,' the clouded majesty of Orohena, the apparition of a rival mountain rose unexpectedly from behind the craggy screen just mentioned, and stood between heaven and earth, more as if of the former than the latter. It was some time before we could reconcile and harmonise the parts of the magnificent spectacle, or conceive by what enchantment its grandest feature had been so suddenly disclosed."

* Very few of the natives then living had ever been to the summit of this mountain, and we found great difficulty in obtaining a guide acquainted with the route. Paths lead as far as the Feiis, (pronounced Fayees,) or mountain plantains, an elevation of one thousand to fifteen hundred feet; but, beyond this, the tops of the ridges are mostly covered with a wiry brake (*Gleichenium*), which grows, in some places, to a height of ten feet, and is almost impenetrable. In order to pass through it, we had to break it down by throwing our bodies at full length upon it, or by diving into it; or, where too high to admit of this mode of progress, we had recourse to burrowing, pushing aside and breaking off its crowded stems, and thus we dug our way for rods. In addition to the brake, the shrubbery often formed a dense thicket, impassable except with a hatchet. These obstacles made our progress slow, and without a native to lead the way, the jaunt, difficult in itself, would have been quite impracticable, in the five days allotted to it. Another discomfort on the route was the want of water, which, after a few days of dry weather, is seldom to be found in the valleys near the summit. A traveller in the mountains of Tahiti should go well provided against this inconvenience. We found dew from the leaves a great luxury, and the news that water had been found in a valley created a sensation of pleasure scarcely describable.

and a climb on the opposite side of the valley were undertaken, and, although the sides were nearly perpendicular, it was accomplished without much difficulty by clinging from tree to tree, with the assistance of ropes, at times, where the mural front was otherwise impassable. By noon of the second day, we had reached an elevation of five thousand feet and stood on an area twelve feet square, the summit of an isolated crest in the ridge on which we were travelling. To the east, we looked down two thousand feet into the Matavai Valley; to the west, a thousand feet into the branch of the Papaua Valley, the slopes, either way, being from seventy to eighty degrees, or within twenty degrees of perpendicular. On the side of our ascent, and beyond, on the opposite side, our peak was united with the adjoining summit by a thin ridge, reached by a steep descent of three hundred feet. This ridge was described by our natives as no wider at top than a man's arm, and a fog coming on, they refused to attempt it that day. The next morning being clear, we pursued our course. For a hundred rods, the ridge on which we walked was two to four feet wide, and from it, we looked down on either side a thousand feet or more of almost perpendicular descent. Beyond this, the ridge continued narrow, though less dangerous, until we approached the high peak of Aorai. This peak had appeared to be conical and equally accessible on different sides, but it proved to have but one place of approach, and that along a wall with precipices of two to three thousand feet, and seldom exceeding two feet in width at top. In one place we sat on it as on the back of a horse, for it was no wider, and pushed ourselves along till we reached a spot where its width was doubled to two feet, and numerous bushes again affording us some security, we dared to walk erect. We at last stood perched on the summit edge, not six feet broad. The ridge continued beyond for a short distance, with the same sharp, knife-edge character, and was then broken off by the Punaavia Valley. Our height afforded a near view of Orohena: it was separated from us only by the Valley of Matavai, from whose profound depths it rose with nearly erect sides. The peak has a saddle shape, and the northern of the two points is called Pitohiti.* These summits, and the ridge which stretches from them toward Matavai, intercept the view to the southward. In other directions, the rapid succession of gorge and ridge that characterizes Tahitian scenery, was open before us. At the western foot of Aorai,

* Pronounced Pée-to-heé-tee.

appeared the Crown. Beyond it extended the Punaavia Valley, the only level spot in sight; and far away, in the same direction, steep ridges, rising behind one another with jagged outline, stood against the western horizon. To the north, deep valleys gorge the country, with narrow, precipitous ridges between; and these melt away into ridgy hills and valleys, and finally into the palm-covered plains bordering the sea.

On our descent, we followed the western side of the Papaua Valley, along a narrow ridge such as we have described but two or three feet wide at top, and enclosed by precipices of not less than a thousand feet. Proceeding thus for two hours, holding to the bushes which served as a kind of balustrade, though occasionally startled by a slip of the foot one side or the other—our path suddenly narrowed to a mere edge of naked rock, and, moreover, the ridge was inclined a little to the east, like a tottering wall. Taking the upper side of the sloping wall, and trusting our feet to the bushes while clinging to the rocks above, carefully dividing our weight lest we should precipitate the rocks and ourselves to the depths below, we continued on till we came to an abrupt break in the ridge of twenty feet, half of which was perpendicular. By means of ropes doubled around the rocks above, we in turn let ourselves down, and soon reached again a width of three feet, where we could walk in safety. Two hours more at last brought us to slopes and ridges where we could breathe freely.

The peculiarities here described characterize all parts of the island. Towards the high peaks of the interior, the ridges which radiate from, or connect with them, become mere mountain walls with inaccessible slopes, and the valleys are from one to three thousand feet in depth. The central peaks themselves have the same wall-like character. It is thus with Orohena and Pitohiti, as well as Aorai, and owing to the sharpness of the summit edge, rather than the steepness of the ascent, Orohena is said to be quite inaccessible. Dr. Pickering and Mr. Couthouy, in an excursion to a height of five thousand feet on this ridge, met with difficulties of the same character we have described.

No traces of a crater have yet been distinguished in or about the mountains of Tahiti. The only place which has been so considered is a depression, occupied by a small lake, situated among the mountains to the southwest of Orohena, and about fifteen hundred feet

above the sea. From the officers of the *Vincennes* who visited it, I learned that it is confined, on three sides, by steep mountain declivities, and on the fourth opens to the southward. It appears to be only the commencement of a valley which continues to the sea, differing in no respect from the common character of the Tahiti valleys at their head. A low ridge fifty feet high forms a barrier between the lake and the continuation of the valley below. According to Lieutenant Emmons, the lake is about half a mile long, and in the middle is ninety feet deep. The waters have no outlet except by some subterranean passage.

Lieutenant Emmons agrees with Lieutenant Collins, of Captain Beechey's Expedition, in supposing that this low barrier was formed by a slide from the declivities.*

Tahiti, though mountainous quite to the water's edge in a portion of its circuit, is bordered in many parts by a plain, raised six to twelve feet above high water level, and in some places nearly a mile in width. These plains are the sites of the principal villages. The situation and general features of these plains render it probable that many of them rest on coral reefs that have become covered with soil from the adjoining hills. The present fringing reefs, in many places, extend out from the shores from one to two hundred yards, and, at low tide, they are usually left bare; if filled in with stones, and covered with earth, many acres of land would be added to the island. The barrier reefs extend from half a mile to a mile from the shore, and are continued, with few interruptions, around the whole island. From Matavai to Papiete there is a narrow and intricate ship channel between the barrier and fringing reefs, (page 41.)

The streams of the island are mostly small, and in many of the narrower valleys, they often disappear entirely among the porous or cavernous rocks which form their bed. The only streams of much size in the region that came under my observation are those of the Papenoo and Punaavia Valleys. Springs are frequent along the shores, proceeding from the streamlets that have taken a subterranean course high up among the valleys, or from the waters which must every where be absorbed by rocks of the cellular structure here so

* We observe in the *Journal of Tyerman and Bennett*, an account of a slide in the Matavai Valley, "that dammed up the channel, till the water had spread into a broad pool, which threatened, when it should burst by accumulation, to devastate all the lower lands." The water opened, however, a slow vent, by which it was finally drained off.—*Vol. i. p. 101.*

common. During the rainy season from December to March, in which rain sometimes falls incessantly for weeks, the streams are very much swollen, "the low lands overflowed, fences washed away, and, unless great care is taken, many plantations destroyed."* It strikes the traveller as remarkable that little debris is to be found at the foot of the precipices or mountain ridges.

I can say but little of the southeastern or smaller peninsula of Tahiti. Its mountains have some general similarity to those we have described. The shores are mostly bordered by a narrow plain, which is said to be noted for its beauty and fertility.

The narrow isthmus between the two peninsulas is described in the Journal of Mr. Couthouy, who visited it from the Vincennes, as "a low narrow belt of sand, chiefly coral detritus and comminuted shells thrown up by the surf, with a small portion of black, ferruginous sand, and minute fragments of olivine, derived from the decomposition of volcanic rocks."

GEOLOGICAL STRUCTURE.—The rocks of Tahiti, with the exception of the coral of the shores, are wholly of igneous origin. Dark gray basalt and basaltic lavas are most common. These alternate occasionally with beds of conglomerate, consisting of the same basaltic material, or a finer tufa of similar origin.

We notice a few of the varieties before proceeding with remarks on the position and character of the beds they constitute.

1. A compact and tough grayish-blue or dark gray rock, with small disseminated grains of chrysolite.
2. The same with small black crystals of augite.
3. The same with chrysolite in crystals, one or two inches long, with smaller grains disseminated.
4. The same without augite or chrysolite.
5. The same, porphyritic, with numerous thin tables of feldspar; crystals mostly compound. Sometimes containing also augite.
6. Brownish-red, with brownish-black augite crystals.
7. Black approaching pitchstone.
8. A light-grayish trachytic basalt, porphyritic with a few crystals of feldspar.
9. A grayish-white syenite, containing acicular crystals of hornblende.

With the exception of the last three, which were not observed in

* Ellis's Polynesian Researches, vol. i. p. 28.

place, these varieties are all of common occurrence on the island. They pass into vesicular varieties, which sometimes appear almost scoriaceous. The rocks also contain magnetic iron, which, in the form of sand, may be found in many places along the seashore. The compass is often rendered useless on the island by the local attraction of the rocks. Bearings taken on the mountains were found to vary two or three points on changing the position of the instrument. The syenitic rock referred to has the appearance of common syenite, yet contains no distinct grains of quartz. It consists of a crystalline feldspar, (near albite,) with a few acicular crystals of hornblende. It appears to be only a feldspathic variety of the same igneous rocks that constitute the island. The trachytic basalt differs from the other varieties in containing more feldspar, and a consequent lighter colour and less specific gravity. It is intermediate between the common basalt and the syenite just mentioned.

The conglomerates are of every degree of coarseness, from a rock with rounded stones six inches through, to a fine yellowish-brown earthy tufa, containing only disseminated crystals of chrysolite or augite. Some of the conglomerates present a singular mottled appearance, from the many colours of the fragments composing them : stones and pebbles of ash-gray, brown, red, and grayish-blue colours being imbedded together in a brownish-yellow or brick-red base. The fragments, though angular in many instances, yet in the cliffs toward the shores are very commonly rounded.

Entering the valleys from the seashore, the first thing in the structure of the hills which strikes the attention, is the regular stratification of the rocks, and a dip or inclination toward the sea. The dip varies from three to ten degrees, or, more rarely, fifteen. Wherever examined, it is uniformly from the centre of the island outward. In many instances the slopes of the summit of a ridge correspond with the dip of the subjacent layers ; but generally the denudation which has taken place has increased somewhat the rapidity of these slopes. Although these declivities are generally overgrown, yet here and there dark lines of rocks appear through, giving a riband character to the surface, and exhibiting the usual seaward dip.

The rocks constituting these layers are mostly vesicular varieties of the light and dark gray basalt, sometimes becoming red or brown. Between these layers, are others of the conglomerate and tufa described. I observed no exposed section where the exact character of the several alternations could be ascertained. Indeed, through the

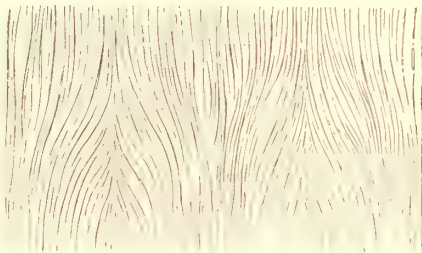
Pacific generally, the luxuriant vegetation is much in the way of geological exploration. The thickness of the layers near the shore varies from six to twenty feet.

Ascending the valleys towards the interior, the layers become thicker, and five or six miles from the sea, bluffs of a thousand feet constitute apparently a single continuous bed; or at least, there is no line of demarcation separating it into parts. Not unfrequently the whole height exhibits a continuous columnar structure throughout. These facts are well observed in the Papenoo Valley. The enclosing ridges of this valley have a rounded contour and sloping sides for the first few miles, through which the thin stratified structure continues; but beyond, they are vertical, and a division into layers is rarely distinguished.

In the lofty peak of Orohena, this massive structure is still more remarkable. In the view of it from the top of Aorai, a surface of three to four thousand feet is exposed to view, almost bare of vegetation, and throughout it no trace of layers was detected. Instead, indications of a columnar structure were observed. It was owing, apparently, to this even continuity of surface, that the usual amount of vegetation was not spread over it, for there was only here and there a crevice that could sustain even a bush. The contrast is very striking between the appearance of these heights and the basaltic bluffs of the island of Madeira, where the stratified structure is distinct to the summits, and as apparent, even many miles distant, as in a cliff of secondary limestone. The same contrast would be observed in the island of Tahiti, could the valley sections of any of the ridges near the shore be stripped of the soil which covers them; for the successive layers, where they may be examined, usually stand out with great distinctness, owing not only to the alternations of soft and wearing tufas with the firmer basaltic rocks, but as much to the open spaces or rugged cavities which separate successive beds of the latter. The interior of the island differs from the circumferential portion not only in general structure, but also in the texture of the rocks. While the latter are usually vesicular, the former are compact, or have only minute cellules, if any. From these central mountains come the gray basalt, containing large crystals of chrysolite, and the trachytic and syenitic varieties. The first four varieties of rock described appear to be most abundant.

An imperfect columnar structure is very common throughout the island, and may often be detected in the thinner beds along the shores.

But distinct and regular columns are seldom met with. One locality in the Matavai Valley, often described by travellers, was visited by Dr. Pickering and J. P. Couthouy of the Expedition. The bluff is from two to three hundred feet in height, and is neatly columnar throughout; the columns are five to eight inches in diameter and without regular transverse joints. They stand nearly perpendicular, except a short distance up the stream, where they curve round in the form of a large segment of a circle. Singular curvatures are occasionally seen in columns forming the interior of a bluff. In the face of a precipice about five hundred feet high in the Matavai Valley, where the columnar structure was displayed with considerable perfection, there were several places in which the columns converged to a point, as is shown in the figure, and then gradually assumed their former direction. The breadth occupied by one of these clusters of converging columns, I estimated at ten feet, but others were much larger.



The columns themselves were from ten to twenty inches in diameter. This anomalous structure has been explained on page 269.

Dikes of basalt are seen in different parts of the island; but the rocks are so seldom bare of soil, that we have not been able to deduce any important conclusions from our investigations. If we may judge from the observations made, we should say that they were far from numerous, compared with most volcanic regions. Under One Tree Hill, just west of Matavai, tufa is intersected by several dikes running to the southward and eastward, and varying in width from one to six feet. The rock is mostly compact and tough; it has a grayish-black colour, and contains some chrysolite, with an occasional crystal of augite. In the hill there are several faults, which dislocate the dikes in many places. Other dikes were observed in the Papenoo and Punaavia Valleys, some of which were remarkable for their curvatures, passing sometimes to a horizontal position, and then resuming an upright course. Scarcely any indication of heat is found in the walls of the dikes, a fact which we observe to be almost universal in the case of one basaltic rock intersecting another. The tufas are, however, much baked for a few inches.

One fact worthy of note connected with the dikes is that they are

seldom attended with any disturbance or uplifting of the layers. We met with no tilted rocks in Tahiti. The slopes are regular and uniform. The only exception to this noticed is at One Tree Hill, where the tufa is much inclined. But of this we speak on a following page.

Minerals.—With the exception of the essential constituents of the rocks already mentioned, we observed nothing of much interest in the rocks of Tahiti. Small geodes of stilbite and analcime were found in pebbles in the Papenoo Valley; and at One Tree Hill the basalt of the dikes contains minute cavities which are filled, apparently, with natrolite. Particles of iron pyrites are occasionally found in the basalt. The augite crystals have the simple form represented in figure 1, of the author's Treatise on Mineralogy. They vary in length from a quarter to three quarters of an inch, and when broken, usually present grayish-brown and brownish-black colours, often with a slight iridescence. The chrysolite has the usual dark apple-green and grass-green colours. The large crystals, two inches in length and an inch broad, are quite brittle, and show no distinct faces of crystallization, yet usually afford rectangular sections.

Decomposition of the rocks.—The basaltic rocks of the island are subject throughout to rapid decomposition. This may be observed on every part of the island; from the very summits of the peaks to the seashore, the rock is almost invariably covered with earth. Where the top of the mountain ridge was a mere edge, but three or four feet wide, there was seldom a spot without soil and a growth of bushes; it is owing to the fact that the shrubbery shuts out the dangers either side and affords some support, that the mountain travelling is at all practicable.

On the declivities back of Matavai and in many places elsewhere, the rocks may be seen in the process of decomposition; and often the soil still retains the form of the original layer, rising into rough points and craggy hillocks, looking like the rock itself; yet so soft as to be gathered up by the hand like so much earth.

In the progress of decomposition, the chrysolite appears to yield first. It turns iridescent, and as the change goes on, becomes finally, in the half-altered rock, an ochre-yellow or brownish-yellow earth, very soft and pulverulent. The compact base next crumbles, and, unless it contains iron or is largely charged with chrysolite, it usually retains a dirt-brown colour, until finally pulverised, when its colour is modified by that of the altered chrysolite. Other beds con-

taining much iron become at once deep red. The crystals of augite next yield, becoming at first crumbling, and then assuming a dark-brownish colour.

The soil produced by decomposition varies in colour from a dirt brown, through yellow and brownish shades, to a brick red or brownish red. Many of the hills are entirely of the latter colour, but a brownish yellow appears to be most common. On the summit of Mount Aorai, the colour was found to vary from brownish yellow to deep red, and in most places, the surface for ten to twelve inches was as black as vegetable mould.

The red soil often makes a good red ochre, and is used as a paint by the natives.

2. EVIDENCES OF CHANGE OF LEVEL.

One of the objects I had in view when commencing the ascent of Mount Aorai, was an examination of the reputed coral bed, located, according to report, on the summits of the Tahitian mountains. There was scarcely a native, but had heard of the *mountain coral* and the *screw shells*; yet it was difficult to find one who had ever seen either. We were at last successful, and started with the assurance from our guide that he had seen both, and would lead us to the spot.

On approaching the summit, the valleys were searched for fragments, but none were found. Having reached the top, we looked around for the bed, but there was nothing in sight on the surface. My guide commenced digging and I joined him. Soon he brought me a coral fragment, a grayish white trachytic variety of the basalt. When told that it was not coral, he insisted that it was coral in Tahiti. We dug still longer and searched around, but it was all unavailing. The *screw shells* he could not find. They were of the same nature, he said, but longer and round. My guide had explained to me on the ascent that they were worn smooth like the stones, yet I scarcely expected so close a resemblance. In some places the ridge was bare, but without any trace of coral.

The peak of Orohena, as it is higher than Aorai, may possibly have its coral bank. Yet we believe that there is no evidence of it whatever. The view from Aorai showed no signs of it: and the examination of the valleys of the island by the officers of the squadron in

their different excursions, supported the same opinion. I was afterward informed by Mr. Cunningham, then English Vice-Consul at the Navigator Islands, and previously long resident in Tahiti, that he had fully satisfied himself that the supposed coral bank on the mountains was a mere fable.

Fragments of coral, sometimes of large size, are met with occasionally at considerable elevations on the island, both in the valleys and on the ridges. It was formerly customary with the natives, when making excursions up the mountains, to carry along a piece of coral to leave at the highest point reached. There was a certain superstitious regard for it, which led to its being selected for this purpose. For the same reason, also, it was carried up the hills to mark the limits between the land of different chiefs. These facts account for the occasional occurrence of coral in the valleys, as observed by Mr. Stutchbury. The height at which it is not unfrequently found, is one thousand to fifteen hundred feet, the region of the Feiis, to which regular paths ascend. Besides coral, shells of various kinds are found about the hills, and especially at the elevation just mentioned, where they are carried by the natives as food. A large species of Turbo is the most common shell, and, in this case, these proofs of elevation are transported to the places where they occur by a soldier crab. I have often met with them at the height of one thousand feet, travelling with their shells on their backs.*

Whether the present reefs of Tahiti indicate any elevation of the island or not, I could not fully assure myself. If any, it is but small, as there are no islands about the reefs which have a higher elevation than they might have acquired by gradual accumulation from the action of the surf. Neither is there any evidence of subsidence apparent. The shore plains, if built upon reefs, as I was assured, may afford proof of a rise of one or two feet.

* Mr. Couthouy remarks in his journal, with reference to the tradition of corals on Orohena, "We saw nothing even remotely justifying such a belief, not a solitary fragment of calcareous rock being met with in any of the villages at the foot of the peak, or on any of the ridges, although I carefully sought for them. True, in the immediate vicinity of the sea, and as high up as one thousand eight hundred or two thousand feet, we saw now and then blocks of coral lying loose on the surface, but they were all recent species, such as are now growing on the reef, and had evidently been carried up, either for landmarks, or some other purpose, perhaps a religious one. Mr. Ormond told me that certain kinds of coral were held sacred in ancient times by the natives."

3. CONCLUDING REMARKS ON THE GEOLOGY OF TAHITI.

In this place, I simply state the most probable view with regard to the formation of the island of Tahiti, reserving for a future chapter the general course of argument bearing upon the subject.

There is abundant evidence that the material constituting the island has been in fusion, and that the main vent of eruption from which the beds of rock of the northern peninsula flowed out, was situated near the centre of the same. The inclination of the rocks outward from the centre, is proof of this fact; as well as the uniformity of the angle of dip varying only between three to twelve degrees.

Why the shore portions for five to eight miles inward differ so strikingly from the interior, the former consisting of thin layers of basaltic lava and conglomerate, the latter of thick beds, in some places more than a thousand feet in depth, may be explained on the same hypothesis. This centre was the centre of heat, the fountain of the liquid rock that flowed over, and produced the beds of the outer portion of the island; and the cooling of this liquid centre, or the influence of the central heat, may have given the solid compact character to the interior.

Have we no remains of the great centre? There is a striking resemblance in the grand amphitheatre at the head of the Punaavia Valley to the central basins described as characterizing other volcanic islands. Von Buch dwells upon this point in support of his own peculiar views, and instances, besides, some of the Canary Islands, Barren Island in the Gulf of Bengal, Santorini in the Grecian Archipelago, and others, as examples of it. If this supposition be correct, the peaks of Aorai and Orohena stand on the edge of the pit; and the ridge partially enclosing the plain may be the remains of its circumference. But we do not give this as our decided opinion. It is possible that the whole plain at the head of the valley may be the result of subsidence.

Whatever view be held, Tahiti, as it is, is but the ruins of what it was. The vast volcanic mountain has been reduced to a collection of ridges and profound valleys, and Orohena and Aorai stand as monuments, marking, though imperfectly, the amount of degradation and subsidence which has taken place to bring out its present features. The causes of these changes rest with *fire* and *water*, and will be discussed in the sequel.

The small elevation, two hundred feet high, on the shores west of Matavai, called One Tree Hill, is the only spot where I have suspected the former existence of a lateral crater. Its tufa character and the inclination of the beds, so unlike, in both respects, the rocks of the hills back, point out the spot as the very probable site of one of those subordinate places of eruption, or those hills of tufa (like Diamond Hill, of Oahu) that often form about active volcanoes. The hill has a bluff front on the water, where it has been worn down by the sea, and it contains some fractures or fissures which dislocate the dikes that intersect the tufa. These fissures appear to belong to the place rather than to the mountain.

As the southern peninsula was not examined, we can speak less decidedly respecting the nature of this part of the island. Yet an analogy with many of the Sandwich Islands, will bear us out in the supposition that this peninsula was another centre of volcanic eruption. Tahiti, if so, originated in the action of two volcanic centres; the two acting together, became united at base, and thus formed the island with its isthmus. The bearing of these centres from one another corresponds in direction with the lines of volcanic action through the Pacific. Tahiti, therefore, may be another twin island, like Maui and Oahu.

Of the other islands of the Society Group, I had only distant views. I have gathered a few facts with regard to them from different sources, and mostly from Ellis, and Tyerman and Bennett.

Eimeo.—The island of Eimeo was described to me as having a part of the interior low with rounded hills, enclosed by high mountains which often present steep walls of rock inward. It is also remarkable for its deep harbours. Taloo Harbour, on the north side, (called, more properly, Oponohu,) was visited by the Vincennes. It is nearly three miles deep, with abrupt shores. Passing up the valley, the central amphitheatre is entered. "The ground clothed with exuberant vegetation rises gradually from the coast towards this interior district, where the whole surface bursts, as it were, into abrupt and precipitous elevations, the crests of which are naked rock of stupendous bulk, and strange forms. Some seem to stand on very narrow bases, with broad and beetling fronts; one facing the harbour resembled a huge tower surmounted by a sharp spire." "The proportions of this temple of earth and sky (for such it appeared) were so harmonious and exact, that its immensity was lost at first sight, for want of a con-

trast whereby to measure its parts. But when we looked back upon the harbour of Taloo, and saw the steep declivities by which we had ascended from the beach, diminished, like peaked points, beneath our feet, we were thus made almost tremblingly sensible of the magnitude of the mountains that here engirdled our horizon, and the breadth of the interjacent valley, in the midst of which we stood."* This peculiar character is highly interesting to the geologist, who may trace in it analogies with other ancient volcanic regions.

The mountains of Eimeo have never been measured: their estimated height is four thousand feet.

On the northeastern side of the island, between the mountains and the sea, there is an extensive lake, called Tamai.

Cook's Harbour is another large bay, separated from Taloo Harbour by a mountain ridge.

Huahine.—A channel, about a mile wide, separates Huahine-iti from Huahine, two islands, which appear as if parts of a single trapezoidal island, broken through along a diagonal; a single coral reef includes the whole. In the distant view, the mass of mountains constituting Huahine has a conical outline; but approaching it, it is found to resemble Eimeo, though somewhat less broken. The valleys are deep, and run in general from the centre towards the shore.

The strait between the two islands is bordered by "craggy precipices, crowding one upon the back of another, to a height of three thousand feet. Over the top of one of these hangs a huge rock, as though it were disrupted from its seat, and falling instantly upon the valley beneath. On the contrary shore, gigantic masses of the same character rear their weather-beaten but immovable ridges. Even the perpendicular faces of the rocks are often overgrown, in this genial climate, with rank and luxuriant vegetation." In these straits, the rocks are somewhat columnar.

Huahine has also deep harbours, but they are inferior to those of Raiatea. There are two lakes or lagoons on the northern part of the island, each of which is about five miles long by two or three broad. Ellis, speaking of one of them, Lake Macoa, suggests that it was originally a part of the sea, and has been cut off from it by the growth of coral, and accumulation from the action of the sea and winds. The western side is low and flat, yet covered with cocoanut and other trees. On the east there is a flat, nearly a mile wide in

* Tyerman and Bennett, i. 30.

some parts, from which the mountains rise more or less abruptly. At the head of Fare Harbour, the shore plain is nearly a mile wide, and the strewn shells and fragments of coral in the soil, strongly indicate that the tract had been recovered from the sea, and that the waves once washed against the very foot of the mountain.*

Raiatea and Tahaa.—These two islands are enclosed within the same reef like Huahine and Huahine-iti; but each has its own slopes and ridges independent of the other, showing no evidence that they have been rent asunder. On the contrary, they may be better compared to the two peninsulas of Tahiti; for were this last-mentioned island to subside but little, we should have Raiatea and Tahaa over again. The channel between these islands is from three to five miles wide, and the sea is quite shallow. The mountains of Raiatea are more lofty than those of Huahine, and equally broken and picturesque. The whole coast is cut up with deep indentations, and in Tahaa they are so remarkable that the natives compare the island to a cuttle-fish, its spreading arms corresponding to the jutting points or capes.

Borabora.—This island, at first sight from the ship, appears like a lofty cone, but a nearer view opens its valleys, and breaks the surface into peaks and ridges. Its height may be estimated at three thousand feet. Coral reefs skirt the shores.

Maurua.—The mountains of this island are, as usual, highest at the centre, and seem to form a single peak, in the distant prospect. They are described as less broken into valleys than the other Society Islands. A reef surrounds the island, with a single break or entrance on the southwest side.

From the accounts of the islands we have here reviewed, we find that they correspond in general structure with Tahiti. At the centre is the highest summit, and from it the valleys radiate more or less regularly towards the shores around. The same origin may be attributed to their features as to those of Tahiti. The nature of the rocks, as far as can be ascertained, is similar. On Borabora, Ellis found "masses of rocks, apparently composed of feldspar and quartz," and on Maurua, a species of granite is found in considerable abundance, along with the vesicular lava, and the basalt common to all the islands. These varieties of rock appear to resemble the syenite of Tahiti,

* Tyerman and Bennett, i. 184, 185.

which is a crystalline feldspathic rock, very similar to a grayish-white feldspathic rock that was observed passing into basalt in New Holland.

The most striking feature of the northwestern islands is the depth of the bays. I shall hereafter show that this fact is connected with a greater amount of subsidence than has been experienced farther south.

The extent of the shore plains, and the large lakes in some places cut off from the sea, evince the accumulating force of the waves, acting along with the growth of coral reefs. There are many places besides those mentioned, where embankments have been thus thrown up by the sea, inside of which are marshy areas. They also appear to indicate, more decidedly than anything observed on Tahiti, a rise of several feet since the preceding era of subsidence ceased.

The great amphitheatre of Eimeo appears to be analogous to that west of Orohena in Tahiti. Yet a more particular examination is required before we can safely base upon it all the deductions which it seems to authorize. The descriptions carry us at once to the volcanic regions of the Canaries, and the walled amphitheatres there; but we forbear urging the comparison.

We have little evidence with regard to the progression in the fires that once burned along the Tahitian range. Still the character of the rocks and the features of the surface lead us to the opinion that the fires were first extinct at the northwest end of the line, and last at the southeast. This corresponds with the course in the Sandwich Islands, and is the reverse of that in the Navigators.

CHAPTER V.

SAMOAN ISLANDS.

THE Samoan or Navigator Islands are eight in number, and three of them are among the largest in Polynesia. Beginning with the westernmost they are as follows :



SAMOAN OR NAVIGATOR ISLANDS.*

Savaii, Apolima, Manono, Upolu, Tutuila, Ofu, Olosenga, and Manua.† There are several isolated rocks or small islets, in the

- * 1. Savaii, Mataautu.
- 2. Island of Apolima.
- 3. Island of Manono.
- 4. Upolu, Peak of Tafua, back of the village of Fasetootai.
- 5. " Apia.
- 6. " Laulii.
- 7. " Saluafata.
- 8. " Falifa.
- 9. " Fangaloo Bay.
- 10. " Lafanga.
- 11. " Falcalili.
- 12. " Islets of Nuutele, Nuulua, Namu'a, and Tapu-tapu.
- 13. " Tutuila, Cockscomb Point.
- 14. " Leone Bay.
- 15. " Pango-pango Bay.

† Pronounced Sahvyee, Apoléemah, Oopóloo, Tootooíllah, Ofoo, Olosèng-ah, Mah-nóoah.

vicinity of the large islands, but they are not of sufficient importance to merit enumeration in this place.

The whole group comprises eight hundred square miles of land, nineteen-twentieths of which are contained in Savaii, Upolu, and Tutuila. The last three islands in the above enumeration lie near one another, and are included within the same horizon. This is also true of the first four. Tutuila is more alone, lying about seventy geographical miles west of Manua, and forty miles east-southeast of Upolu; its principal heights, however, are often seen from the east end of the latter island. Rose Island, a small atoll, may properly be included with the Samoan Group, as it lies in the same range with Ofu and Manua, but seventy-five miles to the eastward. The group is included between the parallels of $13^{\circ} 30'$ and $14^{\circ} 30'$ S., and the meridians 165° and $173^{\circ} 40'$ W.

All these islands were visited by some of the vessels of the squadron; but my own observations have been confined to Upolu and Tutuila, with a hasty glance at Manono, Apolima, and Savaii.

The islands are similar in geological structure: basalt, basaltic lavas, and basaltic and volcanic tufas, are the constituent rocks of each of them. They differ, however, in the age of the rocks that cover the surface; on some we find the features of the oldest islands of these seas, while on others the currents of lava may still be traced, that flowed down from some crater or fissure. Profound valleys, mural precipices, and craggy peaks characterize the former; and the long slopes of a volcanic dome the latter.

The islands stretch along in a west-northwest direction, and volcanic energy appears to have gradually diminished in the same direction; the fires first disappeared to the east-southeast, and were last extinguished in Savaii at the opposite end of the line. This is the reverse of what took place in the Sandwich Islands, where the west-northwest extremity of the group was first extinct. Tutuila has the aged appearance of Tahiti, and contains no prominent cone or crater at centre. Upolu, next to the westward, is characterized in part by the deep gorges and rugged peaks of Tutuila, and in other portions by the gentle slopes of a recent volcanic region, and the scoriaceous lavas of modern eruptions. Savaii, the westernmost, is a single volcanic district, resembling Mount Kea; the sloping surface of its broadly-spread cone, still remains roughened with numberless parasitic craters.

In our remarks on the Samoan Group, we commence with those to the eastward.

I. MANUA, OFU, OLOSENGA, AND ROSE ISLANDS.

The island of Manua is described as having the form of a regular dome.* The sea is bordered in most parts by a cliff of three or four hundred feet, above which the ascent is gentle and comparatively even. Along the shores, layers of conglomerate were observed consisting of coarse fragments of the basaltic rock often as large as the head. "The stratification in the cliffs was distinct, and appeared to be horizontal, although in some places much undulated, and at times contorted."

Ofu and Olosenga form a narrow line of land divided into the two parts which constitute the separate islands merely by a boat channel a fourth of a mile wide. They were apparently once united. Olosenga has bold precipitous shores and is three miles in length. Ofu is similar in its features, but smaller, the length not exceeding three-fourths of a mile.

Rose Island is a low coral atoll. Masses of basalt were observed in one or two places on its reefs, which had probably been carried there by floating logs, or as the ballast of some canoe.

II. ISLAND OF TUTUILA.

Tutuila, in the distant view, is less varied in its outline and less lofty in its mountain heights than the islands of the Society Group.† The highest summit, Matafoa, according to observations with a sympiesometer by Mr. Couthouy, is 2327 feet in height. Its surface presents the same general features as Tahiti, though on an inferior scale. The ridges are precipitous, often rising with mural fronts, and thinning out above to a sharp trenchant edge. A few serrated summits and needle peaks are interspersed among the tamer heights, and distinctly indicate by their features the geological structure of the

* See Narrative, ii. 65.

† We came to anchor at Tutuila late on Friday, and by Saturday noon all hands were ordered aboard to sail for Upolu. A single ramble of four hours and a half was, therefore, all the opportunity I had for examining the island.

mountains. The harbour of Pango-pango, in which our ships lay at anchor, is a large bay several miles deep, on the south side of the island. It curves to the westward, and is confined by mountain ridges from eight to thirteen hundred feet in height, which form a high and steep but verdant wall around it. For a few hundred feet, about two-thirds of the way up the face of the ridge, a bare surface of dark semi-columnar rock is exposed to view. Above this, the front of the ridge again slopes a little, like the part below, and the rocks are soon buried in forest vegetation, which continues with few exceptions to the summit.

Along the shores where the valleys come out upon the sea, there is usually a level plain, sometimes extending back for two miles. These plains are mostly occupied by groves of cocoanut and bread fruit, and the villages of the natives.

The soil of this island is extremely fertile, the whole surface well wooded, and the lands abundantly watered with mountain streams.

Rocks.—The basalt of the island about Pango-pango and on the ridges to the north, is remarkable for the very sparing dissemination of crystals of chrysolite and augite. In many varieties there is a total absence of either, and a strikingly uniform texture throughout. The rock is usually somewhat vesicular, but in some places it is without a cellule. A variety from Cockscomb Hill, a high crest of rock on the north side of the island, resembles in its appearance a very compact, grayish-brown quartz rock, though not silicious; it has no traces of crystallization, is exceedingly tough, and has a glistening lustre. Without a knowledge of its gradations into the other rocks of the island, a hand specimen would not at first be recognised as of igneous origin. Its colour is dirty bluish-brown.

Small feldspathic crystals and minute grains of magnetic iron are occasionally found in the rock. I have collected, from large boulders around Pango-pango, fine specimens of porphyritic basalt, in which large compound tables of feldspar were thickly disseminated through a compact basaltic base. Some of the tables were a fourth of an inch thick, and an inch and a half broad.

The prevailing colour of the basalt is grayish-blue, of different shades, passing into greenish-black and reddish-brown.

I was informed by Mr. W. C. Cunningham, then English Vice-Consul at these islands, that a large current of lava occurs on the southwest portion of Tutuila. I have not seen any specimens of the

lava. This is the only instance, as far as I could learn, of the existence of any recent volcanic appearances.

The basaltic conglomerate consists of fragments of the basaltic rocks: its general characters may be inferred from our description of the similar beds at Tahiti. The fragments, where I examined the rock, were partially rounded, and some of them more scoriaceous than any of the basalt observed in place on the island. It had a dark colour, and a dull earthy aspect when broken. It occurs in layers near the western entrance of Pango-pango Harbour, and along the shores in that direction where it appeared to underlie the basalt. Numerous other localities of it probably exist, but in our rapid glance at the island, I did not meet with them.

The basalt generally exhibits a tendency to a columnar structure, but no distinct columns with regular polygonal forms were observed. A short distance to the east of the harbour there stands a small round islet, rising from the waves like the venerable ruins of an ancient tower. Its erect sides consist of rude columns of basalt. A few spots of verdure relieve the blackness of the walls, and the broken summit is overgrown with shrubbery and a few large trees. The bold shores and steep rocky escarpments, which are the prominent features of Tutuila, result, in many instances, from imperfect vertical cleavages, or a tendency to a columnar structure, characterizing the basalt.

Tutuila has undergone so great changes by convulsions and denuding agents, that the outline of the volcanic cone or cones from which the rocks of the island were ejected, is wholly obliterated. With our present imperfect information, we do not attempt to trace out the position of the central vent or vents; we can only compare the island, in general features, to Kauai, among the Sandwich Islands, and Tahiti, of the Society Group. The basaltic lava, on the southwest side, according to Mr. Cunningham, did not flow from a crater, but probably from some fissure or opening which is now concealed.

The harbour of Pango-pango, with its mural enclosures, reminds us of such valleys as the Val del Bove of Etna, and unless we may look to convulsions and subsidences as the sources of its formation, or to such phenomena as appear at Kilauea, we are at a loss to account for its extent and features.

III. ISLAND OF UPOLU.

I. GENERAL FEATURES.

Upolu is a narrow strip of land, lying nearly in an east-by-south and west-by-north direction. It is a mountain ridge, varying from one to three thousand feet in height. The slopes are of very different character in various parts, and we thus distinguish a *Western, Middle,* and *Eastern* district. In the middle portion, extending from Laulii, on the north side, to Tiavea, a distance of fifteen miles, the mountains have the bold and angular features of the older basaltic islands. Deep valleys cut through their sides; or they fall in abrupt precipices, through many hundred feet of their height. Numerous thready cascades pour down the steep surface in long white lines.

These features are strikingly seen around Fangaloo Bay. The bay is a deep indentation, running nearly three miles into the island, between lofty spurs from the mountains. Amid the dense foliage that covers the inaccessible heights on either side, especially on the eastern, there are several of these high waterfalls. On the west of the bay stands the lofty, pointed summit of Mount Fao, supposed to be the highest on the island: its altitude is about 3200 feet. The only rival is part of the main ridge back of Solo-solo. On the opposite side of Fangaloo, stands with erect front and towering summit, a less lofty but more picturesque peak, called Malatta. At the head of the bay, the ridge runs up into a sharp conical eminence, of very regular shape, called Mount Vaaolata.

The coast of this portion of the island, on the north side, is indented with other large bays, a mile in depth. Tiavea and Eoafatu are the principal of them. On the top of the high mountain that separates Eoafatu from Fangaloo, there is a small lake.

These broken features characterize the whole of the Middle district. Throughout its extent, the mountain declivities, with few exceptions, rise abruptly from the sea, or there is but a narrow strip of land on the shores; and from Falifa to Tiavea the abruptness below the surface of the sea is shown by the absence of the coral reef. Only narrow fringing ledges border the bays.

At Falifa there is a broad plain, which rises gently from the coast, and extends about six miles back. It is from five to six miles long,

though interrupted near the village of Falifa by a spur from the back range. This plain is a peculiar feature of this portion of the island. The greater part of it is backed by a long and lofty precipice. It appears like a section of a sloping mountain, and above there is still a narrow portion of the original slope of the range.

The preceding remarks apply only to the northern side of the island; the southern side between the same limits, partake, in part, of similar features; but the slopes, I am informed, are more gradual and less rugged.

Going in either direction, east or west, from this central district of old and broken hills and deeply indented shores, the declivities rapidly become more even, and the shores more gently undulating. Instead of long points formed by the projection of spurs from the mountains and terminating in ragged cliffs, the sea is bordered by low plains, which almost imperceptibly rise into the gently sloping declivities of the mountain.

In the western half of the island, the smoothness of the declivities and gentleness of the slopes is most remarkable from Sangana westward. Back of Apia, a few miles east of that place, there are many deep gorges, which, as seen from sea, appear only as ravines gullied out of the sloping surface, yet prove on examination, to be several hundred feet in depth, and enclosed by steep and nearly vertical walls. They become more numerous toward the central district. Near Apia there is a somewhat isolated elevation called Vaiea.

The west end of the island, like the vicinity of Sangana, is a low gently sloping plain, three miles wide, and rising inland to the volcanic cone of Tafua, standing back of Fasetoötai.

East of Taivea, toward the east extremity of the island, the same gradually rising surface and the same features characterize the country as at the west extremity. The ravines are few and small. The declivities slope into a plain along the shores, except on the side of the island fronting the southeast, where the smooth-featured mountain terminates abruptly in a bluff wall, three to six hundred feet high.

The Eastern and Western districts, as we shall call them, are both regions of comparatively recent volcanic action. Each contains several craters of perfect unbroken outline, and in each, the smooth slopes, rarely exceeding five or six degrees in inclination, are owing to the broad streams of lava that have poured over from the different volcanic vents. The summit of the ridge in these districts is a little

undulating. At short intervals of a few miles, the horns and gently swelling sides of one crater after another may be clearly distinguished. There are four or five of these craters on the outline of the ridge in the Western district, and as many in the Eastern district of the island, (figures, page 325.) We shall return to this subject, and give a particular description of the craters examined, after completing our general remarks on the features of the island.

The whole island is covered with forests; or rather, it is one dense forest from the extreme east to the west end, and from the water's edge to the very summit of the most rugged peaks. The natives have spread their cocoanut groves and bread-fruit trees along the shores, but in many places the line of forests remains yet unbroken, and nothing can exceed its richness and beauty. Shrubbery and sugar-canes cover some parts of the lower declivities of the mountains, but there is nowhere a spot of natural pasture land.

The island is in general well watered. There is scarcely a day in the year without low and heavy clouds about the summits of the mountains. Many streams of moderate size flow down both sides of the island to the sea. The rivers Falifa and Salangi, on opposite sides of the same ridge, are the largest. The latter rises just south of the Fangalua Mountains, winds about for twelve or fourteen miles as a mountain torrent, occasionally tumbling in cascades through deep gorges, and reaches the sea at Salangi. It is two fathoms deep at its mouth, but rapidly changes to a brawling streamlet, a short distance back. The Falifa River is described as still longer in its winding course. A third of a mile from the sea it comes dashing along over a rocky bed, noisily leaps down a precipice of thirty feet, and then flows slowly and quietly on to the bay. Below the falls it averages by our estimate, eighty feet in width, and has more than three feet of water through this whole distance.

Smaller streamlets are numerous: one empties at Apia, another at Lotofanga, two at Sinaapu; but they scarcely merit naming.

The eastern and western extremities of the island are poorly supplied with streams, on account of the cellular character of the volcanic rocks and the subterranean passages among them. From Apia westward there are many fountains gushing out along the shores, proceeding from the subterranean waters; the number is at least one a mile. Some of the streams flow for a while in the mountains, and then suddenly sink to emerge again in these springs of the coast, or beneath the sea.

2. GEOLOGICAL STRUCTURE.

Rocks, their Mineral Characters.—The following are the principal varieties of basalt found on the island :

1. Dark grayish-blue and grayish-black basalt; very compact without cellules; fracture a little conchoidal; no distinct crystallization; no imbedded grains of chrysolite; lustre slightly glistening. Resembles the rock of Cockscomb Hill, Tutuila, page 310.

2. Similar to the above, but a little cellular and containing minute particles of chrysolite.

3. Grayish-blue; no lustre; rough fracture; harsh feel; sometimes very compact, but generally cellular; occasionally contains chrysolite.

4. Dark grayish-blue; containing crystals of chrysolite and augite thickly disseminated; both very compact and cellular.

5. Black ferruginous basalt; very tough; fracture smooth, a little conchoidal; lustre glistening; usually very cellular and containing a few disseminated grains of chrysolite.

6. A grayish dark-blue basalt, porphyritic with very thin tabular feldspathic crystals. Another porphyritic variety, consisting of the same coloured base, speckled white with points of feldspar.

7. Scoriaceous basaltic lava; brown, dark grayish-blue or brownish-red, very light and cellular, or consisting solely of the thin parietes of small spherical cellules. The material of the rock is without lustre and resembles var. 3.

These several kinds are quite common. All but the fifth and seventh occur in the central district of the island, and may be considered as the older rocks of the island. The third and fifth are the usual forms presented by the more recent rocks. The seventh is found in and about the craters, as at Tafua.

The porphyritic varieties (6), and the basalt with imbedded augite (4), are abundant along the rocky coast between Laulii and Solo-solo. The compact basalt (var. 1), is also found along the same coast. Particular localities of the other varieties need not be mentioned, as they are very generally distributed over the island.

Besides the minerals already noticed, the rocks often contain magnetic iron in small grains or crystals. At a few places along the shores magnetic iron sand may be collected by the handful. Five miles east of Apia is one of its localities.

The tufa and basaltic conglomerates have few peculiarities. The latter are like those of Tutuila, (page 311.) The tufa is a very fine-grained earth-coloured rock, without lustre, and fragile. It is abundant at the eastern extremity of Upolu, and in the adjacent islands, and will receive farther attention on a future page. A variety of a brick-red colour, sprinkled with white points (feldspathic) is used as a paint by the islanders. I have not seen this variety in place, and have suspected that it may be decomposed rock proceeding from the second variety of porphyritic basalt (var. 6, b.) The dissemination of the whitish points is very similar to that of the feldspar in this rock. The tufa resembles a red ochre, and owes its colour to iron.

Structure.—a. A lamellar structure characterizes the rock in some of the cliffs. Just west of Laulii, this structure is finely developed; the rock (var. 4) is divided into layers from half an inch to a foot in thickness. The layers separate with difficulty, although very distinct on the broken surface of the cliff. The layers are often contorted or curved.

The same structure, I am told, is exhibited by recent layers of the black lava, on the south side of Upolu. Layers from an inch to six inches thick, are slowly cleaving off from the roofs of some of the caverns in that part of the island.

b. A concentric structure is not common in the basalt and basaltic lavas of the island. Three miles east of Apia, along the coast, this structure is imperfectly developed. The centres of the concentric masses have a dark greenish-black colour and are compact. The rock adjoining the central mass is altered to an ochre yellow or reddish-brown colour; the latter is the external colour of the two, and is apparently the result of a farther decomposition and a more complete development of the iron in the constitution of the rock. This structure may be seen at other places along the shores; but I have observed no additional facts respecting it worthy of note.

c. Columnar basalt, though common in imperfect forms, is still, according to our observations, of rare occurrence in regular prisms. In the high peaks around Fangaloa the same vertical cleavages may be detected as in the hills of Tutuila. Some of the thin layers of basalt, or basaltic lava, along the coast, are broken, by perpendicular fractures, into columnar masses, from two to five feet in breadth. The fractures generally produce curved surfaces, and the masses or columns stand half an inch or an inch apart.

Along the rocky coast beyond Laulii to the eastward, the surface

of the basalt is occasionally divided by irregular fractures into small polygonal areas, six to twenty-four inches across, and these areas, owing to the filtration of some cementing material into the fissures, are separated by double walls, like the fissured sandstones of Australia. The wear of the surface has left the harder walls prominent, and the appearance is much like that of the sandstone referred to. The infiltrating fluid may have contained silica.

Stratification.—In this place we make a few remarks only on the older rocks of the central district, reserving many facts respecting the more recent basaltic lavas and tufas, till we have described the several craters of the island. On the shores, where alone the rocks are exposed to view, the basalt occurs in a series of layers, which appear to have been formed by successive flowings of the melted rock. The layers average ten feet in thickness, and are partially separated by small rugged caverns and blow-holes. The layers are nearly horizontal, or have a very gradual dip outward, not exceeding five or six degrees. These are the ordinary characters of the rock between Lauili and Tiavea. Just east of Lauili the cliff is partly composed of a basaltic conglomerate. A layer ten feet thick intervenes between the two layers of basalt forming the cliff. The conglomerate consists of rounded and ragged masses of basalt, cellular or compact, imbedded in a fine earthy base, often of a reddish clayey aspect. At the rocky point, just west of Lauili, the same layer of conglomerate extends down to the surface of the water.

Dikes.—The only dikes observed among the older rocks of the island occur in the point east of Fangaloo Bay. There are two at this place;—one follows a southeasterly direction, and dips 80° to the southward and eastward: it is about twenty inches wide. The other is two and a half feet wide, and is mostly vertical: it follows nearly the same course with the preceding. The small number noticed by us, is no evidence that the number may not be large: the rocks are rarely exposed for observation on this thickly-wooded island.

3. EXTINCT CRATERS OF UPOLU.

We describe separately the facts that have been collected respecting the *eastern* and *western* volcanic districts of Upolu.

Western District.—This district includes one half the island of Upolu. The principal craters are situated along the summit of the

main range of the island, and, with one exception, they form very low elevations upon its outline. The excepted one, near Fasetootai, runs up into a high cone, and is called Tafua. (See sketch, page 319.) Of the other craters, the one back of Sangana, and another back of Apia, called Lanu-to'o, are most distinct. Between the first two, the outline of three prominences may be distinguished in the view from the sea, which may possibly be other craters, and two others are seen between the latter two. Tafua forms the western extremity of the main ridge of Upolu, and is the source of the rock and soil that constitute this portion of the island. Below it there are one or two small craters, which are properly subordinate to Tafua.

The overflowings from this line of craters, which extend twenty miles in a direction east-by-south and west-by-north, have produced the long slopes of the mountain in this district. Tafua is the only crater which appears to have been much elevated by cinder eruptions.

Tafua, viewed from the northward and westward, is a truncated cone, of regular form, rising abruptly out of the main ridge of the island, which is here not more than half its usual height. I found its



altitude, by barometrical measurement, to be 2136 feet, while the main ridge to the westward of the peak is 1170 feet high. Viewing it from the northward, where the following portion of the main ridge to the *east* becomes visible, the cone is observed to be lengthened in this direction, and then rapidly declines again, as seen at *d* on the following sketch. Leaving Fasetootai for the crater, we travelled inland for three miles over a gently rising plain, following a path through the forests which led us to the foot of the ridge a little to the west of the cone. The declivity now gradually increased in abruptness, till the path became a steep flight of steps; yet the surface was so covered with soil that the rocks were rarely visible. Having ascended the ridge, we left the path that crosses it, struck along the

summit to the eastward, and commenced climbing the volcanic cone. The sides were covered with soil and scattered blocks of porous lava, which had been ejected during an eruption. No layers of rock were met with on the ascent, from which these loose masses might have been detached. Decomposition was rapidly wearing away much of the scoria, and probably a large portion of the soil had thus originated. The declivity of the cone is quite regular in its slope, the angle of elevation scarcely varying from forty degrees.

On reaching the top, a deep circular cavity opened before us. We stood on a narrow ridge, about twelve feet wide,—the thin rim of the crater. The view of the crater was much obscured by the tall forest trees that cover its interior. Here and there the eye penetrated far down among the foliage, but wandered through the labyrinth of leaves and branches without reaching the bottom. Walking around the ridge or rim of the crater, we found it rarely wider than above stated, and in some parts it was but six feet in width. Its height is very uniform. At one place, on the northwest side, there was a break of thirty feet, but otherwise it appeared as entire and as even in outline, as if the fires of the crater had but just died away. The whole breadth of the mountain bowl was estimated at three-fourths of a mile. We could not use a pocket sextant on account of the trees. The depth by the barometer was three hundred and seventy feet.

We descended into the crater by a very steep declivity, often losing our foothold along the muddy surface and sliding down many yards, till brought up by some root or branch of a tree. The bottom of the cavity is an uneven surface, covered with earth and loose scoria, like the exterior declivities. There was a rank growth of shrubbery of various kinds and tall succulent plants, and these were shaded by some of the loftiest trees of the island. Although the summit is usually shrouded in clouds, and rains are frequent, no water had collected at the bottom. The soil was damp, and, in some places, a little muddy, but far less so than had been expected. The rains probably find some subterranean outlet.

* *a*, Apia. *b*, Mount Vaiea, and above on the summit of the range, Lanuto'o. *c*, Sangana. *d*, Fasetootai, and back of this village, the crater Tafua.



WESTERN DISTRICT, IN OUTLINE, AS SEEN AT SEA OFF APIA.*

The southwest side of the bowl or crater is covered nearly from top to bottom with angular blocks of the light scoria we have described (var. 7). The fragments were from twelve to twenty inches in diameter. They are the ejected masses which were thrown up during the last eruption, and fell back into the crater. Similar scoria, during the same eruption, projected farther outward by the force below, covers the outer declivities of the volcano on the same side. The occurrence of the scoria on this side may be due to the direction of the trade winds, which blow from the northeast. The southwest side of the cone, along which we made our descent, is nearly as steep as the interior of the crater, and continues at an angle of thirty-five to forty degrees for twelve hundred feet, leading down into a valley which opens upon the sea at Falelatai.

No streams of lava appear about the summit of this cone, neither are there traces of such currents on the declivities of the mountain, within nine or ten hundred feet of the top. The thin unbroken lip of the crater shows of itself that no lava has ever boiled over it. It is properly a cinder cone formed after some violent eruption, which had poured forth its lavas at a lower elevation. When the intensity of the action had somewhat abated, and the melted rock had ceased to flow out, the second stage in volcanic action commenced; the still active fires ejected showers of cinders and scoria, which fell around the opening and piled up this volcanic cone. This seems to have been the last effort of the subsiding fires in this part of Upolu.

The present cone occupies apparently but a small portion of the area covered by the original crater at this place; but we are not prepared to state its former extent. It is possible that the deep valley already alluded to, to the southward and westward of the present cone, may have been the great centre of the fires, and in this case Tafua was thrown up on one side of this crater, when the fires in other parts were extinguished. The layers of basaltic lava down this valley and on the seashore adjoining Falelatai, are not different from those on the opposite side of the ridge.

Lanu-to'o.—I commenced the ascent of the Sangana peak, but deceived by my native guide, failed of reaching the summit. Better success attended my efforts to reach the crater and lake back of Apia. This crater is the highest point of the ridge in the *western district*. The barometer indicated an altitude of 2576 feet. The peak, however, forms but a low rounded projection on the outline of the range

back of Apia ; its flattened top—concave in some views—point out its crater character to the traveller, before he lands on the island.

To reach the crater, we took the path over the mountains leading through the inland village, Siusenga. This village lies at the northern foot of the range, three miles from the sea, and forty feet above tide level. Three miles from Siusenga, we came upon one of the mountain gorges, and followed its right bank for nearly a mile. Its sides were very precipitous, yet like the rest of the mountains, overgrown with forests. The depth could not be under four hundred feet. Thus far, and for the following mile, our ascent was very gradual. The path then became steep, and on account of the mud, quite fatiguing ; were it not for the entwining roots of the trees that were bare along the path, the way, owing to the rain of the preceding night, would have been scarcely passable. A mile carried us beyond these steep declivities. About eight miles from Siusenga we left the main mountain path, and followed a half-beaten track to the southward and eastward ; and going in this direction a mile and a half, we reached the crater and the crater lake Lanu-To'o.

A ridge a hundred feet high surrounds very regularly a circular lake about two thousand feet in diameter. We passed the highest peak of the ridge about two hundred yards before reaching the borders of the lake. The shores were low, and on the northwest side the waters deepened slowly ; but on the opposite side the banks were abrupt, and the declivity of the enclosing ridge less inclined. The greatest depth obtained by soundings was sixty feet.* A line of soundings across the lake from northwest to southeast gave successively two and a half, four, five, six, seven, nine and a half, nine, nine, nine, eight and a half, six, four and a half, two, fathoms. The surrounding ridge is clothed with the ordinary forest foliage, enhanced in beauty by the tree-fern with its broad star of finely-worked fronds, and the graceful plumes of a large mountain palm. The poets of the island have appreciated the beauty of the place, and allude to the perpetual verdure which adorns the borders of the lake, in the following lines :—

“ Lanu-to'o e le toi'a e lau mea.”

“ Lanu-to'o untouched by withered leaf.”

I observed no streams of lava around the lake. A few fragments of

* These soundings were taken by Mr. Couthouy, who paddled himself across on two logs lashed together, and used a vine loaded with a stone for a lead.

partially cellular rock (var. 3), were seen scattered over the soil. The layers below were concealed by the soil. The layers of the same basaltic rock crop out two miles distant, and were found in scattered fragments on different parts of the ridge. The light scoria so abundant at Tafua does not occur here. All the appearances of the place are quite different from those of Tafua: the cone low and flat; the ascent very gradual; the edges of the crater broader; and the cavity not one-sixth as deep. Unlike Tafua, the mountain nearly, or quite to its summit, consists of solid lava. Cinders and scoria were therefore but sparingly ejected at the last eruption of the crater.

These accounts of the craters of the western district are necessarily imperfect, both on account of the small amount of time allotted for their examination, and because of the soil and vegetation that envelope the whole surface, scarcely leaving a single point exposed. We might have much to say of the stratification, the alternation with tufa, displacement of dikes, &c., &c., but these facts are all concealed from view. The general dip of the successive currents may be inferred from the slope of the mountain: this shows that the inclination is from three to six degrees. Even the gorges, with nearly vertical sides, that cut deep into the sides of the mountain, are equally enveloped with soil, and clothed in the same luxuriant vegetation. But along the shores the rocks are often visible, and present some facts worthy of remark.

Many of the currents have the recent aspect of the most modern volcanic products. Twisted scoria in scattered fragments mark their path over the face of the country, and the surface of the stream is drawn out in long ropy lines. This is so finely developed that even small hand specimens exhibit it perfectly; occasionally we may break off irregular cylindrical masses, not two inches in diameter, which appear as if drawn out and twisted by art. These evidences of subaerial volcanic action may be seen at Sangana, where the surface is in some parts thickly strewn with fragments of scoriaceous lava. At Apia, near the waterfall, in the stream, similar though less striking facts may be seen. Just above the fall, the stream is crossed obliquely by raised lines of rock, a foot high, running nearly parallel with the edge of the fall. They appear like the successive ridges that are common on the surface of recent lava streams, produced by the interrupted progress of the slow-moving lava. The rock is a black ferruginous basaltic lava, and has a very rugged exterior. It is like the recent lavas of Oahu and Kauai.

The twisted scoriaceous lavas are best displayed on the south side of the island, across from Apia, in the vicinity of Sinapu. They have been described to me by my associates, who took that route for their investigations, as resembling the products of the most modern eruptions.

Lava caverns and long subterranean passages abound on this part of the island (the western district), especially on the south side. They are like those so often described as occurring about recent volcanoes, to which we have alluded in our account of the Sandwich Islands. Some of them open just at the water's surface; others a little below it, and it is then necessary to dive, to reach the entrance, and swim some distance before finding a landing-place within the cavern. The whole country is so thoroughly penetrated by caverns that hollow sounds are often heard beneath the footsteps of one traversing the region.

One of these caverns was visited by Mr. T. R. Peale, who has given me the following facts regarding it. This cavern is near Salani on the south side of the island, eight or nine miles from its western extremity. It was entered about a mile and a half from the sea by a perpendicular descent of twenty-five feet, through an opening made apparently by the falling of the roof. The rock overlying the cavern was about fifteen feet thick.

This subterranean passage proved to be a regular arched way, fifteen feet wide and eight high, extending down towards the sea, in a southeasterly direction. It was followed for nine hundred and eight feet, when the water within reached the roof above, and prevented farther exploration. The top was generally smooth, but was peeling off in many places in laminæ from one to ten inches thick. The flat roof was marked longitudinally with furrows, evidently formed when the rock was flowing lava; they were so regular, and continued for such a distance, that they might be compared to the track of a railway. The rock is the glistening ferruginous lava (variety 5) already described.

The roof, sides, and bottom were covered in many places with a white or yellowish-white incrustation, in the form of stalactites or stalagmites, deposited by the percolating waters. The stalactites are short cones; the largest of them are two inches long, with a base of an inch. The stalagmites have a flattened hemispherical shape, about three inches wide, with a smooth surface and an imbricated appearance along the sides. These masses are composed of a series

of thin layers closely adhering. They break with a resinous lustre, and when fresh and moist may be cut with a knife; but on drying they become nearly as hard as apatite. In two analyses by Professor B. Silliman, Jr., their constitution was ascertained to be as follows:*

	Sp. gr. 1·894.	Sp. gr. 1·689—1·813.
Silica	35·138	31·252
Alumina	31·950	37·208
Water	30·800	30·450
Magnesia	1·050	0·061
Carbonate of lime	1·210	0·008
Fluorine	trace.	trace.
Soda	trace.	0·062
	<hr/>	<hr/>
	100·148	99·041

They are essentially hydrous silicates of alumina, and have resulted from the decomposition of the lavas that overlie the cavern.

Mr. Peale found a passage leading from the place where he entered the cavern to the northeastward, which he supposed to be the continuation of the cavern up the mountain. He traced it along for five hundred feet, and found no termination.

Besides the volcanic region of the western district here described, there appears to have been an eruption of the same age near Laulii, within the central district, intruding there among the older rocks. Crossing a low ridge one hundred or one hundred and fifty feet high, just east of the place near the shores, I passed over large quantities of

* "Alone in a close tube it gives off water copiously, which is neutral to georgina paper. The powder by heating becomes gray, but does not cohere. Alone in the platinum forceps it decrepitates, loses water, becoming opaque, but does not fuse.

"With carbonate of soda it forms a bead, transparent when hot and opaque when cold. With borax it yields a colourless transparent bead, alike in colour both when hot and cold.

"In nitric or hydrochloric acids it gelatinizes and dissolves, leaving a portion of silica; traces of chlorine and sulphuric acid were detected in the nitric solution. Traces only of lime, magnesia, and alkaline chlorids were detected by the usual tests. Ammonia produces a copious gelatinous precipitate of hydrate of alumina in the solution of the mineral. Lime-water throws down from the neutral solution a small precipitate, which, when collected and decomposed by sulphuric acid in a platinum vessel, distinctly etched a glass plate prepared with wax, thus proving the presence of a minute portion of fluorine.

"The partial decomposition of the mineral rendered its composition uncertain, as the water of constitution varied nearly ten per cent. in different portions, and the silica and alumina five or six."—B. S., JR.

scoriaceous lava, some of it in twisted shapes, and with every appearance of subaerial origin. There was probably an eruption here during the period when the crater, now the site of Lanu-To'o, was in action. I did not observe a distinct crater at this place.

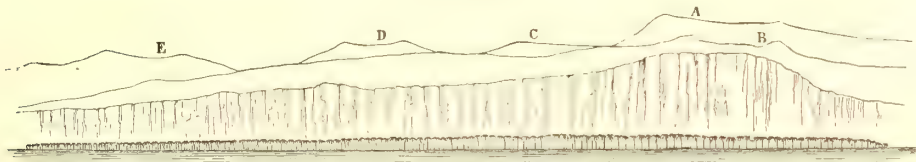
The lavas of the western district have in some places flowed over the old soil and covered fragments of wood, which are now carbonized. The falls at Apia is the only spot, as far as I could learn, where this may be seen. The basaltic lava overlies a tufa in which small fragments of carbonaceous matter are imbedded.

B. *Eastern District.*—In the view of the eastern district from the northwest (fig. 1), the gradually sloping surface rises in the form of a low dome, at the top of which the horns of Olomanga (A), the principal

Fig. 1.



Fig. 2.



crater of this district, slightly project. The summit is prolonged to the southward and westward, and in two or three places is surmounted by the low cones of other large craters. Another crater, Fanganga (B), just shows itself on the eastern slopes of Olomanga, at half or two-thirds of its altitude. C, D, and E are summits of other craters. Figure 2 is nearly an end view of the line of the several craters, and consequently Fanganga is in front of Olomanga. The letters employed to distinguish the craters will enable the reader to compare the cuts. Figure 2 exhibits a remarkable feature in this district: it is a precipice three to six hundred feet high, which fronts the sea to the southeast, and appears to be a section of the dome that once sloped far away in this direction.

Besides these craters, we may connect with this district the four small islets that lie off this end of the island one and a half to two miles from the coast. They are the remains of craters, and in one the

greater part of the wall is still standing. The following figures are views of one of these islets.

Fanganga is the only one of the craters on the main land that I have examined. This crater is less than a mile from the edge of the precipice. The ascent from Lalomanu was mostly through a dense forest over a rich black soil. The rocks seldom outcropped. A few scattered fragments passed on the way consisted of basaltic lava of a dirty gray colour, and more or less cellular (var. 3), containing but few particles of chrysolite. When within a hundred feet of the crater, we left the gentle slopes for a more rapid ascent over loose fragments of lava, which, however, were mostly concealed by soil and overgrown with shrubbery. These fragments were very cellular, many as light as the scoria of Tafua (var. 7). Reaching the top, and walking a few yards, we came upon the verge of the deep gulf. I estimated its breadth at top as a third of a mile, and the depth at three hundred and fifty feet. Its form was very regularly bowl shape, though a little elongated in a northeast and southwest direction. The whole interior was covered with foliage. There were, however, fewer trees and a larger proportion of shrubbery than at Tafua, and, consequently, the sides of the capacious bowl were more completely exposed to view. On the south, the walls were broken through half way to the bottom, and the broad and deep valley which here commenced continued on to the sea.

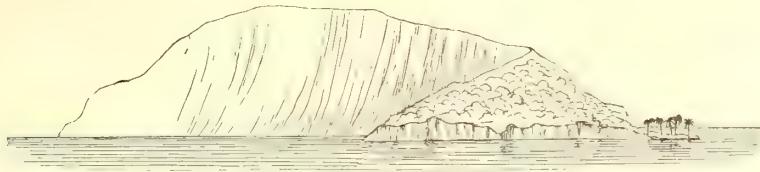
I was informed that Olomanga and the other craters in its vicinity were much like Fanganga. They are deep cavities sunk into the top of a low elevation, and, on account of the soil and vegetation, little else can be seen. Olomanga was described to me as more shallow than Fanganga, and as containing a small lake. One or two of the other craters also contain water. One of them is named Matavai—"the face of the water"—and it is said to be the source of a stream, through some subterranean outlet, that flows down to Tiavea.

On the shore the lava outcrops, in many places, along the beach, and is of the same kind with the fragments above described. The cellules are ragged, and in this respect, as well as in composition and compactness, the rock resembles the lava of Hawaii.

The point near Lalomanu, called Tapanga, near the foot of Fanganga, consists of basaltic tufa, arranged in a series of inclined layers. A few islets near this coast consist of the same tufa, and may be first described.

These islets are named Nuutele, Nuulua, Namu'a, and Tapu-tapu.

Nuutele, represented in the following sketch, preserves most nearly its original crater shape. Two-thirds of the old crater yet stand, though much worn by the rains and sea. The island is a large amphitheatre,



NUUTELE, AS SEEN FROM THE NORTHWEST.

near five hundred feet high, opening to the northeast. Within the horns of the crescent, the land has a steep but even slope on all sides, and is densely wooded. A coral beach, and, beyond it, a native village under its cocoanut trees, lie at the head of the bay. On the outside the sea washes against a naked cliff or precipice, which extends to the summit of the ridge. All the exterior slopes of the once



NUUTELE, AS SEEN FROM THE SOUTHEAST.

regular cone have been carried off by the sea, and only a narrow ridge, curving round in a crescent shape, remains. The present breadth of the island is three-fourths of a mile. In the face of the cliff, the stratification of the tufa and its structure are well exposed for examination. We trace with beautiful distinctness the many overlapping layers, and the varying directions and curvings of the lines that stripe the bold and naked bluff,—evidence of the successive depositions in the course of its formation. The dip is, in all instances, large, generally between twenty and thirty degrees. The stratification is very distinct, and, although the layers average a foot in thickness, we may often distinguish a subdivision into laminæ but a fraction of an inch thick.

The other islands are like Nuutele in the stratification of the tufa, and show equally well the inclined layers in the face of the bluffs. They have suffered so extensive degradations from the sea, that we scarcely trace any resemblance to the original craters: only a small

portion of a single side of the crater remains. The dip of the layers, and their composition, are proofs that the islands were formerly craters. Nuutele is the largest and highest of the four. The others are from a half to two-thirds of a mile long, and are not over three hundred feet in height. Namu'a and Tapu-tapu are connected with the shores of Upolu by the coral reef. Nuutele and Nuulua stand isolated, with deep water around them. The tufa is mostly composed of fine basaltic or volcanic earth, with rarely an imbedded pebble. It has a compact earthy appearance and colour, and is often friable. Coarse varieties, or conglomerates, are uncommon, but isolated masses of basalt are sometimes imbedded in the tufa.

Besides the volcanic materials, the tufa also contains an occasional fragment of *coral*, or *coral limestone*. I collected some specimens of imbedded limestone pebbles from the tufa near the top of Namu'a, two hundred feet above the sea. The pebbles were as white as the coral rock of the reefs, and some of them were as large as walnuts. Tested with an acid, they afforded a brisk effervescence. They were undoubtedly enclosed within the tufa as a part of it, and not subsequently carried up to their present place.

The facts here adduced show that these islands are not the result of lava eruptions. The ejections of lava, if there were such, were submarine. The islands have been formed by ejected volcanic earth or mud falling over the rising walls of the crater, which they consequently overlap, inclining both inwards toward the central vent, and outward down the slopes of the cone. The opening of these submarine vents probably followed some movement in the neighbouring volcanoes, and there may have been an ejection of lava beneath the sea from the fissures thus formed. But subsequently the eruptions consisted of loose cinders and comminuted lava. The present position of the craters in a sea which covers, to a considerable height, their tufa sides, (for the tufa extends with its even dip some distance below the surface,) and so low that the bottom of the crater, as in Nuutele, is not above the level of the sea, is some evidence that these are the results, in part, if not wholly, of eruptions from vents beneath the water. The fragments of coral rock imbedded in the tufa, lead us to the same conclusion; or at least, they show that the vent was liable to incursions of the sea, through some opening below, which carried in the coral pebbles. The coral pebbles were not subjected to a high heat, for they retain their original freshness outside as well as within.

Such eruptions would account for the minute and well-defined stratification of the tufa, and not less satisfactorily for the perfect preservation of the coral limestone. The close resemblance to the tufa craters of Oahu, and the "sand-hills" of Nanawale, Hawaii, will be seen by comparing the descriptions.

Although these are not lava cones, there is still evidence that lava rose in one of the craters during its formation. On the east side of Nuutele, for a few yards above the sea, there are two narrow dikes of black lava. The tufa near the dike is burnt to an ochre-yellow colour, and immediately adjoining it, to a light brick-red. Near the dikes there is also a fissure which extends to the summit, where a small notch marks its termination.

Tapanga Point, on the neighbouring shores of Upolu, consists of layers of tufa stratified like the islands just described.

The dip and the mineral character of the tufa are the same. The low ridge which forms the point is about fifty feet high. The layers of the tufa at the extremity incline thirty degrees to the northeast, while a short distance back on the north side they incline to the north and northwest; and on the low shores at the southern foot of the ridge, from which there has evidently been an extensive degradation and removal of the layers, the dip is towards the south and southwest. These varying inclinations might be explained on the hypothesis of a tufa cone, now to a great extent washed away. Moreover, we detect a farther resemblance to the islands in the imbedded fragments of coral limestone. These fragments are, however, much more abundant, and among them we find portions of shells and some large masses of coral, occasionally three or four inches thick; and with these, the solid basalt also occurs in boulders one to two feet in diameter.

As we go south on the coast, the coral rock becomes more and more largely disseminated through the tufa; and fifty yards distant half the rock consists of coral sand, with fragments of coral and shells, among which I collected some of the common *Astræas* of the coast, and pieces of the large *Tridacna*. Farther from the point, the layers gradually pass into a true coral limestone only a little discoloured with volcanic materials, which resembles the shore-layers of coral limestone found on many other parts of the island,—a formation still in progress at the same level, and with the same dip and other characters; and along the same coast, this rock passes into a coarse boulder conglomerate, consisting of the loose basaltic pebbles and

boulders of the beach, cemented together by the coral which has been thrown over them by the sea.

4. ON THE ERA OF ERUPTION IN UPOLU AND SUBSEQUENT CHANGES IN THE FEATURES OF THE ISLAND.

Era of Eruptions.—One of the most remarkable features in the geological structure of Upolu, is the great number of large craters, and their linear arrangement. In consequence of this peculiarity, the island is a long and narrow strip of land. It has been shown that in the islands of these seas, we may often discover that they originated in the action of one or two large volcanoes, with lateral or subordinate points of eruption. The Sandwich Islands were mostly thus formed; so also the adjoining island of Savaii. But on Upolu there has been a crowded line of large and nearly equal vents: the majority of the craters in both the eastern and western districts are within three or four miles of one another. We do not speak of the linear arrangement as in itself singular, for this is usual; but that so short a line should contain so many distinct vents instead of a large or parent cone, with its subordinate craters. We may safely conclude that the longer axis of the island was originally the course of an extensive fissure, along which, after an eruption of lava, a number of active vents remained open.

We have remarked upon the greater age of the central portion of this island, (more especially the northern side,) and the more broken character of the mountains, and have contrasted with these rocks, the twisted scoria of Sangana and other portions of the western district. Shall we conclude that after the ejection of the central rocks, there was a long interval without eruptions, in which the older mountains were nearly dismantled by denudation and disruptive forces? It is quite as probable that active vents continued open, from the earliest eruption in Central Upolu, through all subsequent periods till the latest fires were extinguished. The greater extent of the western district and its more recent appearances of volcanic action, show that the fires were longer in action in this part than in the eastern district. The declivities in the western district are most broken near the central district, that is, back of Apia and farther to the eastward, and we may therefore infer that here the eruptions of the western district first declined, and the surface was earliest left to

denuding agencies. Back of Sangana, the unbroken declivities as well as the scoria in the region evince a comparatively recent action of the Sangana crater. Farther west, near Fasetoötai, the high unbroken cone of Tafua carries us on to a still more recent period; and here, as we believe, the fires of Upolu finally disappeared. This is the westernmost of the large craters.

We have met with few facts that indicate, even approximately, the period when the volcanic action ceased. I have observed no instances of lava overlying coral, or covering deposits of coral sand such as now form the beaches. Along the shores westward of Apia, the slopes of the island pass beneath the surface of the sea, and continue uninterrupted for five or six miles, inclining even more gradually under water than above; for at this distance the depth is but seventy or eighty yards. From this depth, it drops off at a steep angle: within four hundred yards of a thirty-five fathom cast, our lead descended to two hundred and twenty-eight fathoms, and struck on a bottom of black sand; four hundred yards farther out, we found no bottom with four hundred fathoms of line. The coral reef of these shores is a mile and a half wide to the line of breakers. The continuity of these slopes, and their length, seem to afford satisfactory evidence, that they belong to one and the same process of formation.

There is evidence, however, that the coral was growing on some parts of the island before the fires ceased. This is abundantly shown in the tufa craters of the islets east of Upolu, and at Tapanga Point. But the dilapidated condition of these craters proves that they were long exposed to the action of the sea, before the reefs were completed that now protect two of them from farther degradation. The removal of the tufa deposits of Tapanga Point, is additional evidence that the reefs now half a mile wide at this place, were but just begun, and insufficient to protect it from an encroaching sea, when the hill was formed. The point is cut through by a channel twelve feet wide nearly to the water level; and the amount of tufa removed just south of the point, was fully equal to the present extent of the point, and probably much larger.

In view of these facts we conclude, that although the period of latest activity was subsequent to the introduction of coral to the shores of the island, yet it was before the reefs had become much extended. Possibly the coral grew only in detached spots, as is now the case around Hawaii.

The period of *earliest eruption* is still more uncertain. The cha-

racter of the rocks, and the general topographical features of the central district, remind us of Tahiti and Kauai, and, as far as the facts go, they favour our referring the whole to the same distant era.

Change of Level.—Some partial subsidences have already been alluded to. I refer to the bluff mountain side, back of the Falifa plains, and the long wall, three to six hundred feet high, fronting the sea on the southeast side of the island. The former appears as if all the northern declivity of the mountain, except a small portion at top, had been removed by an extensive subsidence. The wall is five or six miles long, and its height about a thousand feet. The other is a still more remarkable example of subsidence. The wall is not less than seven miles long, and cuts off the greater part of the northeastern declivities of Fanganga. The usual slope of five or six degrees commences just below the upper hundred feet to stretch away to the southward and westward; but it is suddenly broken off by the high precipice. (Figure 2, page 325.) There is a narrow plain at foot bordering the sea, which is the site of several native villages.

We have been unable to discover any proofs of a recent rise of the island. The black ledges of basaltic rock along the shores are perfectly clean from coral, to the water's edge. The layers of beach limestone on the shores sometimes extend a foot above high water mark; but this is not beyond their ordinary height. The layers have the usual character, and incline outward at an angle of seven or eight degrees (p. 44). The reefs of Apia lie nearly at the level of low tide; there is not the slightest reason to suppose that a rise is in progress, or that any has taken place since the coral reef first fringed these shores. If there has been any change it is one of subsidence; but though we have some reason for suspicion, we cannot decidedly prove it. The fact that the surface slopes gradually beneath the sea, instead of being bordered by a cliff, is evidence of some weight in favour of a subsidence of a hundred feet or more; for on Hawaii, wherever recent lava streams have entered the sea, there is usually a cliff of one or two hundred feet, and never a slope of solid lava continuing on uninterrupted beneath the water.

ISLAND OF MANONO.

Manono is a low island, four miles in circumference, situated a mile west of Upolu, to which it is united by the coral reef. Its gently sloping surface rises to a rounded elevation near the centre of the island, not exceeding four hundred feet in height. The rocks are in layers, and resemble those of Upolu.

Manono is a continued grove from one end to the other. It is densely populated, and, although small, is politically the most influential island of the group.

ISLAND OF APOLIMA.

Two miles west of Manono, and about five from Savaii, stands the natural fortress Apolima. A high bluff, from three hundred to four hundred and fifty feet, forms an inaccessible shore on all sides except the northern, where it is partially broken down, and a passage through the walls barely wide enough for a single boat opens into a circular bay. This bay or harbour forms the interior of the island; on each side of it the shores slope rapidly upward to the top of the bluff.

Apolima is the summit of an extinct crater, and the harbour occupies its bottom. The different layers of rock lie curving over one another very irregularly, and, along the outer shores, they dip on all sides away from the crater. The island resembles Nuutele, and is probably of similar origin.

The above few remarks are the results of a distant view, and gleanings from the observations of the officers who surveyed the island.*

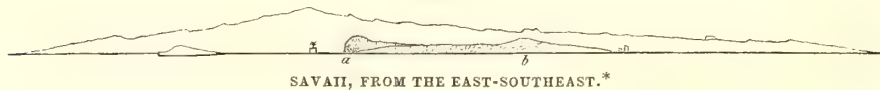
ISLAND OF SAVAII.

Savaii, the largest of the Samoan Islands, contains five hundred and fifty square miles, and measures forty miles in length, by twenty in breadth. It is a single volcanic mountain. From the sea, the land, as seen in a distant view, rises with a very gradual slope—five or six degrees—and with a nearly unbroken surface, as in the annexed out-

* There is a view of this island in the Narrative of the Expedition, vol. ii, p. 107.

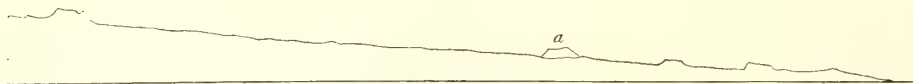
line, attains its greatest height near the centre of the island. We estimated its altitude at six thousand feet. It resembles Mount Kea

Fig. 1.



SAVAII, FROM THE EAST-SOUTHEAST.*

Fig. 2.



OUTLINE VIEW OF NORTH EXTREMITY, MORE ENLARGED.

on Hawaii; it is not so pointed at top, yet less flat and rounded than Mount Loa of the same island. Like Mount Kea, its sides are roughened with parasitic cones. From the harbour of Mataautu, I counted thirty in the northeast portion of the island. There are some broad and deep valleys, the largest of which are on the eastern side of the mountain.

Many of the craters have a very recent appearance, and immense beds of lava, of comparatively modern date, may be traced over the surface. The rocks resemble those of Upolu, or if different, it is in being more cellular and more frequently scoriaceous. The natives have traditions of fire issuing from one of the craters, and an extensive stream of lava, called the "*mu*," is generally spoken of, among them, as the effects of a former eruption. My associate, Dr. C. Pickering, who was on the island for a few days, makes the following remark in his journal: "Near the northern point of the island, I passed a considerable tract, where the rock was in great part exposed, and has all the appearance of a stream of lava, being furrowed concentrically, and otherwise marked like the settling down of a semifluid mass."

The reefs of the island are less extensive than those of Upolu, and hence show that the volcanoes were active on Savaii to a later period.

The whole island, with few exceptions of barren lava fields, is clothed like Upolu, though much less densely, in a wide-spread forest, which not only covers the slopes, but envelopes inside and out the small parasitic cones. The streams are, however, small, owing to the cavernous nature of the rocks. The author had no opportunity for a critical examination of the island.

* In fig. 1, *a* is the island of Apolima; *b* that of Manono.

CONCLUDING REMARKS.

The Samoan, like the Tahitian Group, appears from the account here given to be a series of volcanic islands, proceeding from vents opened along two separate lines having the common trend of the Pacific groups. In Savaii, the westernmost, we find evidence of the most recent fires, both in the lavas of the island and the traditions of the natives; and the comparatively unbroken surface of the great mountain cone is another proof of the same fact. Going eastward, Upolu has distinct craters on its east and west extremities, while a small part just east of the centre, has the deep gorges, columnar cliffs, and compact rocks of Tahiti. The great length of Upolu, as well as the line of craters along the summit, indicates that here several vents on one fissure have been active in producing the island. They were earliest extinct about the centre, and here were soonest turned over to denuding agents; while either side of the centre the volcanic effects, which tend more to build up than to pull down, have kept the slopes in many parts nearly unbroken, so lately have the fires ceased action. Tutuila, farther east, has the fewest indications of recent lava streams, and the most of denudation. It is hence evident, that the fires were soonest extinct to the east, and burnt longest and to the latest period on the western island, Savaii.

The fact of a coincidence between the earthquake that destroyed Valdivia (Chili), September 7th, 1837, and unusual agitations of the sea at the Gambier and Samoan Islands, has been noticed by Dumoulin.* Minute particulars with regard to the successive tides at Tutuila, harbour of Pango-pango, were obtained by Captain Wilkes, while at that island, from the Rev. W. Mills, and they are published in the second volume of the Narrative, Appendix VIII. p. 427. The observations were made by Mr. George Burader.

At 2h. 20', Nov. 7, the sea rose suddenly two feet above high water mark, spring tide; in ten minutes it sunk again to low water mark, neap tide; in five minutes rose to the same height as before; in another five minutes (2h. 40') sunk to low water mark, spring tide; then rushed in with violence, and in two minutes was three feet above its greatest previous height, after which it receded again, and at

* Compt. Rend., vol. vii. p. 75, 1838.

2h. 52' was below low water mark. In three minutes, it again rose, and after receding eighteen inches, suddenly rushed to its former maximum height. These oscillations continued through the afternoon, and into the evening, but with less frequency and more quiet; and on Thursday, the following day, they were still apparent.

These oceanic undulations of November 7th, 1837, are well known to have been very violent at the Sandwich Islands. The American Journal of Science and Arts, vol. xxxvii. p. 358, 1839, contains a notice of the disastrous event, by T. Charles Byde Rooke; and another more circumstantial account is given in the Hawaiian Spectator. To compare the occurrences at the different groups, it must be borne in mind that according to the modes of reckoning time at the Sandwich and the Samoan or Society Islands, the 7th of November, at the former group, is the 8th at either of the latter two; the time at the Sandwich Islands having been fixed by persons going by Cape Horn to the Pacific, and that at the islands south of the equator, by persons going by the Cape of Good Hope. It is unnecessary to repeat here the particulars of this catastrophe. It is described as occurring on "the evening and night of the 7th of November," and at Byron's Bay (Hilo), the sea rose, at 6h. 30' P. M. to a height of twenty feet. A similar event took place at the Sandwich Islands in May, 1819, when the tide rose and fell thirteen times in the space of a few hours.



CHART OF THE YITU GROUP OR FRENCH ISLANDS BY THE U.S. EX. EX. 1840

170 171 172 173 174 175 176 177 178 179

16 17 18 19

176

175

180

179

178

177

176

175

CHAPTER VI.

VITI OR FEEJEE ISLANDS.

I. GENERAL FEATURES.

THE Feejee Islands occupy an area of forty thousand square miles, on either side of the meridian of 180° , and between the latitudes 16° and 20° S. The surface of land is not far from seven thousand square miles. The group might be very appropriately termed an archipelago. Rarely in any part of the globe are such numbers of islands clustered together, and no region can exceed it in dangerous navigation. In this thickly dotted area, ten or a dozen islands might at any time be counted from the ship's deck, and often a much larger number was in sight. They are of all forms and dimensions, from rugged basaltic mountains one to five thousand feet in height, to the coral islet whose sandy surface barely emerges from the ocean's waves; and among and around them, coral reefs are innumerable. Nearly every island has its shores extended by wide coral platforms, and very many are inclosed by irregular barrier reefs, often stretching out for miles in long projecting points. Moreover, the many isolated reefs that low tide brings in view, and others a fathom or two below the surface, multiply greatly the dangers of navigation. A clear sky and a good look-out are required to enable the navigator to thread his way safely through many portions of this coral labyrinth.

There are about one hundred and fifty islands in the archipelago; or, if we include the isolated rocks which stand as outworks around the larger bodies of land, and every humble coral islet overgrown with a thicket of mangrove bushes, the number would be nearly doubled. Viti Lebu and Vanua Lebu, the two largest of the

group, lie near the western limits of the archipelago. The former is ninety-four statute miles long and fifty-five broad, and the latter is one hundred and five miles long by twenty-five in average breadth. To the westward of these islands, a large area is covered with patches of reefs, extending twenty miles from Viti Lebu, towards the Asaua Group, and ten to fifteen miles west and north of Vanua Lebu. Through this immense coral garden—an epithet it well merits—covering an area of one thousand square miles, the waters in the channels among the reefs and beds of coral have an average depth of twelve or fourteen fathoms, seldom falling below nine, and as rarely exceeding twenty fathoms. There is, however, a deep unfathomed passage in this area, which separates the reefs of Viti Lebu from those of Vanua Lebu. The other islands of the archipelago, lying to the eastward of the “Great Feejee,” and the “Great Land,” as the above names signify, are comparatively small, and are generally separated by deep seas which have not been sounded. In several instances, however, adjoining islands even where distant are girt by the same coral reef.

A general idea of the features of these islands may perhaps be best conveyed by supposing some large tract of land crowdedly embossed with mountains, to sink, till here and there a peak, or a ridge, or collections of ridges, stand out of water.

The islands present nearly all the varieties of form which basaltic rocks are capable of assuming. Rugged ridges with bluff escarpments running up into needle peaks, characterize some portions of the group; while others are comparatively flat, and expose along the shores a cliff of basaltic columns. But, in general, the ridges have tamely rounded summits, or if irregular in outline, there is not that variety of lofty pinnacles and deep gorges which forms the principal charm of the scenery in the Tahitian Group.

The larger islands appear to the passing observer to consist of a perpetual succession of ridge and valley, and as far as we could learn by inquiry or examination, the same diversity exists through the interior, with no intervening plains of sufficient extent to require remark. But the declivities are mostly gradual, and often admit of cultivation nearly to the summit. These slopes, especially to leeward, are covered with grass eighteen or twenty inches high, which, from its dry, yellowish appearance, gives the country an arid aspect. Toward the summits, black rocks occasionally crop out or surmount the ridge like ancient ruins. Luxuriant forests also cover the ele-

vated parts of the ridges, where the frequent rains and more frequent mists or clouds afford them the nourishing moisture, which, on the leeward side, is too scantily supplied to the slopes below.

The appearances described vary somewhat upon the different islands, and also upon the opposite sides of the same island. Forest vegetation descends lower on the eastern declivities, which are well supplied with moisture from the trade winds. If our experience is any criterion for a general fact, we should judge that the rain of the southeastern side of Viti Lebu, at least trebles that of the opposite side. A few of the smaller basaltic islands, as I am informed, are covered throughout with luxuriant vegetation. Somo-somo, an island of considerable importance, has been compared to Upolu in richness.

The indentations of the shores around the several islands, are numerous and large; but there are few which would form well-protected harbours without coral reefs as breakwaters. One or two of the deep bays which do exist among these islands are very remarkable. Such is the bay in the small island of Fulanga. The island is but a rim of land,—an elevated ridge—nearly surrounding the large bay or lagoon, which is fifteen miles wide and forty fathoms deep. In Vanua Lebu, there is a bay thirty miles deep, running half through the island and bordered on each side by a mountain ridge. Neither of these bays was visited by the writer.

We deem it unnecessary to enter into a particular description of each of the islands in this archipelago, which, moreover, could not be done from personal observation. The general remarks above made will supply the place of much tedious detail. My investigations were limited to the island of Ovalau and the two large islands Viti Lebu and Vanua Lebu; and in these islands they were restricted to a very small portion of the surface. The treachery of the savages compelled us to confine ourselves, in all instances, to the coast, and even there, we should have been clubbed, and soon served up for a feast, were it not for the salutary influence of our ships, and in part, also, the protection of our private weapons. Some afflicting events, of which a recital may be found in the history of the voyage, gave us most painful evidence of the necessity of caution among these savages.

Viti Lebu, the largest island of the Feejee Group, is traversed by several mountain ridges, which rise, in some parts, into abrupt cones with sharp or truncated summits, having an elevation of at least

five thousand feet. Numerous streams rise in these mountains, especially on the eastern side, some of which, before reaching the sea, become large rivers, which we might have thought of continental origin, were we not acquainted with the limited extent of the land before us. One of the most remarkable of these rivers empties by several mouths along the coast near Rewa, on the southeastern side of the island. It is reported that a large portion of it also disembogues by a separate stream, which runs to the southern shores, the two continuing together till within forty miles of Rewa. The Rewa mouths are eight or ten in number: the more northerly one comes out near Mbau, eight miles above Rewa. The main branch at Rewa has a breadth of three hundred yards, with an average depth of four feet; during heavy rains it increases to eight or ten feet, and sometimes floods the whole district. Captain Eagleston, of the ship *Leonidas* of Salem, informed me that he had watered ship with the water alongside, while lying at anchor in the bay three miles from the entrance of the river. The bay is a large open area many miles in extent, lying within the barrier reef. It is impossible, with the limited data we have, to ascertain accurately the quantity of water brought down by this river. The means at hand afford us the approximate result that, in each minute of time, 500,000 cubic feet of water flow out at the principal Rewa mouth; and by all the mouths in this region, at least treble this amount, or 1,500,000 cubic feet. This is the average during a period of comparatively dry weather, in which the stream, as it passes Rewa, runs about a knot and a half an hour, and has the dimensions above stated. In times of freshets we may estimate that at least five times this quantity is brought down, which gives 4,500,000 cubic feet as the quantity of fresh water which during each minute of time reaches the sea.

Two of our boats, under the charge of Lieutenant Budd and Mr. Davis, ascended the river for thirty-eight miles on a surveying expedition. With the exception of two or three shoals, they found sufficient water for the boats, and in many parts there was a depth of six or seven fathoms. For twelve or thirteen miles, the river winds along through a flat country, between regular alluvial banks; beyond this, the surface of the country becomes undulating, and the rocks which prevail in the mountains make their appearance.

The alluvial tract which has been formed by the deposits of this river, covers an area of about sixty square miles, and has a breadth of ten miles in its broadest part. Like the deltas of other rivers, it is

cut up into numerous islands by the intersecting mouths. It consists of fine mud from the basaltic rocks of the mountains, and near Rewa, which is six miles from its mouth, scarcely a pebble as large as a walnut is to be seen. The bed of the river often changes its position; and during freshets, large portions of the banks are carried off, which form shifting sand-banks in the body of the stream, or are transported to the bay, where several large shoals have been accumulated. I learned from a foreigner who had resided there the preceding ten years, that the river at Rewa had doubled its breadth in that time; and the numerous cocoonut stumps which stood far out in the stream, attested this fact. Another person, who had resided there forty years, stated that during this period, the deposits had lengthened the river half a mile, by encroaching this much on the bay; but I know not how much reliance should be placed on this evidence. All attempts to arrive at more satisfactory results as to the rate of progress in the extension of the delta, proved unavailing. The surveys of the river and harbour by the Expedition will afford data for future comparison to those who may follow us.

The water from this river has destroyed all the living coral on the inner margin of the barrier reef, which, where nearest, is about two and a half miles from its mouth; and, moreover, the whole surface of the reef scarcely bears a live branch, except towards its outer limits, and there, the species are but few and small. There was a time when growing coral was forming these reefs which are now lifeless, and the period was sufficiently long to widen the barrier reef to one or two miles. We have no reason to suppose less rain to have fallen then than now; and how was it carried off without injury to the growing reefs? for the various mouths are all fronted by reefs, and none are more than five miles distant. We may, perhaps, refer to the period, when, before the formation of the delta, the river's mouth was several miles nearer the mountains than at present. But still this distance of the reef from the river may not have been necessary; for the water of the island streams freshens the surface only to the depth of the river itself, and can destroy growing coral to no greater depth.

Other rivers, of equal size, exist on the island of Viti Lebu, but this is the only one examined.

Vanua Lebu, the second island among the Feejees, has a much less uneven surface than Viti Lebu. Few of the summits exceed two thousand feet in elevation, and none are more than three thousand feet. The ridges are lower on the west side, and less irregular, with

long sloping declivities. There is an occasional precipitous bluff near its shores, such as Mathuata and Evaka,* on the north and west sides, and some short ridges of singular mammillated and sugar-loaf outline; but in general there is a dull uniformity in the features of the ridges, and in the dry, grassy fields, which cover the declivities far up towards the region of forest trees. None of its rivers are as large as those of Viti Lebu. We examined one at Tavea, Nailoa Bay, on the northwest side of the island, which is one hundred and fifty yards wide towards its mouth. For the last four miles of its course, it is a deep estuary, running through an alluvial plain, eight or ten square miles in area, evidently formed from the river detritus. The river brings down large quantities of water in the rainy season. The bay—which, however, is no other than the passage within the reef along this side of the island—is fast filling up from its detritus: we found scarcely three fathoms of water over the muddy bottom, instead of the ten or twelve fathoms which is the usual depth in other parts of the channel.

The mangrove bushes subserve a very important part in the formation of these new alluvial tracts. They form a crowded line for miles along the shore, ready to thrust down their new roots and secure every inch of land that is once added, the outermost, usually standing in two to four feet water at high tide. They thus entangle whatever is brought down from the land by the rains, or is washed up from the bay, or deposited by the river. When once the end is gained, and the rescued lands are becoming dry, the bushes gradually disappear and leave it to be occupied by the vegetation of the dry land.

Another river of considerable size empties at Mali Point; but neither this nor any others on the island were examined.

Ovalau is a small island, averaging seven miles in diameter, lying near the northeastern corner of Viti Lebu. It is peculiar in containing an interior plain, surrounded by a high ridge, which follows the circumference of the island, with a single opening to the southward and westward. The ridge varies from one to two thousand feet in height. It rises from the shores very abruptly, with grass fields which soon give way to dense forests, and these again yield to the bare rocks in spots towards the top. The ridge in its highest part presents a beetling front towards the interior plain, and on all sides the declivities are steep. The interior is adorned with an exuberant forest vegetation. Among the forests there are a few villages mostly con-

* Names anglicised to Mudwater and Hy-parker.

cealed beneath cocoanut groves, and a thread of water may be traced at intervals over the verdant surface.

The form and topographical features of the island may be best explained by supposing it to have been a single crater. The day or two on shore were not sufficient to determine beyond doubt the correctness of this hypothesis.

2. GEOLOGICAL STRUCTURE OF THE ISLANDS.

The facts which fell under our observation, in connexion with the inferences that may be drawn from the specimens collected by the officers at the different islands of the group, indicate that the rocks composing the Feejee Islands, in all parts of the archipelago—excepting those of coral composition—have a very similar character throughout; and that numerous more or less ancient volcanic vents, subaerial or subaqueous, have thrown out all the materials which constitute these islands. Farther exploration may require some modification of this view, especially as the interiors of the larger islands remain unexplored, and even their shores have been examined in but few points.

At the present day there is no active volcano in the group, and no tradition of one among the natives. Earthquakes are not uncommon, one or two being usually felt every two or three years. They are all slight, but heavier it is said, in the eastern than in the western part of the group. The most recent appearances of eruption were met with on one of the eastern islands, Oneata, where there is a lava tract resembling the Hawaiian clinker fields.

The only trace of actual volcanic heat which the islands appear to contain, is found on the southeastern side of Vanua Lebu, at Savu-savu Bay, where a large area is covered with hot springs, the water of which is in constant ebullition. The Peacock did not touch at this place; and for the following information I am indebted to the officers of the surveying boats and the Vincennes, and especially to Lieutenant Perry and Mr. Drayton.

These boiling springs are situated on the east side of Savu-savu Bay. A plain rising with a gentle slope from the water, extends back from the shore about three-fourths of a mile, and then passes into the steep declivities of a high broken ridge, running nearly parallel with the coast. Patches of grass, and much low, dense

shrubby, cover the plain near the springs; and some distance to the right and left, large cocoanut groves throw some little beauty into a scene otherwise unattractive. A small streamlet runs out from among the bushes which mostly conceal its previous course, and flowing lazily along over a muddy bottom for a few hundred yards, passes near the boiling fountains, and then follows an oblique course to the bay. A few yards above the hot springs, it receives some addition to its waters from a small source of cool water.

The hot waters bubble up at several places along the shores, below high tide; but the principal springs are collected together in an irregular rectangular basin, near one hundred and fifty yards from the beach. The basin, according to Lieutenant Perry, measured sixty feet by forty, and was eight to ten feet deep. In this small area there were five springs: their gurgling noise announces the violent ebullition some distance before reaching the place. The natives, who use them for cooking, had thrown over the surface a layer of grass, and on removing it, the ebullition mostly ceased, owing, in part, to the contact of the cooling atmosphere, and also, beyond doubt, to the increased radiation of heat from the bottom, which was before cut off by this rude and simple contrivance. When the cover of grass was again thrown over, ebullition went on as before. The thermometer indicated a temperature of 200° to 210° F. The water of the springs is clear, excepting one which throws up mud. The surface of the basin consists of a brown and slate-coloured loam, hardened by the sun, and very much cracked as if by drying; it is, apparently, a deposit from the springs made when the region is inundated by freshets, probably a frequent occurrence. The surface of the springs is about nine feet above high tide.

The cool streamlet adjoining runs so near the largest hot spring, that one hand may be immersed in the former, while the other hand is in the latter. Below this, the streamlet becomes hot; running on to the sea, it gradually cools, and at its mouth forms a very agreeable warm bath, of which the natives often avail themselves.

The springs below tide-water, occur at two places along the coast. One of them covers an area of forty yards or more. The hot water oozes up among the pebbles and sand, which are so warm as to be uncomfortable to the bare feet. Three hundred yards nearer the mouth of the bay, on the same side, and rather more than a hundred yards from the shore, stands a knoll of basalt, measuring about thirty-feet by fifteen, which is covered with two feet of water at high tide. At

the centre of this isolated rock, which is partially hollowed out, there are several jets of boiling water. The heat of the rock is greater than the hand can bear.

Besides the places above described, there are some smaller springs on the shore, to the east of the rock-fountain just mentioned. Another hot spring is said to boil up near the village of Savu-savu, a mile and a half distant, which is famous as a place for preparing the cannibal feasts of the natives.

According to the reports of the officers, there is no appearance of any volcanic cone or current of lava in the neighbourhood; and the specimens obtained by them are evidence of the same fact. They consist of different varieties of compact basalt, much resembling the collections from other parts of the island, and quite unlike subaerial volcanic products. The natives say that the hot springs have always existed there, and have a belief that the spirit who resides in the mountains, sends this hot water for them to cook their food.

From the analysis by Dr. C. T. Jackson, as given in the Narrative of the Expedition, we may infer that the water is probably of marine origin. Its taste is bitter and saline. There are no incrustations around the springs. No attempts were made to collect the escaping vapour, and we are, therefore, in doubt as to its nature. No odour was perceived, except on bringing the head very close to the surface, when a faint smell of sulphur was recognised.*

Rocks.—The rocks of these islands have a very close resemblance to those of the groups to the eastward. Basalts of different colours and texture, scoriaceous and compact, and basaltic and volcanic conglomerates, and sandstones or tufas, are found in different parts of the group. The following descriptions will give an idea of their peculiar characters.

The *basalts* have mostly an extremely compact texture, with very slight traces of crystallization, and are of black, brownish-black, grayish and brownish-red colours. Some of a black colour have a shining lustre, owing to the iron in their composition. Other varieties are porphyritic with minute opaque crystals of feldspar, or with large glassy crystals. A third class contains distinct crystals of black augite, perfect and lustrous, disseminated through an imperfectly crystallized base of a brownish-black colour.

* A full account of this region of hot springs will be found in the Narrative by Captain Wilkes, iii. pp. 196—199, with a fine sketch of the region.

These compact basalts pass into *vesicular* varieties, in which elongate vesicles are generally contained in a base otherwise compact, and not scoriaceous throughout, like many lavas. Occasionally we see fragments in which the vesicles are thickly disseminated. Some of the vesicular basalts have the cavities filled with geodes of quartz, chalcedony, and different zeolites; they have an amygdaloidal character, without, however, becoming true amygdaloids.

The basalts pass into *trachytes*, of a light grayish, grayish-yellow or grayish-blue colour; but I have not observed these rocks "in situ."

The only other variety of igneous rock meriting distinct notice is *pumice*, which is found in very well-characterized masses, and has some light shade of colour, generally grayish-white or a tinge of grayish-blue. It floats readily, and may be collected from the shores of most of the islands, where it has been thrown up by the sea.

The conglomerates consist of the above materials, thrown together in angular or partially-rounded fragments, and imbedded in an earthy base of the same origin. The imbedded masses are of all sizes, to six or eight feet in diameter, and often the coarse and fine are piled on one another without any regularity. The coarse conglomerates in some places pass gradually into a basaltic sandstone consisting of fine grains of very uniform texture. A still finer variety of compact structure resembles an argillaceous rock, and might be mistaken from hand specimens. A remarkable deposit of tufa and pumice-conglomerate occurs at Mali Point, on the north side of Vanua Lebu. The rock varies from a coarse aggregate of fragments of pumice and decomposing trachyte, on the one hand to a fine, almost impalpable argillaceous deposit, and on the other, either slowly or by abrupt transitions, to a very coarse conglomerate, consisting of angular masses of compact and imperfectly vesicular basalt. This pumice-conglomerate and tufa has a white or straw-yellow colour, and presents a clean, neat appearance. It is quite soft, and the fragments composing it are fragile, and apparently half decomposed. Many of them are compact, but look not unlike yellowish cheese, and are scarcely of greater hardness.

Much of the coarse conglomerate in the Mali cliff has a very remarkable aspect: it consists of large angular masses of the black basalt, with the interstices filled in with this light straw-coloured tufaceous material. The tufa and conglomerate are very irregularly intermingled, and are remarkable in forming concurrent and not alternate layers.

The fragmentary rocks have sometimes a very doubtful aspect, and any but their true origin would be suspected by one unacquainted with the locality. One of the most singular varieties was collected by Lieutenant Walker, on the northeast shores of Vanua Lebu. It consists of a fine greenish base, of an arenaceous aspect, containing thickly disseminated grains of quartz, many of which are in regular crystals, partially rounded. The crystals are bipyramidal dodecahedrons, averaging an eighth of an inch in diameter; and excepting the little attrition they have undergone, some of them are perfect. They are associated with a few fragments of a glassy feldspar and some minute crystals of sphene. The greenish base is soft, and fusible before the blowpipe. It appears to have the same nature with the base of the Mali pumice-conglomerate, and is probably derived from a decomposed trachyte, or some allied feldspathic rock. Excepting the fusibility, and some few minute pebbles imbedded, it closely resembles certain specimens from granitic regions.

The mud brought up from the bottom, in the channel to the southwest of Viti Lebu, contains numerous rounded pebbles of quartz in a grayish gritty base. The appearance of it would suggest any but a basaltic origin, and it certainly authorizes a suspicion that either granite or sandstone may occur on the large island. When dried, the specimens strikingly resemble a common grit rock, like many in the carboniferous series. The base contains many opaque white particles and pebbles, appearing to be feldspathic. The quartz is mostly white and translucent, but other pebbles are of rusty yellow and brown colours, and opaque. We are inclined to believe that the constituents of this mud have been derived from the basaltic rocks: yet it must be admitted to be just the kind of mud which might be expected in a sandstone or argillaceous sandstone region. The geodes in the basaltic rocks, and the silicious veins which intersect it, may have afforded the quartz, and the other materials may come from the decomposition of some basalts. The specimens show the necessity of great caution in deciding upon the origin of the materials of sedimentary rocks.

From the above, it appears that the proportion of compact basalt in these islands is very large. No lava stream was observed, and no cone was examined on the two large islands, which could have been a centre of volcanic eruptions, although we can scarcely doubt that such cones must exist in some parts of the group. Many a

peak, as seen on passing, was suspected to be a volcanic cone. Among these, the high conical peak at the south extremity of Kantavu is of least doubtful character; but we had no opportunity for any but a telescopic inspection. Most others, as we afterwards had reason to believe, are merely basaltic needles and sugar-loafs. Our observations leave us no doubt that craters are of rare occurrence. The islands much more resemble Tahiti, in which no crater can be distinguished, than Upolu and Savaii of the Navigator Group, where extinct craters are numerous and streams of lava abound.

The pumice and pumice-conglomerate which have been referred to, afford the most conclusive evidence here found, of recent volcanic action; but our limited opportunities for examination did not enable us to trace the pumice to the place or places of its origin.

Structure.—The basalt frequently shows a tendency to a columnar structure, and at some places occurs in very perfect columns. At Nailoa Bay, a few hundred yards back from the watering-place, there is a rise of fifteen to twenty feet, running nearly parallel with the shores, above which the plain continues back, and is gradually lost in the mountain ascent. In the front of this twenty feet bank, a quarry has been opened by the natives, and a fine series of basaltic columns is exposed to view. They are mostly six-sided prisms, standing erect in the quarry, varying from one to two and a half feet in diameter. Art could scarcely have made them more regular. They have no horizontal cleavages; but for the whole length exposed—about eight feet—they are solid prisms. When broken transversely, the surface of fracture is flat. The rock is extremely compact and tough, and nearly black. Externally, the colour is brownish-yellow, and the surface is sandy, owing to decomposition and discoloration by iron; this alteration is quite superficial, the rock being very durable.

The natives have some superstitions connected with them, and, on account of an imagined sacredness, they sometimes plant them about their *spirit-houses*. One of the columns had been carried to the watering-place, and there set up; and others were observed elsewhere in similar places.

At Kantavu, there is a small island in the harbour consisting of basaltic columns, which have been long held sacred. The natives defended them as they would have defended their lives, and never permitted one to be carried off, till conquered by the chief of Mbau, who transplanted several to his *spirit-houses* and sacred grounds. They resemble those near Nailoa.

The conglomerates differ in hardness, but in most instances bear evidence of the action of heat in the firmness with which the fragments are cemented together. They are sometimes found in close contact with the solid basalt, at first seeming to be imbedded in it. At many localities the rock will as readily break across the fragments of basalt as along the material which unites them. These rocks are generally stratified, though the stratified structure is often more distinctly seen in the distant view than on the spot. In some instances it is very minutely distinct. The strata are generally horizontal; but along the shores it is not unusual to find a large inclination towards the sea. On Ovalau this is very apparent; also at Mali Point on Vanua Lebu.

Some of the higher elevations of Vanua Lebu, consist of these conglomerates. The little village of Mathuata, on the north shores of Vanua Lebu, is overlooked by a frowning bluff two thousand to two thousand two hundred feet in height. Half way to its summit, a very steep declivity is mostly covered with foliage; beyond, it shows a lofty front of naked rock. A dense forest, as usual, crowns its summit, and extends down some of the side valleys. This remarkable bluff, though having a columnar appearance in the distance, consists of a conglomerate prevailing along this part of the island. The resemblance to basaltic columns is rendered striking by the deep furrows on its vertical face, caused by the rains running in rills down its surface. Until closely examined, I had not suspected the true nature of the rock. The furrows are a series of semicircular flutings two and a half to three feet in breadth, and six or eight inches deep. The same were afterwards observed at Mali Point. This conglomerate, though at times nearly as hard under the hammer as the solid basalt, is more rapidly worn away by the elements. Looking at the cliff afterwards, with a glass from the ship, I found that the rock might be distinguished from true basalt by its uneven surface.

Any conjecture as to the relative extent of the solid igneous rocks and the fragmentary deposits, with our present knowledge, would be very hazardous. The latter were met with at almost every point where we landed, and we generally discovered that, where the shore consists of conglomerate, the basalt may be reached by penetrating towards the interior. We have some reason to conclude that, like Tahiti, the fragmentary deposits are more abundant along the shores of the larger islands, and that the solid basalts prevail in the interior. We can draw no inferences regarding the other islands

from the specimens of basalt there collected, as they may have come from the coarse conglomerates, many of which consist of fragments ten to twelve inches in diameter.

Minerals.—The rocks of these islands contain but few minerals and no ores of value. Decomposition of the basalt brings out a deep iron-rust tint, and often impregnates the waters around with a strong chalybeate taste, at the same time incrusting the soil with a rust-coloured coating. This process has formed some deposits of bog-iron ore, of which small specimens were obtained. But I observed no evidence that beds exist which may become of commercial importance. No other metal was observed here excepting the minute crystals of sphene, (an ore of Titanium,) which have been alluded to on page 347. The rocks about Mathuata have often a coppery hue, but it arises from chloritic incrustations.

The common minerals of basaltic regions, augite, chrysolite, and feldspar, are of frequent occurrence; and the first of these is found in very regular crystals, with well-defined and polished faces. They may be collected in large numbers at Livuka, on Ovalau, where they are imbedded in a basaltic conglomerate. A beautiful green sand was brought me by a native at Mathuata, which consisted of grains of chrysolite.

The geodes and nodules in the amygdaloidal varieties of basalt contain the common forms of quartz, with stilbite, natrolite, and analcime; but none of these minerals were observed in elegant specimens.

The islands afford some indications of the action of the seas upon their shores before they were protected by reefs. Yet the period is so distant that it is unsafe to fix with much assurance upon any particular facts; moreover, if these islands have again subsided in part, as seems probable, they have buried with them the abraded shores and their ruins. But we are persuaded that some results of this action may be detected in the numerous small islets, standing detached from the present shores, with which they are identical in geological structure. The island of Mali is, in fact, two islands: they are separated by a narrow passage, and stand but a short distance from the shore. The conglomerate and tufa are identical throughout, and it may be reasonably inferred, that the whole was once a long point, against which the waves of an ancient ocean acted, unparried by coral reefs. Near the summit of the outer island, about one hundred feet high, there is a neat circular well, fifteen feet deep

and four feet in diameter, worn out of the solid tufaceous rock. Its sides are smooth and even, leaving no doubt that it was excavated by the action of water. This natural well is connected below with a horizontal chamber, which opens on the face of the rocky bluff. Another horizontal cavern near by, extended several rods into the hill; but it was too low for exploration. The character of the caverns, and the nature of the place—at the head of a deep valley which opens on the sea—tell us of some former age when the ocean washed these shores. The place reminded us of the blow-holes which are still common among these Pacific islands. The horizontal caverns are gradually enlarging, by a kind of exfoliation usual in soft granular sedimentary rocks; the sand above peels off slowly, in consequence of the crystallization of common salt, or some of the saline minerals which are formed in caverns. This process raises the floor more than the increase in height: so that this enlarging process actually diminishes the passage. The walls of the well are firm, and are not undergoing this kind of enlargement.

The evidence afforded by the coral reefs with respect to an extensive subsidence in the Feejee Group during the progress of these reefs, is presented in another part of this volume. Since this subsidence ceased, there has been an elevation of several feet, as is indicated by the height of the same coral reefs along the shores. The rise referred to, can be proved to equal four or five feet in several parts of the larger islands, and possibly may exceed twice this amount.

On the north-northwestern side of Viti Lebu, the highest part of the shore reef is three feet out of water at low tide. This reef consists of the large massive *Astræas*, ten or twelve feet or more in diameter, lying in the position of growth, and it has not been increased in height by the accumulation of a coral conglomerate, or limestone. An extensive series of observations have proved that a foot above low tide is the extreme height to which the large corals can grow; and with respect to *Astræas*, the instances were so few, and on so small a scale, that it is a safe conclusion that a solid reef of *Astræas* never rises above ordinary low tide.

In addition, we may remark, that this reef lies just at the foot of a declivity of five or six hundred feet, which, in the rainy season, would carry a large amount of fresh water into the sea, proving destructive to the coral, if it were not at some distance below the surface. We may hence conclude that the rise, here indicated, amounts not merely to two and a half or three feet, but probably to twice this height. The

large reef which lies opposite this place, at a distance from the shore, is also about three feet above water at low tide.

The shore reef, which is about half a mile wide, very gradually inclines from its upper limits to the outer edge, where the coral is now growing; we have hence no proof that the elevation here was a sudden one.

Similar facts to the above I observed on Ovalau, also at Sandal-wood Bay, Mathuata and Mali, on Vanua Lebu. At Mathuata, on the last-mentioned island, the village plain rests in part on the coral reef. In the bed of a small stream, which empties there, large corals, now dead, may be seen "in situ" at high water level; and on the island opposite, similar coral occurs two feet above low tide, while the live coral around the same island does not now grow within two feet of low water level. These facts show satisfactorily that these islands have experienced a small elevation—probably four or five feet—since the reefs commenced to form.

Without more extended observation, we cannot state how far this rise has prevailed over the Feejee Group. Both the larger islands, and Ovalau near one of them, have been affected by it: whether the eastern islands have experienced a similar elevation remains undetermined; yet from the extent of the bare reefs without islets, as shown on the map of the group, there is more reason to suspect a subsidence than a rise.

Besides the general elevation, above described, there is some evidence of local elevations. A common report among the white residents affirms that an extensive bed of corals, covered with numerous shells, is found a hundred feet above the sea on the island of Kantavu. They describe the coral tract as two or three miles in extent, and also state that the natives account for these facts by referring to a great deluge. This account has been repeated to me by three different persons, who say that they have seen the corals and shells.

Oniata, a small island one hundred feet high, in the eastern portion of the group, is described as covered with coral, or as consisting wholly of coral rock. But the accounts are so vague and uncertain that they merit little credence without farther confirmation.

CHAPTER VII.

PACIFIC OCEAN.

IN the succeeding pages on the Pacific Ocean, we take up in order the following subjects.

- I. General Review of Volcanic Action in the Pacific.
- II. Mineral Constitution of the Pacific Basaltic Islands.
- III. Origin of the Valleys of the Pacific Islands.
- IV. Changes of Level in the Pacific.
- V. General Arrangement of Land in the Pacific.
- VI. Origin of the General Features of the Pacific, with the bearing of the facts upon the cause of the physiognomic peculiarities of the globe.

I. GENERAL REVIEW OF VOLCANIC ACTION IN THE PACIFIC.

1. VOLCANIC CONES.

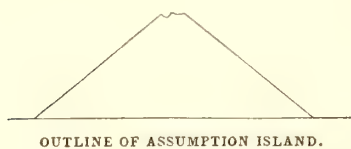
The Hawaiian and other Pacific islands have afforded examples of the different kinds of cones which occur in volcanic regions. They may be referred to the three following divisions, though not always wholly distinct:—

1. Cinder cones; consisting of loose grains or scoria, fine and coarse, and usually presenting some traces of stratification.
2. Tufa cones; consisting of fine volcanic material, earthy in appearance, and distinctly laminated.
3. Lava cones; consisting of cooled streams of lava or molten rock.

1. *Cinder Cones.*

Cinder cones in the parts of the Pacific under examination, are of various heights, to two thousand feet. They have smooth and steep sides, and usually quite regular forms, though often more lengthened or of greater height on the leeward side, in consequence of the action of the winds on the ejected material. The angle of inclination is generally between thirty-five and forty degrees.* As has been often explained, these cones are the result of ejections of the melted lava to such heights that it falls in showers of dry cooled scoria, cinders, or ashes. The bursting of bubbles of vapour, rising in the viscid lava, is the cause of the ejection; and the compression the vapour undergoes, (the amount depending on the viscosity of the lava,) constitutes the projectile force, the strength of which is farther modified by the size of the vent or chimney (as compared with the size of the bubbles) through which the compressed air acts. The colour of these cones is black, or some dark shade like the lavas, unless subsequently altered to red by decomposition, which develops and changes the contained iron to red oxyd.

The peak Tafua of Upolu is a fine example of these cones. Its slopes scarcely vary from forty degrees.



Assumption Island, one of the northern Ladrões, a correct outline of which is here given, is another instance, and one of special interest, as the simple cone stands alone in the ocean; the angle of inclination is the same as in Tafua.

These cones generally rest on a base of lava; for they either follow or attend lava ejections. They are often of mixed character, as the lava cone is frequently finished off with a summit of cinders; cinder eruptions being usually the last effects of the subsiding fires. Mount Kea is a grand example of a mountain cone finishing its career as an eruptive volcano by the formation of a number of cinder cones at

* Humboldt gives the angle as thirty-three to forty degrees. He states that the steepest possible angle, proceeding from loose cinders, is forty-two degrees, (Personal Narrative, Eng. Trans. i. 205, 206.) M. Leblanc (Bull. Soc. Geol. de France, xiv. 85, 1843), after various observations in the Vosges and the Jura, lays down 35 degrees as the maximum slope; $35^{\circ} 16'$ is the inclination of the diagonal of a cube.

summit, three to eight hundred feet in height. These cones are often broken down on one or more sides by subsequent eruptions.

Cinder cones, though abundant over Hawaii and other islands of comparatively recent origin, are of rare occurrence upon those of less modern eruptions. The denudating agents that could scoop out valleys in the solid mountains, easily wash away structures consisting of so loose material.

2. *Tufa Cones.*

Tufa cones vary from a few yards to a thousand feet in height; and like the cinder cones they occur as subordinates to the great craters of the islands. They usually stand near the sea, and often form over submarine vents near shores; in all cases they owe their peculiarities to ejections of water, or unusual volumes of steam along with cinders or earth, as we have illustrated in our remarks on Oahu and Hawaii. Though otherwise similar in origin, they have, therefore, broader summits than cinder cones, shallower and more saucer-like craters, gentler slopes, and a firmer constitution. The angle of inclination seldom exceeds thirty degrees, and may be quite small; and the structure is often as distinctly and thinly laminated as river alluvium. The waters falling upon the rising slopes prevent that sharpness of edge and steepness of inclination which characterize the cinder cone. This cause gives also a yellowish-brown colour to the cinders by rendering the iron a hydrate. The broad summit, and inward as well as outward dip of the layers, and the alluvium-like structure have the same origin. The hills at Nanawale, however, show us that the tufa cone may become closed at summit, and lose its broad crater; but in this case, it appears that the ejections gradually diminished in amount, and assumed nearly a dry cinder character.

These tufa cones have been described as covering lava vents, and as consisting sometimes in part of lava,—thus varying in character like the cinder cones.

3. *Lava Cones.*

The lofty summits of Loa and Kea, and the hillocks of lava upon their sides, are alike examples of lava cones but little altered in gene-

ral features by fragmentary accumulations; and the other summits of the Hawaiian Group and the mountains of most Pacific islands afford additional illustrations, though much modified in features by degradation. The general slopes of these summits as finished by the fires,—or, more correctly, of the layers constituting them,—vary from one to fifteen degrees.

In the molten rock, as Kilauea illustrates before the eye, there are all the elements requisite for producing cones of every angle.

a. The lavas may be jetted from a vent in small ejections, gradually diminishing; they flow only to a short distance before cooling, and layer added to layer by overflowings, produces a cone of twenty degrees or less, to forty degrees.

b. The same lavas jetted in smaller dribbles, the drops falling and adhering, and thus accumulating on one another, raise a very sharp cone, or a column, or spire of lava, (p. 178.) The remarkable instance of a steep raised rim around the great lake of Kilauea, formed by small overflowings cooling on the edge, has been mentioned: to be duly appreciated, it should be remembered that this lake is actually a large crater, the opening fifteen hundred feet in one diameter. The peculiar features of the “Old Crater” of Koloa on Kauai (p. 273), were probably produced by a similar mode of action.*

c. When the overflowings are extensive, the cones that are formed slope at different angles, usually between one and fifteen degrees. The cones at Kilauea, though confined within the crater, are no tiny elevations, for they are sometimes a mile in diameter. They often become steeper above by a variation in the extent of the eruptions, nearly as above explained. The successive ejections flowing to a less and less distance from the summit, thin out below, increasing the steepness of the cone; then larger ejections succeed, and cover the

* From the descriptions of Cotopaxi, by Humboldt, there appears to be a circular wall surrounding the crater, looking like a small cylinder raised on a truncated cone; and it is visible to the naked eye at a distance of two miles and a half. (*Personal Narrative*, English Trans. i. 169.) It may have been produced by a boiling up of the lavas, as in the great lake of Kilauea, or by ejections of lava, which, on falling, still had the cohesiveness of semifluidity. Mr. Darwin, who cites the above, and mentions similar facts as occurring at the Galapagos, (*Volc. Islands*, 83,) attributes the effect “to the heat or vapours from the crater, penetrating and hardening the sides to a nearly equal depth, and afterwards to the mountain being slowly acted on by the weather, which would leave the hardened part projecting in the form of a cylinder or circular parapet.” But the usual effect of volcanic vapours is to decompose, as may be seen in any solfatara and is well shown in the sulphur banks of Kilauea.

whole slopes with a flow of lavas, or, perhaps, many in succession. In this way the model cones of Kilauea vary their features and inclinations.

d. But besides these sources of change, another, equally common, is the opening of fissures around a vent. At the same time that cones are enlarging by overflowings, they are liable to ruptures of their sides in lines sometimes radiating with considerable regularity from the centre, and these fissures at once give exit to a flood of lavas, which spread around, forming a layer over the surface of the cone, and a dike of cooled rock in the fissure itself. These fissures, when starting, as they frequently do, from the central opening, must heighten the slopes; for the dikes are like so many wedges driven into the sides, enlarging the surface and size, and consequently the angle of declivity.

These various facts are matters of observation. When, therefore, cones are visibly accumulating by these processes, beginning at first around a point in an opened fissure, and attaining even rapid slopes in some instances; and when we observe that they continue enlarging by the same means, till even a mile in diameter, we must admit that lava cones may be a result of eruption. We must conclude that in the very earliest commencement of the ejections from a vent, there is a tendency to the formation of a cone, and that the same cone goes on increasing, and is a perpetually growing germ, becoming finally the future mountain. Kilauea gives us examples, on a comparatively small scale, though still of no diminutive character, of the beginning and progress of the rising volcanic cone; and as the slopes of the larger mountain are very accurately represented in these beginnings, the same principle would seem to be sufficient for both cases. The study of the mountains themselves only confirms this view, presenting some new facts for our consideration.

From *Mount Loa* we learn that, with the present slopes, its surface may be covered in any part by beds of lavas, and thus its size continue increasing; and more than this, we learn from the eruption of which an account is given on page 209, that its surface, with the existing inclination, may be covered with a continuous bed of lava, twenty-five miles in length, extending from the summit to the interior plain of Hawaii. The average angle of the slope has been shown to be but six or seven degrees. But over declivities with this average angle, there are many places of much steeper descent, even to twenty-five degrees. Whatever that rapidity may be, the facts prove that the mountain is still enlarging by eruptions extending down its slopes.

The same principle is illustrated by Hale-a-kala, the eastern mountain of Maui. The last great summit eruption forms a continuous stream of lava from the top to the sea: it is nearly two miles wide where it commences at the crater, and enlarges towards the shores of the island. The *average* slope is nine and a half degrees.

We may not, therefore, believe the statement that lavas cannot form beds on a steeper slope than six degrees. We cannot doubt, whatever be the truth in other regions, that Mount Loa and Hale-a-kala, and others of similar features, have actually been formed simply by the process of eruption; and that the angle of declivity was fixed by the mode of eruption in the different phases of the volcano.

But what may be the different phases of a volcano, and what their effects upon the features of the mountain? These different states have been pointed out; but may be here alluded to again.

Influence of different degrees of fluidity.—The lavas may have the fluidity of those of Kilauea, and may boil up and overflow, being too liquid for cinder eruptions. Whenever the heat is sufficient, this simple ebullition and overflow will be the common mode of action. In earlier conditions of our globe, this greater heat must have existed, and igneous centres must have been vast boiling lakes, instead of narrow craters, like the majority of those now active. Kilauea remains to correct our ideas with regard to igneous action, and to evince the important fact that cinder eruptions are, in general, a proof of subsiding fires, not only in particular craters, as has been often admitted, but also throughout the globe.

The most striking feature arising from these two different conditions,—the liquidity of free ebullition, and the viscosity occasioning cinder eruptions,—is seen in the crater of a volcanic mountain. In the *former* case, it is a deep gulf, with vertical walls of stratified rock, and a bottom of solid or boiling lavas. In the *latter*, though there may be a deep pit, the lava vents are surrounded by a rising cone of scoria. In the *former*, the cavity may be of vast size, for there are no limits to the extent of a boiling lake of lava, but such as may result from limited heat; and there may hence be craters of this kind, not only seven miles in circuit like Kilauea, or Mokuaweo, but even three hundred or four hundred miles, like those of the moon, which are evidently of this character.* In the *latter*, the imperfect fluidity

* See *On the Volcanoes of the Moon*, by the author, in the American Journal of Science, ii. Ser. ii. 335.

presupposes a comparatively small area to the vent; the cinders are thrown up, and fall directly around it or back again, and the summit crater has limits, therefore, which cannot be exceeded.

Another consequence of the two conditions, is the following.

In the case where the vent is large, and the molten rock very liquid, the overflow of lavas will be far more copious; the streams will spread over wider areas, may flow of greater depths, and descend steeper slopes. Suppose an overflow to continue for several days in continuous action; such lavas will spread and run down a declivity even of thirty degrees in a continuous stream; for assuredly it could not choose to run or leave its traces in narrow lines.* If the flood is four hundred feet deep, (the depth of the lower pit of Kilauea,) and such a flood is no extravagant assumption, may it not form a bed of great thickness on a slope of ten degrees, especially if the flow be incessant or rapidly intermittent for some days? These ejections succeeding one another rapidly, may accumulate upon one another, even though the declivity be rapid, and thus produce a layer of great thickness, just as, on a smaller scale, steep cones accumulate in Kilauea.†

These are no extravagant assumptions. There is the same evidence that the deeper streams have actually flowed, as the thinner; for both exist in the structure of these mountains under the same circumstances. It is unreasonable to draw conclusions that are to be deemed general laws of igneous action from vents whose sluggish lavas scarcely have motion, except such as come up to the surface through some deep fissure opening from hotter depths. The condition of the lavas of Vesuvius affords us no data for judging of those of Kilauea. The former are so viscid that vapours cannot make their way through till they have accumulated into a vast bubble, and acquired force sufficient to carry the fragments of lava to a height of a thousand feet or more; while in the latter, the vapours pass freely, and thirty feet is the usual height: the action is constant and intense.

A *third* consequence of the two conditions, is the frequency of cinder or fragmentary eruptions, of great violence, from the less fluid vents,

* Streams of cooled lava that descended a slope of fifty or sixty degrees, have been alluded to as occurring on the walls of Kilauea, and as being continuous for three or four hundred feet. They are narrow; but if the source had been more generous, it is difficult to see that they would not have had a greater breadth; and by a succession of ejections upon each cooled layer, even a considerable thickness might have been attained.

† See on this point the memoir by M. C. Prevost, Bulletin de la Soc. Geol. de France, xi. 194, 198.

alternating with the beds of lava; and their rarity over those mountains that are characterized by a crater of boiling lavas. Mount Loa, though so extensive, has no cinders over any part of its surface, excepting small deposits in a few places: there are none at the very summit, where the action has now partially subsided. The various eruptions through fissures, sometimes end, as the heat diminishes in these fissures, by making small cones of cinders; but these are not to be compared with those "showers of ashes" which proceed from a central crater, and sometimes cover the vicinity of volcanic regions for miles to a depth of many yards.

A *fourth* consequence is the more convulsive character of the volcano of the Vesuvian stamp; for an ingress of waters below leads to more violent struggles between the escaping vapour and the semi-fluid lavas: yet this has its exceptions. Again, overflowings at summit may be more frequent where the lavas are very liquid, and fissure eruptions where less so. But this, again, has many exceptions; for Mount Loa itself, at the present time, is ejecting its lavas through fissures.

This leads us to speak of the influence of fissure eruptions on the forms of a volcanic cone.

Influence of fissure eruptions.—It has been remarked that the more fluid boiling lavas, (of which those of Kilauea may be taken as a type, though the pools are but small compared with what the past may have witnessed,) may be so ejected, in extensive summit floods, uninterruptedly or with short intermissions for a period of time, as to flow down slopes of any angle of declivity. But there is a limit to the steepness of a cone of the kind supposed, in the weakness of the rocks which constitute it. The elevation of the mountain increases the force required to raise the lavas to the summit. If, then, by any of the processes pointed out, the summit becomes raised beyond the ability of the mountain's sides to sustain the consequent pressure, eruptions will break through the lower slopes instead of at summit; and the new layers, as well as the interlocking dike, (which sometimes sends laterally interpolating layers,) will strengthen the cone again, and prepare it for other summit eruptions.* The slope of a cone

* See Scrope on Volcanoes, p. 156. Since writing the above, I have observed that he expresses the same opinion, as follows: "Dikes being usually formed in a vertical direction, and therefore transversely to the lateral beds or currents of lava, communicate a vast accession of strength to the structure of the mountain, acting as ties to the latter, which may be likened to the main beams of an edifice." Lateral eruptions tend to for-

will consequently be the resulting balance between the two operations, summit eruptions and lateral eruptions (supposing, of course, that the action does not lose any of its force); and it will be nearly a constant quantity, rendered variable only by the different character or strength of the rocks, the depth of solid material, and the presence or absence of open cavities below. This is one source of the dikes or fissures about volcanoes.

Action of unusual violence is another source, and it sometimes splits down the cone from its summit to its base.

Whichever way dikes are formed, their influence on the form of a mountain cone will depend on the portion of the mountain they intersect. If they take the line of radii, commencing at the centre, and extend part way to the base, they necessarily cause an elevation, and increase the inclination; but if they only intersect the lower slopes, they diminish the inclination, and, at the same time, enlarge the diameter of the mountain. If they extend from summit to base, of equal width, or run transversely to the slopes, they can have little effect except in enlarging the mountain. These dikes, as observed in the Pacific, are remarkably uniform in width from top to bottom, even when exposed for a thousand feet in height. No instance of enlargement above was observed, and they were seldom much larger below. Neither were examples met with of tiltings or dislocations by these dikes, beyond faultings of a few feet.*

An exemplification of this action of dikes is presented us in Mount Loa. The slopes, as shown on page 170, have been extended twenty-five miles beyond Kilauea, and reduced to an average angle of $1^{\circ} 28'$, while above Kilauea, the angle is $6^{\circ} 45'$. And this process of extending the slopes is now going on; for the eruption of 1840 had this effect. Indeed all the eruptions of Kilauea, for a long period, have taken place towards the sea, or beneath it, and have resulted in

tify the sides, and enable the mountain again, perhaps, to pour forth lavas from the summit.

* This non-disturbance of the rocks by volcanic dikes is dwelt upon by M. Constant Prevost.—*Bulletin de la Soc. Geol. de France*, xi. 196.

Darwin also remarks on the great number, height, and even width of the dikes of St. Helena; and observes that one exposed to view for a height of 1260 feet, was but four inches narrower above. An instance of remarkable disturbance is mentioned, and the same was seen by the writer; but he adds that dislocations on so grand a scale are extremely rare in volcanic districts.—*Volc. Islands*, pp. 77, 78.

lengthening the sides of the mountain, and at the same time diminishing the angle of acclivity about its flanks.*

When Mount Loa changed its mode of action from a preponderance in its summit eruptions to fissure eruptions, cannot be known. There may have been a time when devastating floods swept a large part of the surface, and the structure at summit requires the supposition; but at present the lavas break out through opened fissures whether the eruptions take place above or below, and the enlargement now in progress is only by this latter means.*

We find evidence in Mount Kea and the other Hawaiian Islands, that they were formed mostly or wholly at a much lower than their present level. The elevation placing the summits at their existing height, may have been accompanied or followed by a series of changes throughout the group, and an extinguishing of some fires; and with Mount Loa, the new phase in its mode of action, above alluded to, may have then taken place, and been accompanied by the opening of Kilauea. But this is conjecture; yet there is no doubt, we believe, as to the reality of the change.

The history of Mount Loa, therefore, seems to be quite simple and intelligible. The cones of the Kilauea pit, show us a model of the mountain itself. They illustrate the germ-cone, proceeding from eruptions by overflowings, and through fissures: they illustrate the progress of the cone: and by becoming inactive, as they generally do, after reaching a certain size, and eruptions going on in the plain below, they exemplify nearly the existing condition of Mount Loa. The upper slopes of Mount Loa are not too steep to be coated with lavas, for this actually takes place in these recent times, though by fissure ejections. The lower slopes are more frequently flooded, and these are spreading out the base of the dome. The fissure eruptions usually end in producing one or more small cones.

The crater of the mountain may have been once much more extensive, and may have merited comparison with some of the large circular areas inclosed by lofty walls, such as von Buch describes as occurring on Palma, one of the Canaries.† If so, diminishing action

* All late eruptions of Vesuvius and Etna are of this kind. See Bischof, *Amer. Jour. of Science*, xxxvi. 251, 252. Humboldt says of Teneriffe—the interior of the peak shows it to be a volcano, which for thousands of years has thrown out fires only from its sides.—*Reise*, i. 195.

† The Caldera of Palma is a nearly circular area, enclosed by lofty walls, and measuring six or eight square miles in diameter. From the top of the walls, the sides slope

must have gradually narrowed the vent to its present size. The vertical stratified walls, and the absence of scoria about them, might be considered decisive evidence that such cavities had never been craters with overflowing lavas, by those who had not seen a crater like Kilauea; but we have more than once remarked, and the importance of the truth will authorize the repetition, that both the upper and the lower pit of Lua Pele—the latter actually buried with lavas in 1840—have just such stratified walls *without any scoria about them*.

The principles here exemplified by Mount Loa are borne out by other parts of the Pacific, as will be gathered from the descriptions on the preceding pages of this volume. The different phases of volcanic action, depending on the increasing height of the cone, the more or less perfect liquidity of the lavas, the continued or intermittent periods of activity, a gradual diminution of its action at later periods, the equiponderance of summit and fissure eruptions, or the prevalence of the former or latter, are the several modifying circumstances. There may be cases in which the fissurings of the mountains during a prolonged period of activity have taken place mostly from the centre, and have resulted in a constant increase of the angle of acclivity. But in Mount Loa they have in modern times occurred over all its sides, and we have no evidence that these rupturings have recently added to the rapidity of the slopes; while we have evidence that they have diminished the angle, and are still producing this result.

gradually towards the sea. Mr. Darwin, (*Volc. Islands*, p. 30,) mentions a nearly similar area at Mauritius, one thousand feet deep, the shorter axis of which is thirteen geographical miles in length; and another at St. Jago, one of the Cape Verdes, (p. 17, 20.) There is much resemblance in these areas to the circular craters of the lunar volcanoes: yet some of them may have resulted from a subsidence of the interior of the island. Mr. Darwin speaks of the mountains of Mauritius as resembling “the basal and disturbed remnants of a gigantic volcano,” and he quotes M. Bailly as suggesting that the enormous gulf was formed by the sinking in of the whole upper part of one great volcano. (*Volc. Islands*, p. 30, 31.)

As another example of a similar area, we have alluded to the extensive plain on Tahiti, at the base of the lofty peak, forming the head of the Punaavia Valley. Eimeo also appears to be characterized by an extensive interior plain, surrounded by lofty walls, which are much broken into peaks. The resemblance of these circular areas to Kilauea and Mokuaweo is too close in every feature to be passed by without consideration. Were Kilauea broken down at its southeast extremity by a gap like that of Hale-a-kala, we should have a Val-del-Bove of magnificent dimensions. The resemblance of this famous valley to Kilauea or to the Maui crater, is distinctly brought out by the sketch by Mr. Lyell, in his *Principles*, volume ii., plate ix.

Solid Centre of Volcanic Mountains.—One peculiarity in the large volcanic mountains remains to be considered. Tahiti is one of these mountains laid open by extensive degradation. We find that while the circumferential portions consist distinctly of a series of layers from different eruptions, alternating occasionally with conglomerates, and dipping gently outward, the interior peaks are solid to their summits, and imperfectly columnar. The same is the case at Rarotonga, as I was informed by Mr. W. C. Cunningham. On Kauai, the layers become very thick towards the interior, as in Tahiti, a depth of several hundred feet occurring six or eight miles from the shores; but the centre of the island not having been examined, we cannot say how far it corresponds with Tahiti. Similar facts are stated by von Buch and others; and it seems, therefore, to be a general characteristic of the larger lava mountains. Moreover, it appears to be ascertained that these central portions are more feldspathic in character, often more crystalline in texture, and quite compact without a trace of cellules. Clinkstone and varieties of porphyry with syenite or an allied rock, are the usual materials constituting them. These same feldspathic rocks, including even the syenite, inclosing hornblende, occur upon Tahiti.* On Oahu, the compact varieties are found on the Waianae plains, which lie near a former centre of a volcanic mountain. They occur among the lower layers of the eastern Oahu range. At the summit of Hale-a-kala, Mount Kea, and also of Mount Loa, clinkstones appear at the surface, and in some instances they have throughout a crystalline texture. Thus feldspathic rocks seem to prevail at the centres of all the mountains examined, though basaltic rocks constitute the exterior surface and the flanks of the mountain. And when the mountain has been broken through by any cause, the structure at the middle is not stratified, but solid and compact; while in the valleys leading to the interior, there are layers of the different kinds of graystone and basalt, often containing chrysolite, or augite, or both these minerals.

This difference of structure admits of explanation in accordance with the facts which have been described. It would seem that the vast amount of material constituting the solid nucleus must have been simultaneously in fusion, in order to produce so uniform a structure. The hypothesis strikes the mind as almost incredible. But

* Although the locality of the syenite was not ascertained, I obtained a kind of trachyte on Aorai, one of the central peaks.

something of its seeming extravagance vanishes upon seeing in a corner of Kilauea a single lake of boiling lava one thousand feet by one thousand five hundred in diameter; and remembering that were Kilauea in general action over its whole surface, the molten interior might average a mile in breadth by three and a half miles in length. At the top of Mount Loa, the crater, though a mere dot in the summit plain, is two miles in diameter; giving this breadth to the fluid interior, even at a height of nearly fourteen thousand feet, as the figure on page 219 illustrates. Thus in these recent times, with the crater of its present contracted limits, we find that when in full action, Mount Loa bears evidence of a vast amount of matter in fusion within the volcano. And if there is any probability in the supposition that the interior plains of some volcanic islands ten or a dozen miles in diameter were actual craters, (there is no doubt that one hundred, and even one hundred and fifty miles is an actual breadth in the moon,) we can no longer deem it an improbable hypothesis that the whole interior was once in fusion together, over a breadth as great as any facts presented in igneous regions would seem to require. Only twice the breadth of the summit crater of Mount Loa would explain the facts at Tahiti. We learn from the instructive pools of Kilauea, that the boiling centres at times become extended by melting into themselves the adjoining layers, or contract again by cooling; and these variations, which would take place in vents of any size, may account for many facts presented by these islands. Such a central mass of fluidity, covered on all sides from the external air, would cool with extreme slowness, and offer the circumstances necessary for crystallizing the feldspathic rock into syenites, and forming hornblende. We shall recur to this topic in the sequel.

Rapidity of the Formation of Lava Cones.—We know little with reference to the rate of increase of Mount Loa: and if correct data were at hand for the existing period, we could not assume these as data for the past. The whole surface is about two thousand four hundred square miles in area. Consequently it would require one hundred and sixty such eruptions as that of 1840 to cover the mountain with a single layer of twelve feet. If eruptions have happened no more frequently in former times than at present, one thousand two hundred years would be occupied in this increase. Allowing for an occasional outbreak from the summit crater, we may set down eight hundred years as the time, on this hypothesis, required for

an increase of twelve feet over the whole surface. This would give near four hundred thousand years for the formation of the *part* of the mountain above the sea. We leave this computation with the simple mention of the result, and the remark that it indicates the period to have been long, though affording no approximation to the actual amount of time.

The lateral or subordinate cones of the mountain are mostly the product of a day, week, or month; that is, they are the immediate result of particular eruptions. It is a very little matter for Mount Loa to throw up a cone of six or eight hundred feet in height,—very much less than we should gather from some writers upon Jorullo and Monte Nuovo. These lateral cones are seldom centres of any extensive streams of lava, as many descriptions would lead us to infer; on the contrary, the lavas about them have generally flowed from an opened fissure, and the cone is an elevation arising from prolonged eruptions over some part of such a fissure.

Conclusions.—The foregoing discussions have led to the following conclusions:*

I. That Mount Loa and similar summits (among which we would include most of the islands of the Pacific examined by us, besides all others of the same general character) were formed from successive eruptions of molten rock, alternating sometimes with cinder or fragmentary ejections.

II. That the eruptions are in general the result of a rising or ascent of the lavas, owing to the inflation by heat of such vaporizable substances as sulphur and water, the overflow or lateral outbreak taking place in consequence of the increased pressure from gravity, and from the elasticity of the confined vapours; and that the contraction of the earth's surface is no more necessary for an eruption, than the contraction of the sides of a boiling pot of water to make it boil over. The influence of the earth's contraction is extremely gradual, being inappreciable except at long intervals: as is evident from many reasons already stated, it cannot explain the ordinary phases of a volcano from quiet to activity and the reverse.

Farther, that the change from quiet to activity is generally a gradual progressive change, sometimes appearing paroxysmal when the action in its earlier stage is below the surface, and only in its last stage

* For our previous deductions with regard to volcanic action, see pages 193 and 216.

breaks out and becomes externally active; that often when there is a seeming extinction of a crater, the lavas may be accumulating, or rather rising in the vent by the same mode of progress as is exemplified in Kilauea, and that after a period the lavas continuing to rise, the process causes them to show external activity: and finally, either the accumulated pressure alone causes an outbreak, or the greater action promotes the formation of greater volumes of vapour, because a larger or longer surface of heated lavas is exposed to the ingressing waters; or else the extension of heat and increase of vapours open the way for new floods of water to give eruptive force to the volcano: and so in one or another of these ways, or by them combined, the outbreak takes place. Hence the interval between great eruptions in different craters is determined by the time required to produce the rising of lavas in the vent; and this interval may be nearly uniform for the same vent through a long period: seven or eight years has been latterly the interval at Kilauea.* (pages 222, 223.)

III. That eruptions will usually take place from the central vent in case the sides of the mountain will sustain the pressure of the column of lava; and when incapable of sustaining this pressure, lateral outbreaks occur. Fissures are also frequently opened by local action through the pressure of vapours.

IV. That by the balance kept up between the two modes of eruption, terminal and lateral, the form of the mountain is produced: and that the form is farther modified by fissures or dikes, acting like wedges, which may increase or diminish the angle of the slope according to the part of the mountain, the upper or lower, in which they prevail: and farther, that in all recent periods, fissures of the lower parts of most volcanic mountains have been far more frequent than fissures of the upper, in consequence of which, the slopes have been rendered more gradual, and the limits of the mountain have been extended.

V. That lateral cones of cinders, lava and cinders, or lava alone, frequently form over the deeper parts of a fissure of ejection, and are often a thousand feet or more in height; they may be thrown up in a

* The fact of there being long intervals of quiescence in most volcanoes was observed by Humboldt, and he remarks that the interval has a general relation to the size of the volcano. This relation, though perhaps borne out as a general fact, is not a necessary one, as the interval would naturally become longer in such mountains as are approaching extinction.

day, or a few weeks, and generally cease action soon after the eruption becomes quiet, though occasionally of prolonged activity.

VI. That in consequence of the mode of formation pointed out, the volcanic mountain is quite uniformly stratified in its internal structure; yet its layers are often of small lateral extent, patches innumerable having been added here and there about the mountains at different times, till the whole was accumulated.

VII. That the central portion of a cooled volcanic mountain is usually solid unstratified rock, while the circumferential portion is distinctly in successive layers. There is evidence that the central conduit of fluid lava may not be in all instances a narrow channel of a few score of yards, but in former times at least was as large in diameter as the terminal vent, and of divergent size below in case the heat increased downward instead of decreasing; it may, therefore, have had a breadth of several miles; the cooling of such a mass of lava would take place with extreme slowness, and the material would necessarily be unstratified.*

VIII. That the lavas of different adjoining vents act in all ordinary eruptions independently, as exemplified in Mount Loa (p. 218): that we may with much probability view the volcanoes of the Hawaiian Islands as originally communicating by fissures through a common opening to internal fires within the globe; that the closing of the fissures, except at certain points, reduced each fissure to one or two channels, branching from a common trunk below, one corresponding to each separate mountain centre of the different islands. The opening of subordinate fissures around these vents, (we refer here to ordinary fissure eruptions,) which became filled again except at certain points, produced *temporarily* other minor ramifications to this system of fire-channels in this part of the earth. It may be that the channels in various instances became closed below by cooling, and even those of the principal craters might consequently descend only to isolated reservoirs of lava (p. 220).

IX. That the ordinary eruptions and usual action of a volcano proceed principally from water gaining access to the branch or branchlets belonging to a particular vent, and not to a common channel below: the fresh waters of the island are the principal source of

* If these fluid lavas of the interior were to be drawn off by any wide submarine fissure, it might happen that the summit of a volcanic dome or cone should be made to fall in ruins and disappear within the emptied cavity.

the vapours of Kilauea (page 221): that consequently there is seldom any sympathy to be detected between different mountain cones of the same island, and far more seldom between those of different islands, (unless in very close proximity,) inasmuch as the furcation of the channels (when such exists) takes place far below the level to which the waters that ordinarily feed the fires gain access.

X. That pulsations in the central igneous fluids of the globe have but little influence, if any at all, on the action of volcanoes; for vents in the same vicinity are not contemporaneously affected, and the phases of volcanic action are fully accounted for by a more superficial action.*

In the foregoing remarks on volcanic action, there may be observed an implied distrust of the theoretical conclusions of an eminent European geologist. The *elevation* hypothesis of von Buch,† has too readily gained almost universal currency. As an explanation of some particular cases, it may be satisfactory; but its general application to volcanic mountains has not been sustained by facts observed by the writer. The hypothesis supposes the material of a volcanic mountain to be thrown out from several vents nearly on a plain, or

* The views on volcanic action, ably presented by M. G. Bischof, appear to us to be especially erroneous, from his appealing to the internal igneous fluids for the source of volcanic action. In a diagram, he represents the crust fissured through, and supposes these fissures to admit water to these internal fires; an hypothesis which is unnecessary, as we believe, and not tenable. The entrance of water feeding the fires of Hawaii, requires no fracturing of the crust: the process is gradual, and proceeds, as we have shown, from the ingress of surface waters which have become subterranean; any fractures necessary, are simply fractures in the vicinity of the volcanic focus.

† Description Physique des Iles Canaries, by Leopold von Buch, (Paris, 1836,) a work of great merit and high reputation. This French edition by C. Boulanger is a translation of several memoirs which appeared at Berlin between the years 1816 and 1825.

Von Buch's views have been ably advocated by M. Elie de Beaumont in various writings on Etna, the result of much labour and close investigation. See Memoires pour servir à une Description Geologique de la France, tome iv. 1838; Bull. Soc. Geol. de France, volume for 1835; Jameson's Edinb. New. Phil. Jour. xx. 376; Explic. de la Carte Geol. de la France, vol. i. 1841.

See also M. Bischof, in Jameson's Edinb. New. Phil. Jour. xxvi. 1839; and American Jour. of Science, xxxvi. 267, &c.

The theory was first suggested by Humboldt in his travels. See his Personal Narrative, i. 240, (Eng. Edit.)

These peculiar views have been opposed by Mr. Lyell after an examination of Etna, (see his Principles, volume ii. chap. xiii., 6th edit.,) and also with much sound reasoning by M. C. Prevost, Bull. Soc. Geol. de Paris, xi. 183.

at an angle not exceeding three degrees; and subsequently, by forces below its centre, to be raised to a conical shape. It is admitted by this distinguished geologist, that the forces may have been, for a short distance, linear in direction, though approximately central. The actual formation of cones in Kilauea, exact models of the great mountain-volcanoes, beginning and progressing as cones, is better evidence on this point than any supposed impossibility of lavas descending rapid slopes; for we have shown that the conical form commences through eruptions from the terminal vent and fissures, and undergoes no essential change, as enlargement goes on. We see no foundation whatever in the Pacific for the view that the mountains waited till the material was thrown out before the action began which elevated the centre. We are taught rather that the elevating forces were more powerfully at work in the earlier periods, when the mountain structure was begun. In its very earliest origin, if ever, the centre would be radiately fissured, and the angle of acclivity increased; and this effect would gradually diminish as the size and activity of the crater diminished, and the general action subsided, or became generally lateral through flank fissures. While, therefore, we present no opinion here as to the particular cases claimed as instances of elevation craters, we cannot admit the hypothesis to the rank of a general theory.*

* As a more distinct enunciation of some of the principles to which we have been led by our investigations, we may notice here some of von Buch's deductions, not in accordance with facts as we have observed them.

On page 296 of his *Canary Islands*, he says, that in "all *craters of eruption*," (the term used to distinguish certain craters from supposed *craters of elevation*), "the craters are broken down on one side." What is Mount Loa on this principle? Lavas have flowed from its summit even at a height of fourteen thousand feet, ten thousand feet above Kilauea; and although issuing through an opened fissure, it is properly no less a crater of eruption. The Kilauea lavas are as high above the sea as the peak of Vesuvius; yet they accumulate over a large area till the bottom is raised near four hundred feet, when the mountain yields to the pressure, and the lavas flow out. Here is eruption, as much as if the sides of the mountain held their ground and the crater had overflowed; yet the crater is not broken down on one side. If Mount Loa should be ranked with craters of elevation, we should be equally troubled to distinguish a correspondence with the characters given for this class of volcanoes. If the prevalence of fissure eruptions be the evidence, we reply, that this may proceed from subsiding fires, or from a general elevation of the mountain in which the whole island has participated: no raising of the centre by a sudden movement at any period in its history can be proved by any facts apparent; and none is needed to explain the phenomena. The actual change which the preceding descriptions sustain, is a change from a state in which eruptions produced an increase in

In the observations on volcanoes which have here been made, the author has given his deductions from the facts observed, without mentioning that some of his conclusions have been presented by others. This course has been followed because they give the effect of facts on a mind unbiassed by any theory, and they should, therefore, have more interest as additional testimony on debated points in

height, and in the rapidity of its slopes, to a state in which they produce an increase of breadth and diminution of the average angle of its slopes. It was once a crater of elevation, *through its eruptions*; it is now a *crater of complanation*, through the same means, —a distinction correctly recognised by Prevost.

Hale-a-kala is a mountain of like slopes with Mount Loa (or a little more rapid), and answers the description of a crater of eruption in its broken summit. Yet the same facts, as regards structure, are to be accounted for as with Mount Loa.

On page 367, von Buch says, "that if the vapours find an exit and escape, then no rock enters into fusion, and no lavas are formed." Whether Kilauea, in the sense intended, gives exit to vapours or not, it may be difficult to say. Certain it is that vapours do escape on a grand scale, and lavas boil with unequalled activity, and over immense areas. The process instead of being paroxysmal, as von Buch's remark implies, is gradual and incessant. Much of the error, with regard to the paroxysmal action of craters being an essential feature, has evidently arisen from the study of those volcanoes only which have been long on the decline, the condition of igneous action generally over the earth at the present time.

On page 307, it is remarked that "if Lancerote had had a crater of eruption, there would probably have been none of its numerous cones of eruption," implying that lateral eruptions would not have taken place. The correctness of this opinion may be judged of from what has been already presented. The fact that long after lateral eruptions have begun, the lavas may still ascend to the summit, is well shown in Mount Loa, in which eruptions take place at top while Kilauea is boiling ten thousand feet below.

On page 323, von Buch says that there is only one volcano in the Canary Islands, the peak of Teyde or Teneriffe: "this is the grand outlet for vapours." But we ask again, How much effect has the crater of Kilauea, with all its great breadth and extent, on the summit eruptions of Mount Loa, though situated on the flanks of this mountain? These channels or internal conduits of heat and lava are probably as much isolated in volcanic regions generally, as in Hawaii. There is no reason to believe in the sympathy of adjoining islands except in some remarkable cases of action, as we have already sufficiently explained.

Judging from the descriptions of the Canaries, they have strong analogies in structure with the Hawaiian Islands. Teneriffe and Lancerote are double islands, resembling Maui and Molokai. M. von Buch suspects that Hualalai is the *central volcano of Hawaii*; carrying out thus, his idea of a *central vent* of action, even at the expense of Mount Loa and Kea, far loftier than Hualalai, and not more steep in their slopes; and also, while Mount Loa is in eruption from top to bottom.

The several considerations presented by M. Elie de Beaumont, in his able Memoirs, are sufficiently replied to in the preceding pages, as far as they relate to volcanic theory in general.

science. The views of M. C. Prevost, of the Geological Society of Paris, have been so nearly followed, both as regards the nature of volcanic action and the formation of volcanic mountains,* (though unaware of the fact when first written out,) that his name is entitled to special mention in this place. The science is greatly indebted to him for his lucid exhibition of the principles of volcanic action, in which he has led the way against much error.

II. MINERAL CONSTITUTION OF THE BASALTIC ISLANDS OF THE PACIFIC.

The rocks of the mountains in the Pacific have been described as varying between basalt and clinkstone or porphyry, the former passing into the latter as feldspar becomes the predominant and finally the constituting mineral. The basalts are either homogeneous and wholly uncrystalline; or they contain crystals of augite or feldspar, or grains of chrysolite, or magnetic iron; again, they are compact or vesicular; and the latter pass into scoriaceous and obsidian varieties. The feldspathic rocks are mostly a clinkstone, or a compact rock, like the base of porphyry, and approaching trachyte; and they pass into a variety of crystalline texture like syenite. The feldspars as far as examined are *soda-feldspars*. This is the case with the lavas of Kilauea, the glassy crystals of Maui, which are near Andesine, and other crystals from Samoa.

The terms *basalt* and *basaltic lava*, used in this volume, are necessarily indefinite, inasmuch as the rocks themselves vary indefinitely in character; we therefore use them in preference to more specific terms. They imply the presence of augite and some feldspathic mineral as the essential ingredients. The nature of the rocks can be better learned from the particular descriptions, than from any names that are applied to them.

We propose to inquire whether any facts observed will illustrate the origin of these different rocks, and the peculiar conditions and relations under which they occur.

The most striking fact connected with these relations has been pointed out as noticed in most volcanic regions, viz., the occurrence of feldspathic varieties at the centre of the mountains, while the ex-

* Bulletin de la Société Géologique de France, especially vols. xi. p. 183, and xiv. p. 270.

terior and circumferential portions, consist of basaltic rocks: at the same time, the former have usually a solid, unstratified character. We refer to the preceding pages for the facts,* merely instancing here, as regards the feldspathic axis, the single case of Mount Loa, in which there is clinkstone at the very summit, while around the slopes, wherever below, the rocks are exposed in sections, and whenever recent eruptions take place, there is nothing but some variety of basalt or basaltic lava.

The solidity of the portions of the mountain about the axis, is explained on the ground of the fluidity or great heat of this axial portion, during the action of the volcano. But what has separated the feldspar, iron, and augite, that constitute the basaltic rocks, and left nearly pure feldspar alone at the centre?

The only points of difference in the characters of the minerals on which this remarkable fact can in any way depend are the following: 1. The different specific gravity of feldspar and augite, the latter usually having its specific gravity as high as 2·9 to 3·2, while that of the former is only 2·4—2·5, or one-sixth less. 2. Their fusibility, augite and basalt being a little more fusible than feldspar and feldspathic rocks. 3. In composition, basalt contains generally about ten per cent. more of oxyd of iron, and ten per cent. less of silica.

The *greater age* of the feldspathic rocks, (although it may be a general truth,) cannot be in itself an explanation. There is reason to believe that true scoria, or vesicular basaltic lavas, might have formed from subaerial eruptions in the earlier periods of our globe, as at present, if the same amount of feldspar and augite were present, the same degree of atmospheric pressure, and not so high a temperature of the air as to influence very decidedly the rate of cooling. This

* M. von Buch, in his account of Teneriffe, speaks of high cliffs of trachyte covered with basalt, and mentions also the occurrence of trachyte at the summit; and he concludes that the crater was originally trachytic, and more recently basaltic. Similar facts were observed at the Gran Canary. He speaks of an elevated peak of trachyte characterizing the different centres of volcanic action. M. von Buch also remarks that Teneriffe and Palma are in the same line trending west-northwest and east-southeast, and that this has determined the trachytic eruption, while Fuerteventura and Lancerote, as he states, have no trace of trachyte.

There are other cases, as at St. Helena, where feldspathic eruptions have taken place subsequent to basaltic, and flowed in streams; though the above represents the facts as they usually occur,—feldspar constituting the interior, and when in layers, forming the lower layers of the mountain.

remark is opposed to the assumptions of many writers on igneous rocks, yet appears to be founded in truth; for heat and pressure, and slowness of cooling, the requisite material being present, are the prominent influencing causes, determining the formation of particular minerals or rocks; and the existence of the constituents in the proper proportions, is shown in the many trap and hornblendic rocks of ancient date.

Moreover, these feldspathic rocks are apparently an essential part of the volcanic dome, during its whole progress, as they occur along the centre, often to the very summit. We have no grounds for supposing such an insertion of feldspar rocks after the dome was completed, and as little for imagining a feldspar peak (of fourteen thousand feet for Mount Loa), to have been first thrown up.* The only conclusion sustained by the facts is, that the main body of the mountain, and its feldspathic centre, were in cotemporaneous progress, at least as long as there were summit eruptions.

May there be a *separation of the basaltic material by gravity*, and thus feldspathic eruptions take place at summit, while the lateral are basaltic? This ingenious view is presented by Mr. Darwin. But if there were a simple subsiding of the ferruginous basalt, should we not sometimes find the phonolites graduating below into basalt, or becoming more ferruginous? But this is never the case, as far as facts are known.† It is, moreover, remarkable that in Kilauea, the scoria

* It has been frequently said that feldspathic lavas are not as liquid as the basaltic; and this assumption is made in order to account for a supposed swelling up of the molten rock into domes. It is true that perfect liquidity requires greater heat for the former than the latter: but what is there in the nature of things, or what reason of any kind, for this limited heat at all former periods? If it be considered that viscosity in the lavas of a vent, necessarily occasions scoria or cinder eruptions, provided waters gain access below, it will be obvious that the absence of such cinder eruptions is some evidence of unusual liquidity.

† Mr. Darwin supposes that the feldspar rises in the lava as feldspar crystals, and the augite sinks as crystals of augite. (Volc. Islands, p. 120.) But if any thing is in fusion, it is feldspar or augite, (supposing these to be the constituents of the lava,) and while in fusion there are no crystals, as crystallization is the first step in the process of solidification. If there is any sinking, therefore, it must be a sinking and separation of these materials in the fluid state; or, at least, this must be the case with the augite, which is the more fusible of the two minerals, and will be the case with both at certain depths, wherever the temperature is that of the fusion of feldspar. The impossibility of there being any crystals of feldspar, will farther appear from the fact that the material of clinkstone is generally without a distinct crystalline texture.

of the surface is mostly a silicate of iron, containing more iron than the rock below, and consequently of high specific gravity. The hypothesis does not appear to be satisfactory. Yet what better solution can be offered of this difficult problem? Trusting to the teachings of Kilauea, we proceed with such suggestions as have presented themselves.

We have stated that the lavas are made up of materials of different degrees of fusibility, as well as of unlike specific gravity: it is also a fact which will be admitted that the volcanic action is promoted by vaporizable substances within the fused mass—partly sulphur, from the material fused, and partly water, which is constantly finding access to the fires. These are the data for our conclusions.

1. The vaporizable substances tend to become vapours, and the greater their abundance, the more they inflate the lavas, lessening the specific gravity; this effect increases rapidly the nearer they approach to the summit of the column, where the pressure is constantly less, so that the lava finally is actually much expanded by them. This effect produces, as explained on page 204, a slow rising of the lavas about the central part of the conduit, towards the surface, and accompanying this action, a descending current along the sides, though of less distinctness. The ebullition at the surface is only the escape of these confined vapours. The large lake of Kilauea has the very motions here represented. Thus far, therefore, there is no hypothesis.

2. The material in fusion has been described as consisting of augite and feldspar, minerals of unequal fusibility.* Wherever the temperature of the liquid mass begins to be less than that necessary to retain the feldspar in fusion,† there the feldspar will commence to solidify, or will slowly stiffen in the midst of the fluid material made up of the other ingredients. In this state, the vapours ascending in the conduit, will urge upward the feldspar much less freely than the more liquid part of the lava; for the latter will yield more readily to the inflating vapours, and thus become lighter, and rise to the surface; and this process, going on constantly through the whole pro-

* Whether the mineral augite is decomposed at the heat which melts feldspar, and at that temperature its constituents are in fusion in some different combination, rather than as augite itself, we cannot say. Neither is it essential to the explanation if feldspar is the more infusible ingredient.

† The temperature of fusion, and that of solidification, do not appear to be identical in all minerals, as the temperature of the fluid mass may be carried some degrees below that required to commence fusion, before incipient solidification will appear.

gress of the cone, it will keep the centre feldspathic below a short distance from the summit; though not to so great a distance as to preclude the possibility of summit eruptions of feldspathic rock at certain periods of unusual convulsion or violent activity. In the boiling pools of Kilauea, the light frothy scoria is the more fusible part of the lava brought like a scum to the surface; at the same time, as stated, it is mostly a silicate of iron.* It is brought up because it is the most liquid part of the material, in the diminished heat near the surface. This is precisely a parallel case with that supposed in the great central vent, and we believe, therefore, that with such facts, we may again say we have thus far made no unwarranted assumption.

3. The return current of lavas, if such there be, must arise from the liquid flowing in, to some extent, on either side, to supply the place of the ascending current; and this action would imply the necessity of a descent of the lavas of the surface, such as appears to be witnessed in the great boiling lake of Kilauea. The more basaltic portions would, therefore, constitute this exterior descending part. Thus a feldspathic centre and basaltic flank eruptions are a result of one and the same process.

But it does not necessarily follow that the lavas of fissure eruptions have, in all instances, been thus derived. For they may proceed, to a great extent, from portions of the liquid lavas, away from the direct centre of the mountain, which have not experienced this separating process, inasmuch as lavas so situated would not undergo this separation, unless there was a chance for the vapours to ascend and escape, and thereby establish a current.

In conformity with these principles, we should find comparatively little chrysolite in the crater lavas of Kilauea, for the reason that this ferruginous magnesian silicate is a very difficultly fusible mineral. It does not fuse at all in the flame of the common blowpipe. It is a fact that although common in the scoria, it occurs on the whole but sparingly within the crater, compared with what is found in the results of some fissure ejections, (p. 204.) Thus the magnesia of the lava, or a large part of it, is engaged in combination and used up, as we may say, deep below. It may sometimes be wholly so, leaving

* This glassy scoria, the composition of which is given on p. 200, appears to be a silicate of iron, together with the elements of a portion of augite and soda feldspar. One variety, the dark, afforded a large proportion of soda (21 per cent.), while the other had nearly the composition of an iron augite.

none to form augite; and in other cases only part may be thus absorbed (this probably depending on the proportional amount of silica present, and the temperature*), the rest, at a higher elevation in the lava conduit, going to the formation of augite or some allied compound.

The various points in the problem appear to have been met and explained by reference to actual facts. The basaltic mountain with a feldspathic centre, and the different constitution of fissure and crater eruptions, are necessary results of the general laws of physics; and we are not compelled to suppose the feldspar interior to have been formed first or last. The whole is proved to be one single operation, governed by principles illustrated in the ordinary processes of the laboratory.

The production of syenite is but a consequence of the same facts. The feldspathic centre is enclosed within a thick covering of rocks, and will therefore cool slowly; and though generally forming only disseminated crystals of feldspar in an earthy base, the cooling is sometimes sufficiently gradual to allow of the whole crystallizing; and in this case, the texture throughout is crystalline, and the rock much resembles a granite. Under the same circumstances (or even a less gradual cooling) the elements of augite present will crystallize as hornblende: for these two minerals are identical except in crystallization; and this difference depends on temperature and rate of cooling, hornblende requiring the slower rate. Thus we have crystals of

* Chrysolite contains usually about 41 per cent. of silica, with 59 of magnesia and protoxyd of iron. Augite consists of about 54 per cent. of silica with 46 of magnesia, lime, and protoxyd of iron, the iron often amounting to 6 per cent., and sometimes to 10 or 12. The following are analyses of each.

	CHRY SOLITE.		AUGITE.	
	From Mount Somma.		From Etna.	From Vesuvius.
Silica, - - -	40.08	50.55	50.90	
Lime, - - -	" "	22.29	22.96	
Magnesia, - -	44.22	13.01	14.43	
Protoxyd of iron, -	15.26	7.96	6.25	
Protoxyd of manganese,	0.48	—	—	
Alumina, - - -	0.18	4.85	5.37	

The analysis of chrysolite is by Walmstedt, *K. Vet. Acad. Handl.*, 1824, ii. 359; the two of augite are by Kudernatsch, *Poggend. Ann.* xxxvii. 577.

The formation of chrysolite at all in a volcanic focus must therefore be determined by the presence of a large proportion of magnesia compared with the amount of silica; and also by the temperature and pressure. The conclusions in the text require to be farther tested by experiments on the crystallization of chrysolite.

hornblende which are common in trachytes; and when the feldspar also becomes crystalline, the two together produce the syenitic rock we have described, specimens of which were obtained at Tahiti. The same remarks will also apply to mica, another of the minerals occasionally occurring in trachytes, and met with by the writer in an extinct volcano on the Sacramento, in Northern California.

The same cause which makes the feldspar centre of the volcanic mountain, will also cause to be detained within the feldspar (perhaps at considerable depths) the excess of quartz not in combination; for this mineral, like chrysolite, is of very difficult fusibility. Hence trachytes are often quite silicious. Hence, too, all the elements of true granite may occur within a volcanic focus, and as the fires die out and solidification takes place with extreme slowness, granite itself might form, and any of the common granitic minerals whose elements are present in the requisite proportions.

Thus we arrive at the same statement with which we commenced—that particular rocks have no necessary relation to time on our globe, except so far as time is connected with a difference in the earth's temperature or climate, and also in oceanic or atmospheric pressure: for if the elements are at hand, it requires only different circumstances as regards pressure, heat, and slowness of cooling, to form any igneous rock the world contains. The granite-like fragments thrown out from Vesuvius, consisting of glassy feldspar, mica, hornblende, spinel and other minerals, illustrate these principles. They show that there has been slow cooling for a long period in some part of this crater, producing crystalline rocks, fragments of which later action has ejected.

The fact that granites on our globe sometimes form a collection of summits with hornblende rocks surrounding in part the region, suggests a strong analogy to the trachytes with a circumference of basalts;* and temperature will account for the difference. The size of these granitic regions will not be made an objection after the views and facts which have been presented. This analogy, however, should be cautiously applied.

The occurrence of hornblendic and basaltic dikes so commonly over the globe, and pertaining to all periods, accords with this system of igneous operations. For like the dikes of a volcano, they come from a region where the separating process has not been in action. Such dikes, however, may often be feldspathic, since feldspathic

* See Remarks by the author in the American Journal of Science, xlv. 125.

ingredients may exist in places below, where there is not the iron and magnesia necessary to augite and hornblende.

III. ORIGIN OF THE VALLEYS AND RIDGES OF THE PACIFIC ISLANDS.

The general characters of the valleys of the Pacific islands have been particularly noticed in our remarks upon the several groups. It is, therefore, only necessary in this place to present briefly a systematic view of the facts, preparatory to our consideration of the causes from which they have resulted.

The valleys have usually a course from the interior of the island towards the shores; or when the island consists of two or more distinct summits or systems of heights (like Maui) they extend nearly radiately from the centre of each division of the island. They are of three kinds:

I. A narrow gorge, with barely a pathway for a frisky streamlet at bottom, the enclosing sides diverging upward at an angle of thirty to sixty degrees. They have a rapid descent, and are bounded by declivities from one hundred to two thousand feet or more in elevation, which are covered with vegetation though striped nearly horizontally by parallel lines of black rock. There are frequent cascades along their course; and at head, they often abut against the sides of the central inaccessible heights of the island. The streamlet frequently has its source in one or more thready cascades, that make an unbroken descent of one or two thousand feet down the precipitous yet verdant walls of the amphitheatre around.

II. A narrow gorge, having the walls vertical or nearly so, and a flat strip of land at bottom more or less uneven, with a streamlet sporting along, first on this side, and then on that, now in rapids, and now with smoother and deeper waters. The walls may be from one hundred to one thousand feet or more in height; they are richly overgrown, yet the rocks are often exposed, though every where more than half concealed by the green drapery.

These gorges vary in character according to their position on the island. Where they cut through the lower plains, (as the dividing plain of Oahu,) they are deep channels with a somewhat even character to the nearly vertical walls, and an open riband of land at bottom. The depth is from one to three hundred feet, and the breadth as many yards. Farther towards the interior, where the mountain slopes and vegetation have begun, the walls are deeply fluted or fur-

rowed, as already described, the verdure is more varied and abundant, and cascades are numerous.

This second kind of gorge, still farther towards the interior, changes in character, and becomes a gorge of the first kind, narrowing at bottom to a torrent's course, along which are occasional precipices which only a torrent could descend.

III. A wide valley leading towards the interior, with a very broad open area at bottom usually covered with vegetation, and enclosed by precipitous heights, exemplifies the *third* kind. They sometimes abut at head against vertical walls, but oftener terminate in a wide break in the mountains.

The ridges of land which intervene between the valleys are flat table land, or only undulated where these valleys intersect the lower plains or slopes; but in the mountains, they are narrow at top, and sometimes scarcely passable along their knife-edge summits. Some of them extend inward, becoming narrower as we proceed, and terminate in a thin wall, which runs up to the central peaks. Others stop short of these central peaks, and the valleys either side consequently coalesce at their head, or are separated only by a low wall, into which the before lofty ridge had dwindled. The crest is often jagged, or rises in sharp serratures.

The main valleys, which we have more particularly alluded to above, have their subordinate branches; and so the ridges, in necessary correspondence, have their subordinate spurs.

Tahiti, with its ridges, peaks, and valleys, is a good illustration of the features here described; and a brief consideration of the foregoing remarks, (in connexion with the account on page 286 and beyond,) will enable the reader to conceive perfectly of this skeleton island.

The causes operating in the Pacific, which have contributed to valley-making, are the following:

1. Convulsions from internal forces, or volcanic action.
2. Degradation from the action of the sea.
3. Gradual wear from running water derived from the rains.
4. Gradual decomposition through the agency of the elements and growing vegetation.

The *action of volcanic forces* in the formation of valleys, is finely illustrated in the great rupture in the summit of Hale-a-kala (Kauai). The valleys formed by the eruption are as extensive as any in the Hawaiian Group, being two thousand feet deep at their highest part, and one to two miles wide. They extend from the interior outward

towards the sea. Above they open into a common amphitheatre, the remains of the former crater, the walls of which are two thousand feet high.

Other examples of volcanic action are seen in the pit craters of Mount Loa, among which Kilauea stands pre-eminent. This great corral, if we may use a foreign word, is a thousand feet deep, one to two miles wide, and over three long, so that it forms a cavity which may compare advantageously with many large valleys; and were the walls on one side to be removed, it would become the head of a valley like that of Hale-a-kala on Maui.

As an example of this kind of valley upon islands which have lost their original volcanic form, we venture to refer to the wide Nuuanu, back of Honolulu, (island of Oahu,) which has at its head on either side a peak rising above it to a height of two thousand four hundred feet, or four thousand feet above the sea.

The immense amphitheatre to the west of the lofty Orohena and Aorai, on the island of Tahiti, is remarkable for its great breadth, and the towering summits which overhang it; and if not a parallel case to that of Maui, that is, if the head was not originally the great crater, there must have been a subsidence or removal of a large tract by internal causes.

The precipice of the eastern mountain of Oahu, is another example of the effect of convulsion in altering the features of islands, causing either a removal or subsidence.

The many fissures which are opened by the action of Kilauea, might be looked upon as valleys on a smaller scale, and the germs of more extensive ones. But with few exceptions, these fissures as soon as made are closed by the ejected lava, and the mountain is here no weaker than before. Those which remain open, may be the means of determining the direction of valleys afterwards formed.

Action of the Sea.—The action of the sea in valley-making is often supposed to have been exerted during the rising of land; and as such changes of level have taken place in the Pacific, this cause, it would seem, must have had as extensive operation in this ocean as any where over the world, especially as the lands are small and encircled by the sea, and there is, therefore, a large amount of coast exposed, in proportion to the whole area.

But in order to apprehend the full effect of this mode of degradation, we should refer to its action on existing shores.* At the outset

* See also De La Beche's Geological Researches, page 192.

we are surprised at finding little evidence of any such action now in progress along lines of coast. The islands and the shores of continents have occasional bays, but none that are deepening by the action of the sea. The waves tend rather to fill up the bays and remove by degradation the prominent capes, thus rendering the coast more even, and at the same time, accumulating beaches that protect it from wear. If this is the case on shores where there are deep bays, what should it be on submarine slopes successively becoming the shores, in which the surface is quite even compared with the present outline of the islands? Instead of making bays and channels, it could only give greater regularity to the line of coast.

Upon our own American coast, from Long Island to Florida, there are no valleys in progress from the action of the sea; on the contrary, we ascertain by soundings that the bottom is singularly even; and the bays, as that of New York, are so acted upon by the sea, that were it not, in the case mentioned, for the action of the current of the Hudson River, its limits would continue gradually to contract. Around Tahiti there are no submarine valleys. The valleys of the land are often two thousand feet deep; but they die out towards the shores. Thus over the world, scarcely an instance of valley-making from the action of the sea, can be pointed out. During the slow rise of a country, the condition would be no more favourable for this effect than in a time of perfect quiet. If America were to be elevated, would the action make valleys in the shores just referred to? If England were slowly to rise, would this favour the scooping of valleys through its beaches? would not beach formations continue to be the legitimate production of the sea along its line of wave action; and where the rocks should favour the opening of a deep cove, would not the same action go on as now, causing a wear of the headlands and a filling up of the cove at its head? Were Tahiti now to continue rising, could the waves make valleys on the coast? The increasing height of the mountains would give the streams of the land greater eroding force, and more copious waters; but the levelling waves would continue to act as at the present time. The effects of the sea in making valleys have been much exaggerated, as is obvious from this appeal to existing operations, the appropriate test of truth in geology.

The action of a rush of waters in a few great waves over the land, such as might attend a convulsive elevation, though generally having a levelling effect, might it is true produce some excavations; yet, it

is obvious on a moment's consideration, that such waves could not make the deep valleys, miles in length, that intersect the rocks and mountains of our globe.

But it is supposed that there may be fissures about volcanic islands in which the sea could ply its force. Yet even in these cases, unless the fissures were large, the seashore accumulations would be most likely to fill and obstruct them. To try this hypothesis by facts, we remark that there are no such shore fissures around Mount Loa, nor any of the other Hawaiian Islands. The fissures formed by volcanic action immediately about a volcano, are generally filled at once with lavas as we have stated, and the vent is mended by the force which made it. It is, therefore, a gratuitous assumption that such fissures have been common. The existence, however, of large valleys such as have been attributed above to convulsions cannot be doubted; but the sea would exert its power in such places, nearly as now in Fangaloo Bay, Tutuila, and other bays in continents;—a beach forms, and a shore plain, and afterwards there is little action from the sea in these confined areas of water.

In the Illiwarra district, New South Wales, there are several places where dikes of basalt have been removed by the sea, and channels one hundred yards in length, of the width of the dike (six feet), now exist, cutting straight into the rocky land. This is an example of the action of the sea where everything is most favourable for it. And we observe that there is little resemblance in this narrow channel with but a trifling wear of the inclosing rocks, to the valleys which are to be accounted for in the Pacific; and little authority to be derived from it for attributing much efficiency to the sea in wearing out valleys. The reason of this is apparent in the fact that the sea rolls up the coast in great swells, and cannot parcel itself off, and act like a set of gouges: this latter effect it leaves for the streams and streamlets of the shores, which are gouges of all dimensions.

Although the sea can accomplish little along coasts towards excavating valleys, yet when the land is wholly submerged, or only the mountain summits peer out as islands, the great oceanic currents sweeping over the surface and through channels between the islands, would wear away the rocks or earth beneath. From the breadth and character of such marine sweepings, we learn that the excavations formed will be very broad rounded valleys; and their courses would correspond in some degree with the probable direction which the currents of the ocean would have over the region in case of a submergence. The direction of the Gulf Stream and that of the North Polar

current of the Atlantic indicate the course of the flow of waters over the eastern part of North America, were the land under the sea, excepting such deviations as the form of the land then above the water might produce. It is obvious that the valleys of the Pacific islands have nothing in their features attributable to such a cause.

Running water of the land, and gradual decomposition.—Of the causes of valleys mentioned in the outset we are forced to rely for explanations principally upon running streams: and they are not only gouges of all dimensions, but of great power, and in constant action. There are several classes of facts which support us in this conclusion.

a. We observe that Mount Loa, whose sides are still flooded with lavas at intervals, has but one or two streamlets over all its slopes, and the surface has none of the deep valleys common about other summits. Here volcanic action has had a smoothing effect, and by its continuation to this time, the waters have had scarcely a chance to make a beginning in denudation.

Mount Kea, which has been extinct for a long period, has a succession of valleys on its windward or rainy side, which are several hundred feet deep at the coast and gradually diminish upward, extending in general about half or two-thirds of the way to the summit. But to westward it has dry declivities, which are comparatively even at base, with little running water. A direct connexion is thus evinced between a windward exposure, and the existence of valleys: and we observe also that the time since volcanic action ceased is approximately or relatively indicated, for it has been long enough for the valleys to have advanced only part way to the summit. Degradation from running water would of course commence at the foot of the mountain, where the waters are necessarily more abundant and more powerful in denuding action, in consequence of their gradual accumulation on their descent.

Hale-a-kala or Maui offers the same facts as Mount Kea, indicating the same relation between the features of the surface and the climate of the different sides of the island. On Eastern Oahu the valleys are much more extensive; yet still the slopes of the original mountain may be in part distinguished. And thus we are gradually led to Kauai, where the valleys are very profound and the former slopes can hardly be made out. The facts are so progressive in character, that we must attribute all equally to the running waters of the land. The valleys of Mount Kea alone, extending some thousands of feet up its sides, sustain us in saying that time only is required for ex-

plaining the existence of any similar valleys in the Pacific. As in Tahiti, these valleys in general radiate from the centre, that is, take the direction of the former slopes; they often commence under the central summits, and *terminate at the sea level, instead of continuing beneath it.*

The fluting of the walls of the Hanapepe Valley, a thousand feet or more in height, has been described on page 263. It cannot be doubted here that water was the agent; for the rills are still at work. The contrast between the same valley near the sea, and in the mountains, (the walls in the former case being nearly unworn vertically,) is explained on the same principle: for the mountains are a region of frequent rains and almost constant clouds, and therefore abound in streams and streamlets and threads of water; while below, there are grassy plains instead of forest declivities, and but little rain. These furrowings vary from a few yards in width and depth to many furlongs.

The precipice of Eastern Oahu, (page 236,) is an excellent place for studying farther this action. It is fluted in the same style as the Hanapepe Valley. In the distant view the vertical channels appear very narrow; but when closely examined they are found to be deep and often winding passages. The precipice faces to the windward, and is directly under the whole line of peaks in the mountain range; both of which facts account for an abundance of water. Going to the westward along the range, the precipice changes to a sloping declivity, and these passages become deeper and longer, and more winding, just in proportion to the increasing length of the slopes. Moreover, at the same time they decrease in number. Where there is no slope to collect the waters the rills act independently, and their furrowings like themselves are small, narrow, and numerous; but as the declivity becomes gradual, the rills flow on and collect into larger streams, and the furrowings become deeper and more distant. Over this region, no distinction can be drawn as regards origin between the flutings and gorges: and in respect to features, only this difference appears, that the size of the excavations is less and the number greater, the steeper the declivity. If a fissure be appealed to as the commencement of the longer valleys, it should also be admitted for each of the flutings. But this idea is wholly inadmissible.

A brief review of the action and results of flowing waters will render the origin of these features intelligible.

a. Suppose a mountain, sloping like one of the volcanic domes of the Pacific. The excavating power at work proceeds from the rains or condensed vapour, and depends upon the amount of water and rapidity of slope.

b. The transporting force of flowing water* increases as the sixth power of the velocity,—double the velocity giving sixty-four times the transporting power. The rate will be much greater than this on a descending slope, where the waters add their own gravity to the direct action of a progressive movement.

c. Hence, if the slopes are steep, the water gathering into rills, excavates so rapidly that every growing streamlet ploughs out a gorge or furrow; and consequently the number of separate gorges is very large, and their sizes comparatively small, though of great depth.

d. But if the slopes are gradual, the rills flow into one another from a broad area, and enlarge a central trunk, which with incessant additions from either side, descends towards the sea. The excavation above, for a while, is small: the greater abundance of water below, during the rainy seasons, causes the denudation to be greatest there, and in this part the gorge or valley most rapidly forms. In its progress, it enlarges from below upward, though also increasing above, while at the same time the many tributaries are making lateral branches.

e. Towards the foot of the mountain, the excavating power gradually ceases when the stream has no longer in this part a rapid descent,—that is, whenever the slope is not above a few feet to the mile. The stream *then consists of two parts, the torrent of the mountains and the slower waters below*, and the latter is gradually lengthening at the expense of the former.

f. After the lower waters have nearly ceased excavation, a new process commences in this part,—that of widening the valley. The stream which here effects little change at low water, is flooded in

* It has been shown by Mr. W. Hopkins that the moving force of running water, (this force being estimated by the volume or weight of a mass of any given form which it is just capable of moving,) varies as the *sixth* power of the velocity. He says “if a stream of ten miles an hour would just move a block of five tons weight, a current of fifteen miles an hour would move a block of similar form upwards of fifty-five tons; a current of twenty miles an hour would, according to the same law, move a block of three hundred and twenty tons: again, according to the same law, a current of two miles an hour would move a pebble of similar form of only a few ounces in weight.”—*On the Transport of Erratic Blocks*, Trans. Camb. Phil. Soc. viii. 1844, p. 221, 233.

certain seasons, and the abundant waters act *laterally* against the inclosing rocks. Gradually, through this undermining and denuding operation, the *narrow bed becomes a flat strip of land between lofty precipices*, through which, in the rainy seasons, the streamlet flows in a winding course. The streamlet, after the flat bottom of the valley is made, deposits detritus on its banks, which in some places so accumulates as to prevent an overflow of the banks by any ordinary freshet. Such is the origin of the deep channels with a riband of land at bottom that cut through the "dividing plain" of Oahu, and which are common towards the shores of many of the Pacific islands.

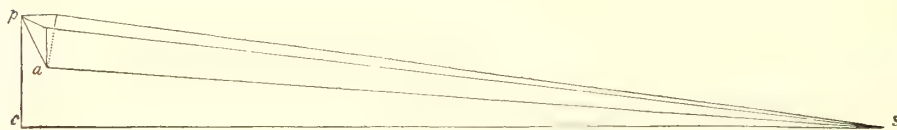
g. The torrent part of the stream, as it goes on excavating, is gradually becoming more and more steep. The rock-material operated upon, consists of layers of unequal hardness, varying but little from horizontality and dipping towards the sea, and this occasions the formation of cascades. Whenever a softer layer wears more rapidly than one above, it causes an abrupt fall in the stream: it may be at first but a few feet in height; but the process begun, it goes on with accumulating power. The descending waters in this spot add their whole weight, as well as a greatly increased velocity, to their ordinary force, and the excavation below goes on rapidly, removing even the harder layers. The consequences are, a fall of increasing height, and a basin-like excavation directly beneath the fall. Often, for a short distance below, the stream moves quietly before rushing again on its torrent course; and when this result is attained by the action, the height of the fall has nearly reached its limit as far as excavation below is concerned, though it may continue to increase from the gradual wear and removal of the rocks over which it descends.

h. As the gorge increases in steepness, the excavations above deepen rapidly,—the more rapid descent more than compensating, it may be, for any difference in the amount of water. Moreover, as the rains are generally most frequent at the very summits, the rills in this part are kept in almost constant action through the year, while a few miles nearer the sea they are often dried up or absorbed among the cavernous rocks. The denudation is consequently at all times great about the higher parts of the valley, (especially after the slopes have become steep by previous degradation,) and finally an abrupt precipice forms its head.

i. The waters descending the ridges either side of the valley or gorge, are also removing these barriers between adjacent valleys, and are producing as a *first* effect, a thinning of the ridge at summit to a

mere edge; and as a *second*, its partial or entire removal, so that the two valleys may become separated by a low wall, or terminate in a common head,—a wide amphitheatre enclosed by lofty mountain walls. In one case the ridge between two valleys begins at the shores of the island with rather a broad back, and high up, in the regions of mists and frequent rains, becomes a narrow wall, and thus connects with the central summit. In the second, the ridge finally terminates quite abruptly, leaving a deep valley separating it from the main mountain.

The following sketch may assist the mind in conceiving of the action upon the Pacific mountains. It represents one of the valleys



of Tahiti from the centre to the shore, excepting its irregularities of direction and descent, and the uneven character of its walls, arising from lateral valleys and minor denudations. The height of Tahiti is about eight thousand feet; its radius cs is ten geographical miles. The head of the valley at a is three thousand feet below the summit peak, p . The descent, from a to s , averages five hundred feet to the mile. If a be four thousand feet below the summit, (the exact depth was not ascertained,) it would still give four hundred feet to the mile.

This subject is beautifully illustrated in some of the tufa cones of Oahu, where, on a smaller scale, we have the same kind of gorges and valleys, (see figure, page 240;) and there is no doubt that denudation was the cause by which they were produced. The valleys have the direction of the slope, and are similar in form and winding character to those of the mountains. The intervening ridges are also similar: many of them become very thin at summit as they rise towards the crest of the volcanic cone, and others have this upper part adjoining the crest wanting, owing to the extent of the degradation, so that two valleys have a common head against the vertical bluff. A better model of the mountain gorges could hardly be made, and it stands near by convenient for comparison.

We need add little, in this place, on the capabilities of running water, after the statement, based on mathematics, that the transporting force varies as the sixth power of the velocity. If we remember that these mountain streams at times increase their violence a million fold

when the rains swell the waters to a flood, all incredulity on this point must be removed.

A few thousand feet in depth, even in the solid rocks, is no great affair for an agent of such ceaseless activity, during the periods which have elapsed since the lands became exposed to their influence. And when we take into view the lofty heights of the Pacific islands, their rapid declivities giving speed to the waters and transported stones and earth, we must admit that of all lands, these are especially fitted for denudation by torrents.

The nature of the rocks also favours wear and removal. They are in successive layers, soft conglomerates or tufas frequently alternating with the harder basalt. Moreover, the rocks are commonly much fissured, owing to a tendency to a columnar structure; besides, they are often cellular. The waters thus find admission, promoting decomposition and also degradation. There are, also, frequent caverns between layers, which contribute to the same end.

There is every thing favourable for degradation which can exist in a land of perpetual sunshine: and there is a full balance against the frosts of colder regions in the exuberance of vegetable life, since it occasions rapid decomposition of the surface, covering even the face of a precipice with a thick layer of altered rock, and with spots of soil wherever there is a chink or shelf for its lodgment. The traveller ascending a valley on one of these islands on a summer day, when the streams are reduced to a mere creeping rill which half the time burrows out of sight, seeing the rich foliage around, vines and flowers in profusion covering the declivities and festooning the trees, and observing scarcely a bare rock or stone, excepting a few it may be along the bottom of the gorge, might naturally inquire with some degree of wonder, where are the mighty agents which have channeled the lofty mountains to their base? But though silent, the agents are still on every side at work: decomposition is in slow, but constant progress; the percolating waters are acting internally, if not at the surface. Moreover, at another season, he would find the scene changed to one of noisy waters, careering along over rocks and plunging down heights with frightful velocity; and then the power of the stream would not be disputed.*

* The rise of the streams is often so rapid, from the rains of the mountains, that in some instances, the native villages of the coast become flooded, before they have time even to remove their property.—*Miss. Herald*, xxiii. 207.

Mr. Coan, who has often traversed the coast of Hawaii, north of Hilo, and during the

But if the waters have been thus efficient in causing denudation and opening valleys, may not fissures or dikes have determined their courses? The only test of truth, an appeal to facts, may answer the question. Mount Loa is a mountain yet unchanged. It has its dikes in great numbers: but over these dikes the country is more apt to be raised a little from the overflow of lavas than depressed, and this would turn off the water. Again, we see no instances of dikes yielding, and offering a course for a stream. As to unfilled fissures, there are few of them, and these, with rare exceptions, are immediately about the active vents. Is either supposition sustained by the facts presented? We know the tendency of water to take the lowest parts of a surface, and will it not follow these parts, whether or not there be a dike or fissure? It is obvious that whatever ravines or depressions the floods of lava may have left, would be the courses of the waters; and these depressions would be followed to the sea, and ultimately become valleys. We may hence conclude that the waters would not wait till there was a convenient fissure; they would go where *inclination* led, and make valleys with little difficulty, if there were no guiding or aiding fissures. Were the dikes filled by a rock more decomposable than those enclosing it, or more easily worn away, as is the case in some granitic regions, we should expect that they would frequently become water courses: but this is seldom the case in the Pacific islands.

The valleys in some of the Canary Islands, extend from the shores

drier seasons, (which, however, are of short duration on this, the windward coast,) fords the shallow streams without difficulty, gives the following account of his journey during a time of rains. "Great and continued rains fell during my absence, and the numerous rivers became so swollen and furious that the very sight of them was fearful. These raging streams crossed my path about once in half a mile for a distance of about thirty miles, and I was compelled to pass them to return home. Most of them run at a rate of twenty or thirty miles an hour, and in their course there are numerous cataracts from ten to a hundred and fifty feet in perpendicular descent. Though the torrents were so fearful as to make one almost quail at the thought of struggling with their fury, ropes were provided, and several men employed for the adventurous task. Great calmness and presence of mind, and great energy and muscular effort, were required to retain one's grasp of the rope, and buffet with the foaming flood. We at last succeeded, though at imminent peril. At one of the rivers, we spent three hours in finding a place where we might, with any degree of safety, extend our hawser across, and transfer our party to the opposite bank. The streams are at the bottom of narrow ravines, with the banks exceedingly precipitous, and often perpendicular bluffs of basaltic rock."—*Miss. Herald*, xxxviii. 157.

part way to the summit, as on Mount Kea and Hale-a-kala, and evidently for the reason already explained. We can detect in regions of a similar kind, no evidence that the valleys have depended for their origin on the mountain's being a "crater of elevation," as von Buch urges.* The regular stratification of the sides of these valleys; the absence of all tiltings; their situation, as related to the rains, and the absence of fissures ready for making valleys on the leeward declivities, are points which favour no such theory: and, moreover, it is a wholly unnecessary hypothesis.

Conclusion.—Between convulsions from subterranean forces, and degradation from waters supplied by the rains and attending decomposition, the lofty volcanic dome with its even surface may be changed to a skeleton island like Tahiti. We have referred to Mount Loa as still unfurrowed; to Mount Kea and Hale-a-kala as having only the lower slopes deeply channelled with narrow gorges; and to other islands, as exemplifying all gradations in these effects, to those in which the original features are no longer to be traced: we have pointed out the difference in the windward and leeward slopes, and have shown a relation between the quantity of rain and the amount of degradation: we have exhibited a model of the mountains, an undeniable result of denudation, placed at their very base, as if for illustration:—and thus we have traced out and elucidated all the steps in the valley-making process, and have also shown how they are a necessary result from the action of running water. At the same time we have explained the fact that although the sea levels a coast, it makes no valleys.

Again, results of convulsions and igneous forces have been pointed to, in the great gorge of Hale-a-kala; in Kilauea and other Hawaiian craters; in the mountain wall of Oahu, and similar scenes on other islands; in the wide amphitheatre of central Tahiti: and the importance of this means of change has thus been exhibited. Yet it has been observed that few such changes are apparent on any one island, and these are marked by decided characters not often to be mistaken. Fissures made by the same cause, may in some cases have given the direction to valleys, though they are by no means necessary in order that valleys should commence to form.

With literal truth may we speak of the valleys of the Pacific islands, as the furrowings of time, and read in them marks of age. Our former conclusions with regard to the different periods which

* See Iles Canaries, p. 285.

have passed over the several Hawaiian Islands since the fires ceased and wear begun, is fully substantiated. We also learn how completely the features of an island may be obliterated by this simple process, and even a cluster of peaks like Orohena, Pitohiti and Aorai of Tahiti, be derived from a simple volcanic dome or cone. Mount Loa, alone, contains within itself the material from which an island like Tahiti might be modelled, that should have near twice its height and four times the geographical extent.

IV. CHANGES OF LEVEL IN THE PACIFIC OCEAN.

We have learned from recent investigations that the continents have undergone extensive changes of level, wide seas with only here and there an island occupying their place at some former eras. Even as late as the tertiary period, it is believed that a large part of the continents emerged from the waters. It is an inquiry of interest, therefore, whether the oceans and the land beneath have not participated in such changes; or whether, while all other lands were in constant change of level, the Pacific islands alone have stood firm, unmoved and immovable. This question is not to be answered by a guess or assertion. Those who may be unacquainted with geological reasoning, will note that it is as much an assumption to affirm that changes have not taken place, as that they have; and the analogies suggested will sustain us in saying that the former is the more unreasonable, the more "absurd" affirmation of the two.

Evidences of change of level are to be looked for in the height or condition of the coral reef formations or deposits; in the character of the igneous rocks; and in the features of the surface. The points of evidence are as follows:—

A. *Evidences of Elevation.*

1. *Patches of coral reef, or deposits of shells and sand from the reefs, above the level where they are at present forming.*

The coral reef rock has been shown occasionally to increase by growth of coral, to a height of four to six inches above low tide level when the tide is but three feet, and to twice this height with a tide of six feet. It may, therefore, be stated as a general fact that the height to which coral *may* grow above ordinary low tide, is about one-sixth the height of the tide, though it seldom attains this height.

Beach accumulations of large masses seldom exceed *eight* feet above high tide, and the finer fragments and sand may raise the deposit to ten feet. But with the wind and waves combined, or on prominent points where these agents may act from opposite directions, such accumulations may be *thirty* to *forty* feet in height. These are drift deposits, finely laminated, generally with a sandy texture, and commonly without a distinguishable fragment of coral or shell; and in most of these particulars they are distinct from reef rocks, (pp. 45, 64.)

2. *Sedimentary deposits, or layers of rolled stones interstratified among the igneous layers.*

3. *Compactness of the igneous rocks.* The great uncertainty of this evidence has been shown in the preceding chapter.

B. *Evidences of Subsidence.*

1. *The existence of wide and deep channels between an island and any of its coral reefs; or in other words, the existence of barrier reefs.*

2. *Lagoon islands or atolls.*

3. *Submerged atolls.*

4. *Deep bay-indentations in coasts as the terminations of valleys.*—In the remarks upon the valleys of the Pacific islands, it has been shown that they were formed in general by the waters of the land, unaided by the sea; that the sea tends only to level off the coast, or give it an even outline. When, therefore, we find the several valleys continued on beneath the sea, and their enclosing ridges standing out in long narrow points, there is reason to suspect that the island has subsided after the formation of its valleys. For such an island as Tahiti could not subside even a few scores of feet without changing the even outline into one of deep coves or bays, the ridges projecting out to sea on every side, like the spread legs of a spider. The absence of such coves, on the contrary, is evidence that any subsidence which has taken place, has been comparatively small in amount.

5. *Seashore alluvial flats or deposits.*

6. *The lava surface of a volcanic island, sloping without interruption beneath the water, instead of terminating in a shore cliff of a hundred feet or so.*

C. *Probable Evidence of Subsidence now in Progress.*

1. *An atoll reef without green islets, or with but few small spots of verdure.*—The accumulation requisite to keep the reef at the surface-level, during a slow subsidence, renders it impossible for the reef to rise above the waves unless the subsidence is extremely slow.

From the above review of evidences of change of level, it appears that where there are no *barrier* reefs, and only fringing reefs, the corals afford no evidence of subsidence. But it does not follow that the existence of only fringing reefs, or of no reefs at all, is proof *against* a subsidence having taken place. For we have elsewhere shown, (p. 134,) that through volcanic action, and, at times, other causes, corals may not have begun to grow till a recent period, and, therefore, we learn nothing from them as to what previously may have taken place. While, therefore, a distant barrier is evidence of change of level, we can draw no conclusion either one way or the other, as is done by Darwin, from the fact that the reefs are small or wholly wanting, until the possible operation of the several causes limiting their distribution has been duly considered.

The influence of volcanoes in preventing the growth of zoophytes, extends only so far as the submarine action may heat the water, and it may, therefore, be confined within a few miles of a volcanic island, or to certain parts only of its shores.

There are three epochs of changes in elevation which may be distinguished and separately considered. 1. The subsidence indicated by atolls and barrier reefs. 2. Elevations during more recent periods, and also during the same epoch of subsidence. 3. Changes of level anterior to the atoll subsidence and the growth of recent corals.

1. SUBSIDENCE INDICATED BY ATOLLS AND BARRIER REEFS.

In a survey of the ocean the eye at once observes its numerous atolls, and sees in each, literally as well as poetically, a coral urn upon a rocky island that has sunk beneath the waves. Through the equatorial latitudes, such marks of subsidence abound, from the Eastern Paumotu to the Western Carolines, a distance of about six thousand geographical miles. In the Paumotu Archipelago there are about eighty of these atolls. Going westward, a little to the north of west, they are found to dot the ocean at intervals, as our map is dotted with green; and at the Tarawan Group, the Carolines commence, in which are seventy or eighty atolls.

If a line be drawn from Pitcairn's Island, the southernmost of the Paumotus, by the Gambier Group, the north of the Society Group,

Samoa, and the Salomon Islands to the Pelews, it will form nearly a straight boundary trending N. 70° W., between the atolls and the high islands of the Pacific, the former lying to the north of the line, and the latter to the south.

Between this boundary line and the Hawaiian Islands, an area nearly two thousand miles wide and six thousand long, there are two hundred and four islands, of which *only three are high* exclusive of the eight Marquesas. These three are Ualan, Banabe (Ascension or Pounypet) and Hogoleu, all in the Caroline Archipelago. South of the same line, within three degrees of it, there is an occasional atoll; but beyond this distance, there are none excepting the few in the Friendly Group, and one or two in the Feejees. The colouring of the map indicates their positions.

If each coral island scattered over this wide area indicates a subsidence of an island, we may believe that the subsidence was general throughout the area. Moreover, each atoll, could we measure the thickness of the coral constituting it, would inform us nearly of the extent of the subsidence where it stands; for they are actually so many registers placed over the ocean, marking out not only the site of a buried island, but also the depth at which it lies covered. We have not the means of applying the evidence; but there are facts at hand, which may give at least comparative results.

a. We observe, *first*, that barrier reefs are in general evidence of less subsidence than atoll reefs, (p. 130.) Consequently, the great preponderance of the former just below the southern boundary line of the coral island area, and farther south the entire absence of atolls while atolls prevail so universally north of this line, are evidence of little depression just below the line; of less farther south; and of the greatest amount, north of the line or over the coral area.

b. The subsidence producing an atoll, when continued, gradually reduces its size, and finally it becomes so small that the lagoon is obliterated; and consequently a prevalence of these small islands is presumptive evidence of the greater subsidence. We observe, in application of this principle, that the coral islands about the equator, five or ten degrees south, between the Paumotus and the Tarawan Islands, are the smallest of the ocean: several of them are without lagoons, and some not a mile in diameter. At the same time, in the Paumotus, and among the Tarawan and Marshall Islands, there are atolls twenty to fifty miles in length, and rarely one less than three miles. It is probable, therefore, that the subsidence indi-

cated was greatest at some distance north of the boundary line, over the region of small equatorial islands, between the meridian of 150° W. and 180° .

c. When, after thus reducing the size of the atoll, the subsidence continues its progress, or when it is too rapid for the growing reef, it finally sinks the coral island, which, therefore, disappears from the ocean. Now it is a remarkable fact that while the islands about the equator above alluded to indicate greater subsidence than farther south, north of these islands, that is, between them and the Hawaiian Group, there is a wide blank of ocean without an island, which is near twenty degrees in breadth. This area lies between the Hawaiian, the Fanning and the Marshall Islands, and stretches off between the first and last of these groups, far to the northwest.

Is it not then a legitimate conclusion that the subsidence which was least to the south beyond the boundary line, and increased northward, was still greater or more rapid over this open area; that the subsidence which reduced the size of the islands about the equator to mere patches of reef, was farther continued, and caused the total disappearance of islands that once existed over this part of the ocean?

d. That the subsidence gradually diminished southwestwardly from some point of greatest depression situated to the northward and eastward, is apparent from the Feejee Group alone. Its northeast portion, as the chart shows, consists of immense barriers, with barely a single point of rock remaining of the submerged land; while in the west and southwest there are basaltic islands of great magnitude. Again, along to the north side of the Vanikoro Group, the Salomon Islands, and New Ireland, there are coral atolls, although scarcely one to the south.

In view of this combination of evidence, we cannot doubt that the subsidence increased from the south to the northward or northeastward, and was greatest between the Samoan and Hawaiian Islands near the centre of the area destitute of islands, about longitude 170° to 175° W. and 8° to 10° N.

But we may derive some additional knowledge respecting this area of subsidence from other facts.

Hawaiian Range.—We observe that the western islands in the Hawaiian range, beyond Bird Island, are coral islands, and all indicate some participation in this subsidence. To the eastward in the range, Kauai and Oahu have only fringing reefs, yet in some places these reefs are half a mile to three-fourths in width. They indicate a

long period since they begun to grow, which is borne out by the features of Kauai showing a long respite from volcanic action. We consequently detect proof of but little subsidence of the islands. Moreover, there are no deep bays; and, besides, Kauai has a gently sloping coast plain of great extent, with a steep shore acclivity of one to three hundred feet, all tending to prove the smallness of the subsidence. We should, therefore, conclude that these islands lie near the limits of the subsiding area, and that the change of level was greatest at the western extremity of the range.

Marquesas.—The Marquesas are remarkable for their abrupt shores, often inaccessible cliffs, and deep bays. The absence of gentle slopes along the shores, their angular features, abrupt soundings close alongside the islands, and deep bays, all bear evidence of subsidence to some extent; for their features are very similar to those which Kauai or Tahiti would present if buried half their height in the sea, so as to leave only the sharper ridges and peaks out of water. They are situated but five degrees north of the Paumotu, where eighty islands or more have disappeared, including one of at least fifty miles in length. There is sufficient evidence that they participated in the subsidence of the latter, but not to the same extent. They are nearly destitute of coral.

Gambier or Mangareva Group.—In the southern limits of the Paumotu Archipelago, where, in accordance with the foregoing views, the least depression in that region should have taken place, there are actually, as we have stated, two high islands, *Pitcairn's* and *Gambier's*. There is evidence, however, in the extensive barrier about *Gambier's* (see cut on page 130), that this subsidence, although less than farther north, was by no means of small amount. On page 47, we have estimated it at 1150 feet. These islands, therefore, although towards the limits of the subsiding area, were still far within it. The bays of the Mangareva Islets are of great depth, and afford additional evidence of the subsidence.

Tahitian Islands.—The Tahitian Islands, along with Samoa and the Feejees, are near the southern limits of the area pointed out. Twenty-five miles north of Tahiti, within sight from its peaks, lies the coral island Tetuaroa, a register of subsidence. Tahiti itself, by its barrier reefs, gives evidence of the same kind of change; amounting, however, as we have estimated, to a depression of but two hundred and fifty or three hundred feet. The northwestern islands of the group lie more within the coral area, and correspondingly, they have

wider reefs and channels, and deep bays, indicating a greater amount of subsidence.

Samoa.—The island of Upolu has extensive reefs, which, in many parts, are three-fourths of a mile wide, but there is no inner channel. We have estimated the subsidence at one or two hundred feet. The volcanic land west of Apia declines beneath the sea with an unbroken gradual slope of one to three degrees. The absence of a low cliff is probable evidence of a depression, as remarked on page 332. The island of Tutuila has abrupt shores, deep bays and little coral. It appears probable, therefore, that it has experienced a greater subsidence than Upolu. Yet the middle district of Upolu has very similar bays on the north (p. 312), which may be evidence of a similar subsidence; it is quite possible that the facts indicate a sinking which either preceded the ejections that now cover the eastern and western extremities of Upolu, or accompanied these eruptions. Savaii has small reefs, from which we gather no certain facts bearing on this subject. East of Tutuila is the coral island, Rose. It may be therefore, that the greatest subsidence in the group was at its eastern extremity.

Feejee Islands.—We have already remarked upon this group. A large amount of subsidence is indicated by the reefs in every portion of the group, but it was greatest beyond doubt in the northeast part.

Ladrones.—The Ladrones appear to have undergone their greatest subsidence at the north extremity of the range, the part nearest the axis of the coral area: for although the fires at the north have continued longest to burn, the islands are the smallest of the group, the whole having disappeared except the summits which still eject cinders. The southern islands of the group have wide reefs, which afford evidence of little subsidence since the reefs began to form.

We have thus followed around the borders of the coral area, and besides proving the reality of the limits, have ascertained some facts with reference to a gradual diminution of the subsidence towards and beyond these limits. A line from Pitcairn's to Bird in the Hawaiian Group (see chart) appears to have a corresponding position on the northeast with the southern boundary line of the atoll seas: it includes a large triangular area. An axis bisecting this triangular space, drawn from Pitcairn towards Japan, actually passes through the region of greatest subsidence, as we have before determined it, and

may be considered the *axial line* or *line of greatest depression* for the area of subsidence.

It is worthy of special note, that *this axial line or line of greatest depression coincides in direction with the mean trend of the northwest ranges of islands, its course being N. 52° W.*

The southern boundary line of the coral area, as laid down on the chart, lies within the area of subsidence, although near its limits. There are places along this line where this area has been prolonged farther than elsewhere, as shown by the reefs. One of these regions lies between Samoa and Rotuma, and extends down to the Feejees and Tonga Group; another is east of Samoa, reaching towards the Hervey Group. Each of these extensions trends parallel with the groups of islands, and with the part of the line east of Tahiti. It would seem, therefore, that the Society and Samoan Islands were regions of less change of level than the deep seas about them.

What may be the Extent of the Coral Subsidence?—It is very evident that the sinking of the Society, Samoan, and Hawaiian Islands has been small compared with that required to submerge all the lands on which the Paumotus rest and other Pacific atolls. One, two, or five hundred feet could not have buried all the many peaks of these islands. Even the 1150 feet of depression at the Gambier Group is shown to be at a distance from the axis of the subsiding area. The groups of high islands above mentioned contain summits from 4000 to 14,000 feet above the sea; and can we believe it possible that throughout this large area, when the two hundred islands now sunk were above the waves, there were none equal in altitude to the mean of these heights? That all should have been within nine thousand feet in elevation, is by no means probable. However moderate our estimate, there must still be allowed a sinking of several thousand feet: and however much we increase it within probable bounds, we shall not arrive at a more surprising change of level than our continents show that they have undergone.

Between the New Hebrides and Australia the reefs and islands mark out another area of depression, which may have been simultaneously in progress. The long reef of one hundred and fifty miles from the north cape of New Caledonia and the wide barrier on the west cannot be explained without supposing a subsidence of one or two thousand feet at the least. The distant barrier of New Holland is proof of as great if not greater subsidence.

Effect of the Subsidence.—The facts surveyed give us a long insight into the past, and exhibit to us the Pacific scattered over with lofty

lands where there are now only humble monumental atolls. Had there been no growing coral the whole would have passed without a record. These permanent registers, planted ages past in various parts of the tropics, exhibit in enduring characters the oscillations which the "stable" earth has since undergone. Thus Divine wisdom creates and makes His creations inscribe their own history; and there is a noble pleasure in deciphering even one sentence in this Book of Nature.

From the actual extent of the coral reefs and islands, we infer that the whole amount of high land lost to the Pacific by the subsidence, was at least fifty thousand square miles. But since atolls are necessarily smaller than the land they cover, and the more so, the farther the subsidence has proceeded;—since many lands, from their abrupt shores, or through volcanic agency must have had no reefs about them, and have disappeared without a mark;—and others may have subsided too rapidly for the corals to retain themselves at the surface; it is obvious that this estimate is far below the truth. It is apparent that in many cases, islands now disjoined, have been once connected, and thus several atolls may have been made about the heights of a single subsiding island of large size. Such facts show farther error in the above estimate, evincing that the scattered atolls and reefs do not tell half the story. Why is it, also, that the Pacific islands are confined to the tropics, if not that beyond thirty degrees the zoophyte could not plant its growing registers?

Yet we should beware of hastening to the conclusion that a continent once occupied the place of the ocean, or a large part of it, which is without proof. To establish the former existence of a Pacific continent is an easy matter for the fancy; but Geology knows nothing of it, nor even of its probability.

The island of Banabe in this archipelago affords evidence of a subsidence *in progress*, as my friend, Mr. Horatio Hale, the Philologist of the Expedition, gathered from a foreigner who had been for a while a resident on this island. Mr. Hale remarks, after explaining the character of certain sacred structures of stone: "It seems evident that the constructions at Ualan and Banabe are of the same kind, and were built for the same purpose. It is also clear that when the latter were raised, the islet on which they stand was in a different condition from what it now is. For at present they are actually in the water; what were once paths, are now passages for canoes, and as O'Connell [his informant] says, 'when the walls are broken down the water enters the inclosures.'" Mr. Hale hence

infers "that the land, or the whole group of Banabe, and perhaps all the neighbouring groups, have undergone a slight depression." He also states respecting a small islet near Ualan, "From the description given of Leilei, a change of level of one or two feet would render it uninhabitable, and reduce it, in a short time, to the same state as the isle of ruins at Banabe."

Period of the Subsidence.—The period when these changes were in progress, was probably within and since the tertiary epoch. In the island of Metia, elevated over two hundred feet, the corals below were the same as those now existing, as far as we could judge from the fossilized specimens. At the inner margin of shore reefs, there is the same identity with existing genera. We do not claim to have examined the basement of the coral islands, and offer these facts as the only evidence on this point which is within reach. We cannot know with absolute certainty that the present races of zoophytes were not the successors of others of the secondary epoch: but we do know that we have little reason in facts observed for even the suspicion. For a long time volcanic action was too general and constant for the growth of corals: and this may have continued to interfere till a comparatively late period, if we may judge from the appearance of the rocks, even on Tahiti.

The evidence of subsidence from coral islands might be pursued to other regions in other seas; but we here only refer to the facts on this point presented in our review of the geographical distribution of corals, (page 134,) since we cannot speak from personal observation.

The subsidence has probably for a considerable period ceased in most if not all parts of the ocean, and subsequent elevations of many islands and groups have taken place, which we shall soon consider. In some of the Northern Carolines, the Pescadores, and perhaps some of the Marshall Islands, the proportion of dry land is so very small compared with the great extent of the atoll, that there is reason to suspect a slow sinking even at the present time: and it is a fact of special interest in connexion with it, that this region is near the axial line of greatest depression, where, if in any part, the action should be longest continued.

Among the Kingsmills and Paumotus there is no reason whatever for supposing that a general subsidence is still in progress; the changes indicated are of a contrary character.

The results to which we have here been led obviously differ in many particulars from the deductions of Mr. Darwin.

2. ELEVATIONS OF MODERN ERAS IN THE PACIFIC.

Since the period of subsidence, the history of which has occupied us in the preceding pages, there has been no equally general elevation. Yet various parts of the ocean bear evidence of changes confined to particular islands or groups of islands. While the former exemplify one of the grander events in the earth's history, in which a large segment of the globe was concerned, the latter exhibit its minor disturbances over limited areas. The instances of these changes are so numerous and so widely scattered, that they convince us of a cessation in the previous general subsidence.

The most convenient mode of reviewing the subject is to state in order, the facts relating to each group, and we here commence with the Paumotus.

PAUMOTU ARCHIPELAGO.—The islands of this archipelago appear in general to have that height which the ocean may give to the materials. Nothing was detected which satisfied us of any *general* elevation in progress through the archipelago. The large extent of wooded land shows only that the islands have been long at their present level: and on this point our own observations confirm those of Mr. Darwin. There are examples of elevation in particular islands, however, some of which are of unusual interest. The instances examined by the Expedition, were Honden (or Henuake), Dean's Island (or Nairsa), Aurora (or Metia), and Clermont Tonnerre. Beside these, Elizabeth Island has been described by Beechey, and the same author mentions certain facts relating to Ducie's Island and Osnaburgh, which afford some suspicions of a rise.

Honden or Dog Island.—This island is wooded on its different sides, and has a shallow lagoon. The beach is eight feet high and the land about eleven. There are three entrances to the lagoon, all of which were dry at low water, and one only was filled at high water. Around the lagoon, near the level of high tide, there were numerous shells of *Tridacna* lying in cavities in the coral rock, precisely as they occur alive on the shore reef. As these *Tridacnas* evidently lived where the shells remain, and do not occur alive more than six or eight inches, or a foot at the most, above low tide, they prove, in connexion with the other facts, an elevation of *twenty inches* or *two feet*.

Nairsa or Dean's Island.—The south side of Dean's Island, the

largest of the Paumotus, was coasted along by the Peacock, and from the vessel we observed that the rim of land consisted for miles of an even wall of coral rock, apparently six or eight feet high. This wall was broken into rude columns, or excavated with arches and caverns; in some places the sea had carried it away from fifty to one hundred rods and then there followed again a line of columns and walls, with occasional arches as before. The reef, formerly lying at the level of low tide, had been raised above the sea and subsequently had undergone degradation from the waves. The standing columns had some resemblance in certain parts to the masses seen here and there on the shore platforms of other islands; but the latter are only distantly scattered masses, while on this island, for the greater part of the course, there were long walls of reef rock. The height moreover was greater, and they occurred too on the *leeward* side of the island, ranging along nearly its whole course.

The elevation here indicated was at least *six feet*; but it may have been greater, as the observations were made from shipboard. Any incredulity with regard to the rise of the island, was at once set aside by Metia, the next island visited, situated only thirty miles to the southward.

Metia.—This island has already been described, and its elevation stated at *two hundred and fifty feet*. (See page 67.)

Clermont Tonnerre,* according to Mr. Couthouy, shows the same evidence of elevation from Tridacnas as Honden Island. Clermont Tonnerre and Honden are in the northeastern limits of the Paumotus.

Elizabeth Island was early shown to be an elevated coral island by Beechey. This distinguished voyager represents it as having perpendicular cliffs fifty feet in height. From his description, it is obviously of the same character as Metia; the elevation is *eighty feet*.

Ducie's Island is described by Beechey as twelve feet high, which would indicate an elevation of at least *one or two feet*.

Osnaburgh Island, according to the same author, affords evidence of having increased its height since the wreck of the *Matilda* in 1792. He contrasts the change from "a reef of rocks," as reported by the crew, to "a conspicuously wooded island," the condition when he

* This island was not visited by the writer, as only the officers of the *Vincennes* attempted to land on it.

visited it; and states farther that the anchor, iron-works, and a large gun (4-pounder) of this vessel were two hundred yards inside of the line of breakers. Captain Beechey suggests that the coral had grown, and thus increased the height. But this process might have buried the anchor if the reef were covered with growing corals, (which is improbable,) and could not have raised its level. If there has been any increase of height, (which we do not consider certain,) it must have arisen from subterranean action.

TAHITIAN GROUP.—The island of Tahiti presented us no conclusive evidence of elevation. The shore plains are said to rest on coral, which the mountain debris has covered; but they do not appear to indicate a rise of the land. The descriptions by different authors of the other islands of this group, do not give sufficient reason for confidently believing that any of them have been elevated. The change, however, of the barrier reef around Bolabola into a verdant islet encircling the island, may be evidence that a long period has elapsed since the subsidence ceased; and as such a change is not common in the Pacific, we may suspect that it has been furthered by at least a small amount of elevation. The observation by the Rev. D. Tyerman with regard to the shells found at Huahine high above the sea may be proof of elevation; but the former erroneous conclusions with regard to Tahiti, teach us to be cautious in admitting it without a more particular examination of the deposit.

HERVEY AND RURUTU GROUPS.—These groups lie to the southwest and south of Tahiti.

Atiu (Wateoo of Cook) is a raised coral island. Cook observes that it is “nearly like Mangaia.” The land near the sea is only a bank of coral ten or twelve feet high, and steep and rugged. The surface of the island is covered with verdant hills and plains, with no streams.*

Mauke is a low elevated coral island.†

Mitiaro resembles Manke.‡

Okatutaia is a low coral island, not more than six or seven feet high above the beach, which is coral sand. It has a light-reddish soil.

Mangaia is girded by an elevated coral reef *three hundred* feet in height. Mr. Williams speaks of it as coral, with a small quantity of

* Cook's Voyage, vol. i. pp. 180, 197. Williams's Miss. Enterprises, i. 47, 48, first Am. edit., Appleton.

† Williams's Miss. Ent., pp. 39, 47, 264.

‡ Ibid. pp. 39, 264.

fine-grained basalt. He states again that a broad ridge (the reef) girts the hills.*

Rurutu has an elevated coral reef *one hundred and fifty* feet in height.†

With regard to the other islands of these groups, *Manuai*, *Aitutaki*, *Rarotonga*, *Rimetara*, *Tubuai*, and *Raivavai*, the descriptions by Williams and Ellis appear to show that they have undergone no recent elevation.

SCATTERED ISLANDS *in the latitudes between the Society and Samoan Groups*.—These coral islands, as far as we can ascertain, are low like the Paumotus, excepting some of the Fanning Group north of the equator, and possibly Jarvis and Malden. Of the Fanning Group, (situated near the equator, south of the Hawaiian Group,)

Washington Island is three miles in diameter, without a proper lagoon. The whole surface, as seen by us, was covered densely with cocoanut trees. This unusual size for an island without a lagoon indicates an elevation, which the height of the island, estimated at twelve feet, confirms. The elevation may have been *two* or *three* feet.

Palmyra Island, just northwest of Washington, is described by Fanning as having two lagoons: the westernmost contains twenty fathoms water. *Fanning's Island*, to the southeast of Washington, is described by the same voyager as lower than that island. The accounts give no evidence of elevation.

Christmas Island, still farther to the southeast, according to the description of Cook, its discoverer, had the rim of land in some parts three miles wide. He mentions narrow ridges lying parallel with the seacoast, which "must have been thrown up by the sea, though it does not reach within a mile of some of these places." The proof of a small elevation is decided, but its amount cannot be determined from the description. The account of F. D. Bennett, (*Geographical Jour.* vii. 226,) represents it as a low coral island.

Jarvis Island, as seen from the Peacock, appeared to be eighteen or twenty feet in height, which, if not exaggerated by refraction, (we

* Williams, *Miss. Ent.*, p. 48, 50, 249. See also Mr. Darwin, p. 132.

† Williams, *Miss. Ent.*, p. 50.—Stutchbury describes the coral rock as one hundred and fifty feet high. *West of England Journal*, i.—Tyerman and Bennett describe the island as having a high central peak with lower eminences, and speak of the coral rock as two hundred feet high on one side of the bay and three hundred on the other (ii. 102).—Ellis says that the rocks of the interior are in part basaltic, and in part vesicular lava, iii. 393.

think it not probable,) would show an elevation of six or eight feet. This island is a sand flat, with little vegetation, and is but two hundred miles south of Christmas Island.

Malden, two hundred and fifty miles southeast of Jarvis, in latitude 4° S. and longitude 155° W., visited by Lord Byron, is described as not over forty feet high; but this may be the whole height, including the height of the trees.

TONGA ISLANDS *and others in their vicinity.*

All the islands of the Tonga group about which there are reefs, give evidence of elevation. *Tongatabu* and the *Hapai* Islands consist solely of coral, and are elevated atolls.

Eua, at the south extremity of the line, has an undulated, mostly grassy surface, and is in some parts eight hundred feet in height. Around the shores, as was seen by us from shipboard, there appeared to be an elevated layer of coral reef rock, twenty feet thick, worn out into caverns, and with many spout-holes. Between the southern shores and the highest part of the island, I observed three distinct terraces. Coral is said to occur at a height of three hundred feet. From the appearance of the land, we judged that the interior was basaltic; but nothing positive was ascertained with regard to it.

Tongatabu lies near *Eua*, and is in some parts fifty or sixty feet high, though in general but twenty feet. It has a shallow lagoon, into which there are two entrances. Some hummocks of coral were observed by the writer standing eight feet out of water.

Namuka and most of the *Hapai* cluster, are stated by Cook to have abrupt limestone shores, ten to twenty feet in height. *Namuka* has a lagoon or salt lake at centre one and a half miles broad; and there is a coral rock in one part twenty-five feet high.*

Vavau, the northern of the group, according to Williams, is a cluster of elevated islands of coral limestone, thirty to one hundred feet in height, having precipitous cliffs, with many excavations along the coast.†

Pylstaart's Island, south of *Tongatabu*, is a small rocky islet without coral. *Tafua* and *Proby* are volcanic cones, and the former is still active.

Savage Island, a little to the east of the Tonga Group, resembles *Vavau* in its coral constitution and cavernous cliffs. It is elevated *one hundred* feet.‡

* Cook's Voyage.—Williams, p. 296.

† Williams, p. 427.

‡ Williams, p. 275, 276. Foster estimates the height at fifty feet, and speaks of a depression about the centre.

Beveridge Reef, a hundred miles southeast of Savage, is low coral.

SAMOAN ISLANDS.—No satisfactory evidences of elevation were detected about these islands.

SCATTERED ISLANDS, *north of Samoa*.

These islands are all of coral, and several indicate an elevation of one to six feet. On account of the high tides, (4 to 6 feet,) the sea may give a height of ten or twelve feet to the land.

Swain's, near latitude 11° S., is fifteen to eighteen feet above the sea, where highest, and the beach is ten to twelve feet high. It is a small island, with a depression at centre, but no lagoon. The height proves an elevation of *three to six* feet.

Fakaafo, ninety miles to the north, is fifteen feet high. The coral reef rock is raised in some places three feet above the present level of the platform. Elevation at least *three* feet.

Nukunono, or Duke of Clarence, near Fakaafo, was seen only from shipboard.

Oatafu, or Duke of York's, is in some parts fourteen feet high. Elevation *two* or *three* feet.

Enderby's and *Birnie's*, still farther north, are twelve feet high. Judging from the double slope of the beach on Enderby, this island may have undergone an elevation of *two* feet, the height of the upper slope; yet we think it doubtful.

Gardner's, *Hull's*, *Sydney* and *Newmarket* were visited by the Expedition, but no satisfactory evidences of elevation on the first three were observed. The last is stated by Captain Wilkes to be *twenty-five* feet in height.

FEEJEE ISLANDS.—The proofs of an elevation of four to six feet about the larger Feejee Islands, Viti Lebu and Vanua Lebu, and also Ovalau, have been given in our report on this group, on page 351. How far this rise affected other parts of the group, I have been unable definitely to determine; but as the extensive barrier reefs in the eastern part of the group rarely support a green islet, they rather indicate a subsidence in those parts than an elevation.

ISLANDS NORTH OF THE FEEJEES.—Horne Island, Wallis, Ellice, Depeyster, and four islands on the track towards the Kingsmills, were passed by the Peacock; but from the vessel, no evidences of elevation could be distinguished. The first two are high islands, with barriers, and the others are low coral. *Rotuma*, (177° 15' E., and 12° 30' N.,) is another high island, to the west of Wallis's. It has encircling reefs, but we know nothing as to its changes of level.

SANDWICH ISLANDS.—*Oahu* affords decided proof of an elevation of twenty-five or thirty feet (p. 251). There is an impression at Honolulu, derived from a supposed increasing height in the reef off the harbour, that the island is slowly rising. Upon this point I can offer nothing decisive. The present height of the reef is not sufficiently above the level to which it might be raised by the tides, to render it certain, from this kind of evidence, that the suspected elevation is in progress.

Kauai presents us with no evidence that the island, at the present time, is at a higher level than when the coral reefs begun; or at the most, no elevation is indicated beyond a foot or two. The drift sand-rock of Koloa appears to be a proof of elevation, from its resemblance to those of Northern *Oahu*: but if so, there must have been a subsidence since, as it now forms a cliff on the shore that is gradually wearing away.

Molokai, according to information from the Rev. Mr. Andrews, has coral upon its declivities three hundred feet above the sea. The same gentleman informed us that on the western peninsula of *Mauï*, coral occurs in some places eight hundred feet above the sea; and other specimens were obtained at a height of five hundred feet. These islands were not visited by the writer.

With regard to *Molokai*, Mr. Andrews writes to the author that the coral occurs "upon the acclivity of the eastern or highest part of the island, over a surface of more than twenty or thirty acres, and extends almost to the sea. We had no means of accurately measuring the height; but the specimens were obtained at least three hundred feet above the level of the sea, and probably four hundred. The specimens have distinctly the structure of coral. The distance from the sea was two to three miles."

Mr. Andrews, who appears to doubt the connexion of the supposed coral on *Mauï* with reefs, states in a letter to the author: "In no case have I seen the coral in a rocky ledge; it is generally mixed with the lava rock, to which it adheres. It has usually the appearance of burnt lime; and thus, large stones and rocks seem as though they had been whitewashed several times over, and sometimes it amounts to an inch in thickness, or an inch and a half. At other times the whitewash has found its way into cracks in the stones. Sometimes only one side of a stone is whitened by it, or only a corner of it. It is sometimes soft and crumbly, and at other times quite hard; and again it is mixed with the earth." From this description it appears to resemble the lime incrustations and seams of Diamond Hill, Punch-

bowl and Koko Head, Oahu, which occur at the same height, but most certainly give no evidence of elevation, as they have proceeded beyond doubt from aqueous eruptions carrying lime in solution. Fragments of coral, it will be remembered, occur in the tufa of these hills. This evidence from Maui, should therefore be received with great hesitation until farther examined.

Besides the above, there are large masses of coral rock, according to Mr. Andrews, along the shores of Maui, from *two* to *twelve* feet above high water. From his descriptions, this rock appears to be the reef rock, like the raised reef of Oahu, and is probably proof of an elevation of at least *twelve* feet.

KINGSMILLS OR TARAWAN GROUP.—This group of atolls is remarkable for the variety of its productions and the abundance of fresh water.

Taputeouea or *Drummond*.—This is the southern island of the group. The reef rock near the village of Utiroa is a foot above low tide level, and consists of large massive *Astræas* and *Meandrinæ*. The tide in the Kingsmill seas is seven feet; and consequently this evidence of a rise might be doubted, as some corals may grow to this height where the tide is so high. But still these *Astræas* and *Meandrinæ*, as far as observed by the writer, are not among the species that may undergo exposure at low tide, except it be to the amount of three or four inches; and it is probable that an elevation of at least *ten* or *twelve* inches has taken place.

Apia or *Charlotte's* Island, one of the northernmost of the group, has the *reef rock* in some parts raised bodily to a height of six or seven feet above low water level, evidencing this amount of elevation. This elevated reef was observed for long distances between the several wooded islets; it resembled the south reef of *Nairsa* in the *Paumotu* Archipelago, in its bare, even top, and bluff worn front. An islet of the atoll, where we landed, was twelve feet high, and the coral *reef rock* was five or six feet above middle tide. A wall of this rock, having the same height, extends along the reef from the islet. There was no doubt that it was due to an actual uplifting of the reef to a height of full *six* feet.

Nanouki, *Kuria*, *Maiana* and *Tarawa*, lying between the two islands above mentioned, (p. 50,) were seen only from the ship, and nothing decisive bearing on the subject of elevation was observed. On the northeast side of *Nanouki* there was a hill twenty or thirty feet in height covered with trees; but we had no means of learning that it

was not artificial. We were, however, informed by Kirby, a sailor taken from Kuria, that the reef of *Apamama* was elevated precisely like that of Apia, to a height of five feet; and this was confirmed by Lieutenant Dehaven, who was engaged in the survey of the reef. We were told, also, that Kuria and Nanouki were similar in having the reef elevated, though to a less extent. It would hence appear that the elevations in the group increase to the northwestward.

Maraki, to the north of Apia, is wooded throughout. We sailed around it without landing, and can only say that it has probably been uplifted like the islands south. *Makin*, the northernmost island, presented in the distant view no certain evidence of elevation.

The elevation of the Kingsmills accounts for the long continuity of the wooded lines of land, an unusual fact considering the size of the islands; and also for the amount of fresh water obtained from springs (p. 76). The wear from storms would also be greater on islands which have been elevated.

RADACK, RALICK AND CAROLINE ISLANDS.—No evidences of elevation in these groups are yet known. The very small amount of wooded land on the Pescadores inclines us to suspect rather a subsidence than an elevation; and the same fact might be gathered respecting the islands south, from the charts of Kotzebue and Kruesenstern.

LADRONES.—The seventeen islands which constitute this group, may all have undergone elevations within a recent period, but owing to the absence of coral from the northern, we have evidence only with regard to the more southern islands.

Guam, according to Quoy and Gaynard, has coral rock upon its hills more than six hundred feet (one hundred toises) above the sea.

Rota, the next island north, afforded these authors similar facts, indicating the same amount of elevation.

PELEWS AND NEIGHBOURING ISLANDS.—The island *Feis*, three hundred miles southwest of Guam, is stated by Darwin, on the authority of Lutke, to be of coral, and ninety feet high. *Mackenzie* Island, seventy-five miles south of Feis, is a low atoll, as ascertained by the Expedition. No evidences of elevation are known to occur at the Pelews.

MELANESIAN ISLANDS.—Among the New Hebrides, New Caledonia, and Salomon Islands, the evidences of elevation have not yet been examined.

The details on the preceding pages are presented on the chart of the Pacific, in this volume, and also in a tabular form on the next page.

		FEET.
Paumotu Archipelago, - - -	Honden, - - -	1½ or 2
" " "	Clermont Tonnerre, - - -	2
" " "	Nairsa or Dean's, - - -	6
" " "	Elizabeth, - - -	80
" " "	Metia or Aurora, - - -	250
" " "	Ducie's, - - -	1 or 2
Tahitian Group, - - -	Tahiti, - - -	0?
" " "	Bolabola, - - -	?
Hervey and Rurutu Groups, -	Atiu, - - -	12?
" " " "	Mauke, - - -	somewhat elevated.
" " " "	Mitiaro, - - -	" "
" " " "	Mangaia, - - -	300
" " " "	Rurutu, - - -	150
" " " "	Remaining Islands, - - -	0?
North of the Tahitian, - - -	Washington Island, - - -	2 or 3
" " " "	Christmas, - - -	2?
" " " "	Malden, - - -	?
" " " "	Jarvis, - - -	6 or 8?
Tongan Group, - - -	Eua, - - -	300?
" " "	Tongatabu, - - -	60
" " "	Namuka and the Hapai, - - -	25
" " "	Vavau, - - -	100
Savage Island, - - -	- - -	100
Samoa Islands, - - -	- - -	0
North of Samoa, - - -	Swain's, - - -	3 to 6
" " "	Fakaafu, or Bowditch, - - -	3
" " "	Oatafu, or Duke of York's, - - -	2 or 3
" " "	Enderby's, - - -	2?
" " "	Gardner, Hull, Sydney, Newmarket,	0?
Feejee Islands, - - -	Viti Levu and Vanua Levu, Ovalau,	5 or 6
	Eastern Islands, - - -	0?
North of Feejees, - - -	Horne, Wallis, Ellice, Depeyster,	0?
Sandwich Islands, - - -	Kauai, - - -	1 or 2?
" " "	Oahu, - - -	25 or 30
" " "	Molokai, - - -	300
" " "	Maui, - - -	12—
Tarawan Islands, - - -	Taputeouea, - - -	1 or 2
" " "	Nanouki, Kuria, Maiana and Tarawa,	2 or more?
" " "	Apamama, - - -	5
" " "	Apia or Charlotte, - - -	6 or 7
" " "	Maraki, - - -	2 or 3?
" " "	Makin, - - -	0
Carolines, - - -	- - -	none ascertained.
Ladrones, - - -	Guam, - - -	600
"	Rota, - - -	600

	FEET.
Feis,	90
Pelews,	0?
New Hebrides, New Caledonia, Salomon Islands, - - -	none ascertained.

Several deductions are at once obvious:—

1. That the elevations have taken place in all parts of the ocean.
2. That they have in some instances affected single islands, and not those adjoining.
3. That the amount is often very unequal in adjacent islands.
4. That in a few instances the change has been experienced by a whole group or chain of islands. The Tarawan Group is an instance, and the rise appears to increase from the southernmost island to Apia, and then to diminish again to the other extremity.

The Feejees may be an example of rise at the west side of a group, and possibly a subsidence on the east; while a little farther east, the Tonga Islands constitute another extended area of elevation. We observe that while the Samoan Islands afford no evidences of elevation, the Tonga Islands on the south have been raised, and also the Fakaafo Group and others on the north.

We cannot, therefore, distinguish any evidence that a general rise is or has been in progress; yet some large areas appear to have been simultaneously affected, although the action has often been isolated. Metia and Elizabeth Island may have risen abruptly: but the changes of level in the Feejees and the Friendly Islands, appear to have taken place by a gradual action.

3. CHANGES OF LEVEL IN THE PACIFIC PRECEDING THE CORAL REEFS.

The evidences of change of level previous to the growth of coral are to be looked for in the topographical features of the high islands, and the occurrence of conglomerate layers of rolled stones in the structure of the mountains.

To arrive at any general results on this subject requires, therefore, a thorough knowledge of the surface of the islands, as well as their interior structure: and as regards the last-mentioned point, the soil and vegetation over these tropical lands is everywhere an obstacle in the way of investigation. Our own surveys have led to few results, and these can be stated in a single paragraph.

In our account of the island of Oahu, we have mentioned the occurrence of layers of rounded stones and earth interstratified with

finer material at Ewa, and occurring at a height of sixty feet above the sea. We were informed of similar deposits up a valley on this part of the island, at a much greater elevation, but did not have an opportunity to examine them. In crossing the mountains of the western peninsula of Maui, Dr. Pickering observed a basaltic pudding-stone, or conglomerate of half-rounded stones, two thousand feet above the level of the sea. On Mount Kea, similar beds were met with by Dr. Pickering at a height of six thousand feet. On the island of Tahiti a coarse conglomerate of partially rolled fragments was observed by the writer up a branch from the Matavai Valley, at an elevation of about one thousand five hundred feet above the sea. From these facts, and others similar in the Feejees and Samoa, we may infer that many of the islands were at a lower level during some portion of their early history, while their formation was in progress. But they do not prove their submarine origin, nor anything definite respecting the actual condition of the seas. This remains for future exploration. The compact rocks of the interior of the islands, and especially the crystalline syenitic rocks of Tahiti, were at one time considered by the author evidence of their eruption beneath the pressure of an ocean; but this is not satisfactory, (see p. 377,) since the pressure required for compactness would be afforded in the interior of a volcano, by the molten lava itself.

From the surface of Mount Loa we learn that the occurrence of beds of lava with ropy lines characterizing the surface (produced by the flowing of the lava) indicates a subaerial origin. In ejections beneath the sea, the surface of the lava is so acted upon by the cold waters that such lines are not preserved. From these indications we ascertain that Tahiti, Upolu, Savaii, Oahu, Maui, and Kauai were nearly at their present height when the *latest* eruptions took place.

We learn again from Mount Loa, that a subaerial origin is shown by a great number of lateral cones of lava or cinders. The absence of these small cones from Tahiti cannot, however, prove the contrary; since the island has been subject to extensive denudation, and these minor craters would be the first parts to disappear. Western Maui, as well as the larger part of Kauai, resembles Tahiti. On Eastern Maui and Savaii these lateral cones are still numerous, and the surface of these lands bears every evidence of recent, subaerial fires, and little denudation.

The cavernous nature of Mount Loa, is another point that may be looked upon as proof of subaerial origin; and it is conclusive upon

this point, as far as regards the exterior coating of Mount Loa, the only part exposed to view. Like the two preceding kinds of evidence, it is of very difficult application. In Eastern Oahu, however, in the lower slopes beyond Diamond Hill, there are many caverns so similar to those of Mount Loa, that they clearly evince that the land was above water when the ejections took place.

The recently ejected rocks of Mount Loa, though often very compact, still contain some ragged cellules; and this kind of cellule is a good proof of the rocks cooling without pressure above. The application of this test leads us to no different results from those already stated.

We arrive, therefore, at the conclusion, that while it is apparent that the latest eruptions of many of the Pacific islands were subaerial, and the most of these lands were at a much lower level in the course of their progress, we cannot point out which were of submarine origin; and of course we learn nothing with regard to the earliest condition of these centres of eruption, from examining the rocks above the present sea level.

The action of the sea on the cliffs of the islands before these shores were protected by reefs, is another source of evidence with regard to the level of the land at an early epoch. Such facts are identified with difficulty; and we have distinguished only a single undoubted case. This occurs on the north side of Vanua Lebu, one of the Feejees, where there is a cylindrical well-like cavity, which was probably a former blow-hole. It is already described on page 350.

V. GENERAL ARRANGEMENT OF LAND IN THE PACIFIC.

The linear ranges of islands in the Pacific, and the extent of the great chains over this third of the earth's surface, have been pointed out in an early part of this volume.* This arrangement, in lines, has often been correctly attributed to the opening of fissures, and we have pursued this view to some interesting conclusions respecting the Hawaiian Islands. We repeat here our general deductions, adding farther illustrations, where the subject seems to require it.

* The pages referred to should be reperused in connexion with this chapter, and as introductory to it. The facts might have been deferred to this place: yet were properly connected with a general review of the topography of the ocean. The following discussions could not have been given in that place without anticipating many facts and conclusions since detailed.

1. *Ruptures seldom continuous at the surface for long distances, and usually consisting of a series of rents; the rents often largest at one extremity.*—It has heretofore seemed the most natural supposition that a long linear group of islands like the Hawaiian chain, should have occupied the site of a single uninterrupted fissure, and this view is often implied by writers treating of the origin of chains of islands as well as ranges of mountains. That it is a gratuitous assumption it is needless to assert; and moreover it is obvious from the various courses and irregularities in a single mountain range that it cannot be always true. The facts in the Hawaiian Islands prove that the group originated in a *series* of rents; for they show that for several of the islands the fissure was largest towards the southeast part of the island, where the fires were longest in action, a fact which could not be comprehended if we admit only a single fissure for the group, and is perfectly compatible with the idea that there was a number of them. This is farther confirmed by the fact that the subordinate rents correspond in character with the series as a whole, the *southeast* portion of the series, as well as of the separate islands, bearing evidence of having been the part where the widest rupturing took place (page 281).

From the nature of the earth's crust—a brittle material, of somewhat uneven texture and probably also of unequal thickness,—we should infer that its fractures would be a series of rents rather than a continued straight line of rupture. For the latter would require an even application of force, upon a material of very regular structure and uniform texture,—a condition of infinite improbability as regards the earth.

Whatever the force causing rupture, we learn from actual facts, and especially from the progress and effects of earthquakes, that this power has its point or region of maximum effect, from which, along some determinate line, it gradually diminishes, or towards which it gradually increases. And this condition, and the others alluded to, would necessarily produce the result so well exemplified in the Hawaiian Group.

Another example of fires dying out at an extremity of a group has been found in the Samoan Islands: we have, therefore, the same evidence here, that the ruptures which originated the group were largest towards one extremity. This extremity is the *western* in Samoa, and therefore the force instead of being greatest to the southeast, as in the case of the Hawaiian chain, was here greatest to the northwest.

A third undoubted example is before us in the *Ladrones*. For in these islands the same evidences of long extinction of the fires are apparent in the southern islands, while to the north, these indications gradually disappear, and at the northern extremity of the range, the fires still burn. The smaller size of the northern islands is no proof of their more recent origin, but rather of a longer continued subsidence. We cannot judge of the actual size and extent of a volcanic mountain by the part above the water, any more than we can decide upon the length of a line from the size of the buoy attached to it.

The Society Islands require farther examination before we can confidently state their relation to the system. This is the case also with regard to the New Hebrides, which have been but little explored.

2. *The fissures of a range may constitute*

a. *A single line or "continued" series.*

b. *An "advancing" or "receding" series, the successive parts lying somewhat to one side of each other, though having a common direction.*

c. *A compound series, including several parallel lines, and in either case there are often*

d. *Other transverse lines at right angles, or nearly so, to the prevalent trend of the group.*

In figures of Australian dikes beyond, we have represented instances of the overlapping of the successive parts — a common feature of fissures.* Among the Pacific groups, this point is fully illustrated. In the long Hawaiian chain, the successive parts evidently recede, as we trace the line from the west eastward, each being a little to the northeast of the preceding. The lines inclosing the chain on the Pacific chart, are drawn so as to show this feature of the group. We cannot, of course, point out the exact courses of all the various fissures that were opened when the islands began; but we may discover enough to convince us of the general fact alluded to. In the eastern portion of the chain, where, as we have remarked, the rupturing was greatest in amount, we observe the two

* Upon this point we can refer to no more valuable work than the Report by Dr. J. G. Percival on the Geology of Connecticut, (8vo. New Haven, 1842,) where the numerous trap dikes of the state are laid down with minute accuracy of detail. The able author points out the different kinds of series in the lines of dikes, the "*continued*," where the several linear rents form a continued series in the same line as well as direction; and "*receding*" or "*advancing*" series, where they have a common direction, but the successive parts have a position a little behind or in advance of one another. See also *Am. Journ. Sci.* ii. ser. iii. 390.

parallel lines of islands, which we have named on a former page, the Loa and Kea ranges.

In the Samoan Group, we have pointed out two distinct lines of islands as constituting the range, and the distance between the parallel ranges is about thirty miles. This is shown on the General Chart, and also on the map of the islands, page 307.

Following the great central Pacific chain from Samoa northwestward, we observe the Vaitupu (or Ellice) range in two series, parallel to one another. In the Kingsmills there are several distinct lines, as may be deduced from the map, page 50. From Taputeouea, (Drummond's) or rather from Hurd Island, two hundred miles to the southeast, to Maiana is a single line; Apamama and Tarawa may constitute a *second* parallel line; Apia (or Charlotte) lies in a *third* parallel line, as the trend of the island itself shows; and Maraki and Pitt's Island appear to make a *fourth* line. The several lines form an advancing series, and they are distinct, not only in the bearing of the islands, but mainly in the direction of the longer diameter of each island.

We do not say that the islands from Taputeouea to Maiana originated in a single fissure: on the contrary, we believe that there were several ruptures, as in the Hawaiian Group, perhaps one for each island. It is probable that this principle of a "receding" or "advancing" series, characterized the subordinate parts, as it is actually a more common mode of fissuring than the "continued" series. This remark we would apply to other groups. We do not undertake to point out all the possible examples of the system, but only such as are obvious from the facts before the eye on a good map. The positions and features of the Kingsmill Islands, and of the other groups above referred to, were carefully ascertained by the surveys of the Expedition.

In the Marshall Islands, northwest of the Kingsmills, the two main ranges, the *Radack* and *Ralick* Groups, are nearly parallel. The latter forms a series nearly in a line with the southern half of the Kingsmills. The Radack chain, to the eastward, has the general form of the Kingsmill Group, the northern part becoming gradually more easterly in position than the southern. Arrowsmith's, Pedder and Daniel, lie in a transverse position at right angles with the trend of the group. The several parallel lines, forming an advancing series, are not so distinct in this group as in the Kingsmills; yet the positions would seem to indicate a conformity to the principle. There are too many

possible irregularities in the opening of fissures from internal forces, for us to expect so well-defined lines, in all instances, as the Radack chain and others that have been pointed out; and when the subsidence has caused a disappearance of all but the coral that is based upon it, there is still more reason to expect some difficulty in determining the courses of former fissures.

The Ladrões, as seen on the chart, constitute a line of islands extending through a degree of latitude. This line, which is nearly straight in its lower half and trends N.N.E., bends slightly westward in its northern half. Although it is evident that the bend must take place from a gradual veering in the line of ruptures, we cannot distinguish satisfactorily their several relations. From the positions of some of the islands transverse to the trend of the group, and conformable to the west-northwest system of the Pacific, we might infer that although the course of the group is nearly north and south, several of the fissures were opened transversely to this course.

The Society and Paumotu Islands indicate, by the trends of the several islands and lines of islands, a great number of nearly parallel ruptures; but they are so clustered that we do not venture to point out definite series. They lie in numerous lines, and are so related that they exhibit well the general principles we are endeavouring to illustrate. The Marquesas consist of two parallel lines, a north-eastern and southwestern; and Nukuhiva and Fatuhiva are two large islands having a transverse position.

In the southwestern Pacific, a correspondence with the system here explained is obvious on a glance at a map. The New Hebrides, New Caledonia, Salomon Islands, New Ireland and others, exhibit a series of parallelisms between groups and parts of groups.

The Galapagos, as shown by Mr. Darwin, lie in three or four parallel lines, trending nearly northwest, while transverse lines are also apparent.* The Canaries and Azores in the Atlantic are other examples.†

3. *Curvatures of Ranges.*—In our first chapter, the curvatures of some of the main ranges of the Pacific have been briefly pointed out. The great central chain, six thousand miles long, has a simple curvature, convex southwestward. The New Guinea chain, viewing it through its whole length from Southern New Caledonia, or perhaps

* Volcanic Islands, p. 115. American Journal of Science, ii. Ser. iii. 384.

† American Jour. of Science, ii. Ser. iii. 386.

New Zealand to the Andaman Islands, north of Sumatra, has very distinctly a double curvature, the line bending from northwest to west, and then to the northwest again in Sumatra. We need not repeat the evidence that the whole should be viewed as portions of a single system; it is apparent upon any good chart.

On the north and east of the Pacific, other great curved ranges may be distinguished. To the north, the Aleutian Archipelago, six hundred miles long, stretches across between the two continents, America and Asia, with a strong convexity towards the ocean. From Kam-schatka, at the eastern termination of this archipelago, commences a *second* curve, which extends south by the Kuriles to Yeso, having a length of fifteen hundred miles. From Yeso commences a *third* (or rather from the island Sanghalian just north,) which stretches along Nippon to its southwest extremity, nine hundred miles long. A *fourth* extends from the termination of the preceding, through Kiusiu and other islands, to Loochoo and Formosa, about nine hundred miles. A fifth includes Formosa, Luzon, Palawan and Western Borneo, a distance of two thousand miles.

The general forms of these curves are very similar; they are alike in being convex towards the Pacific, or to the *southeast*, and moreover they are so closely united at their extremities, and are so regularly *rectangular at their intersections with one another*, that the whole naturally constitutes a single series, continuous over a length of seven thousand miles.

Besides these great curvatures, there are often subordinate curves in the course of the ranges, conforming in general to the system to which they belong.

In the East Indies, the north of Celebes makes an east and west line parallel with Java; eastward it gradually bends northward, and is connected with Southern Mindanao through Sanguir and other islands.

The Sooloo Islands form a part of another similar curve connecting Northwestern Borneo with Western Mindanao, Negros Island and Panai. Both of these curves are convex towards the Pacific, like the larger curves before pointed out.

The Ladrões have a slight curvature (see chart); and if we may connect with the curving line, the islands Mackenzie, Yap, and the Pelews, we distinguish another curve of corresponding character and form with those already mentioned. New Britain makes a similar curve between the west extremity of New Ireland and New Guinea. Like those of the Asiatic coast and others alluded to, it commences

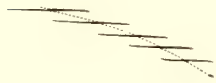
with a course nearly north and south, and gradually bends towards east and west.

In the great central chain of the Pacific, the islands of a group seldom make a direct straight line, but show a tendency to bend a little northward, in the northwestern portion of each. Thus the general course of the Radack Group is northwest in its lower half, and much more northerly in its northern portion. The same is true of the Kingsmills. Consequently a line representing the general course of these groups must be somewhat curved; and like the main range the curve for each is convex *westward*.

The prevalence of curves throughout the island ranges of the Pacific Ocean and East Indies is so obvious, that we cannot fail to consider it a fact of general importance, bearing upon any theory that explains the physiognomy of the earth. It is interesting to observe them in Eastern Asia: the courses of the mountain chains, as well as coast lines, curve like the chains of islands off the coast. The Stanovoi and the Khingan Mountains form three great curves, convex *towards* the Pacific or to the southeast. The Altai have a parallel course. The mountains of the globe will probably be found to illustrate fully the principles we are endeavouring to present, when their courses are ascertained and laid down on charts with accuracy.

We have remarked that islands are but the culminant peaks of mountains, and consequently whatever has been ascertained with regard to the chains of islands, is so much with reference to mountain chains. The mountains of Australia are shown by Strzelecki to consist of a series of curves, convex eastward; and the same, as stated by Prof. Rogers, is the character of the Appalachians in America.*

4. *Mode of Curvatures*.—In our remarks on fissures, we observed that the fissures were frequently in *advancing* or *receding* series. This fact alone is the occasion of curves, as in the annexed cut. This, as we have shown, is the arrangement of the islands in the Kingsmills, by which the curved form of this linear group is produced. The same principle is seen to some extent in the great chains of the ocean. In the central or Samoan chain, the Rarotonga, Aitutaki and Society lines form the southeastern extremity, and the Rarotonga line is the most external of the whole range. Going westward from this group, the lines are successively in advance of one another, and it is



* Trans. Assoc. Amer. Geologists, 1840-1842, p. 540.

partly in this way that the great curve results. To illustrate:—Samoa is in advance of the Rarotonga line, being nearly continuous with the course of the Aitutaki line. The Vaitupu line is a little in advance of Samoa; and, moreover, consists of two parallel series, the northeastern of which is in advance of the other. The Southern Kingsmills constitute another line in advance of the last, and the northern are shorter lines each in advance of the preceding. The Ralick Islands are nearly continuous with the Northern Kingsmills, while the Radack Islands are in advance, or to the northeastward of the Ralick; the northern of the Radack Group being the most in advance. It is plain, therefore, that while part of the curve is due to a change in the trend of the groups as we proceed northwestward, a still larger part is owing to this advancing of the successive lines, each being, with a rare exception, a little to the northeast of the one preceding. Were there no curve, the range straightened out would extend from Rarotonga toward the Pelews, south of the Ladrões. Were there only the curve depending on the change of trend in the groups (from N. 65° W. at Rarotonga, to N. 37° W., in the Radack Group), the Ralick Islands would have extended along just east of Hogoleu. The difference, therefore, between this and their present position, measures the amount of curvature derived from the position of the successive subordinate lines in the range.

In the New Guinea chain, the successive parts are in several series, and although there is not a regular “advancing” or “receding” order, we observe the system to be so complete, that when there is an interval between two groups in the same line, there is, to one side, another range to occupy the interval. Thus, opposite the interval between the Salomon Islands and the New Hebrides, lies the *Santa Cruz* (or Vanikoro) Group. The line of the Salomon Islands is continued in the Admiralty Islands, and then dies out, but south, commences the large island of New Guinea. There seems thus to be a certain relation between the several parts, which cannot be mistaken. The curvature in this range rises almost wholly from a change of trend in the separate parts.

In the Ladrões, the curve may be due to an advancing arrangement of the parts of the group. But whether this be actually so in this case, and in the remaining curves alluded to, must be determined by future observations.

The facts adduced are sufficient to illustrate the different ways in

which the various curves characterizing the chains of the globe are produced. They evince that (1) *while straight ranges are of occasional occurrence, curved ranges are still more common*; also (2) *that curvatures may arise either from a gradual change of trend in the subordinate parts, or from the positions of these parts in a series*; and (3) *that the same great chain may change its direction sixty degrees or more*; and consequently (4) *the course of a chain can be no evidence of its age*.

5. *Rectangular Intersections of Chains or Parts of Chains*.—The rectangular intersections of the Sumatra and Java range in the East Indies with the ranges from the north, are described with some detail on an early page, where we have shown that the trend of the latter is determined by the course of the former, the two varying together. The same general fact is illustrated by the Feejee and associated groups. The successive great curves along the east of Asia have been pointed out as commencing and ending at right angles with one another, or nearly so. Many instances of transverse trends of islands in the different groups of the Pacific have been pointed out, and these are other examples of the tendency to a rectangularity in intersecting lines.

6. *Two Systems of Trends*.—This subject also has been briefly presented in our first chapter. We have shown that throughout the Pacific, westward and northwestward lines prevail, and at the same time there are some instances of northward and northeastward lines in the Ladrões, the Tonga Group, and New Zealand. The rectangularity in the intersections above alluded to is often closely connected with the existence of these two systems.

We have also mentioned cases of the northeast lines curving around from north by northeast to east and west, as the curves on the coast of Asia; while also the northwest lines (the New Guinea chain, for example) bend around from north through northwest to east and west, and again curve northwest and north.

7. *Leaving the Pacific Ocean*, we discover throughout the globe, a conformity to the system of topography there exemplified. The two systems of trends characterize the lines of coasts, and give the forms to continents: and the islands of the Atlantic as well as Indian Ocean present other examples. What can be more remarkable than to find the Western Islands and Canaries trending parallel with the Sandwich Islands, eight thousand miles distant in the Pacific, and these with the New Hebrides and New Caledonia, three thousand five hundred miles beyond to the southwest?

In the continents of America and Europe, we observe the following parallel lines, parallel with the *northwest* lines of the Pacific.

1. The northeast coast of South America continued west to California, and here bending more northerly.
2. The line of great lakes from Erie through Michigan, Superior, Winnipeg, Slave and Bear Lake, to the coast by the mouth of the Mackenzie.
3. The southwest side of Hudson's Bay.
4. The coast on the west and east of Davis Strait and Baffin's Bay.
5. The Cape Palmas coast of Africa, or rather the Kong Mountains in the interior adjoining, following the same direction with the northeast coast of South America.
6. The Pyrenees, parallel to the last.
7. The Red Sea, Adriatic and British Isles.
8. The Persian Gulf.
9. Western Hindostan.
10. The coast from Calcutta by Malacca.

The above are close approximations to parallelisms, with such variations as have been shown by examples in the Pacific to be parts of the system.

The following, passing over the same ground, are *northeast* trends.

1. The southeast coast of South America, four thousand miles long.
2. The coast line from the Gulf of Mexico along by Newfoundland and Greenland, a distance of five thousand miles.
3. The line of Lakes Ontario, and Erie, and the River St. Lawrence.
4. The Appalachians.
5. The coast on the northwest of Hudson's Bay, and that by Prince Regent's Inlet.

1. The east coast of the Atlantic by western Africa, Spain and Norway or the Baltic. The line is nearly a continuation of the southern coast of South America, and the break made by the ocean is partly filled by the islands Fernando Noronha, St. Paul, and the Cape Verds.

2. The eastern coast of Africa.
3. Madagascar.
4. Northern coast of Asia from the Obi Gulf to the northeast cape.
5. The east coast of Hindostan.
6. The east coast of Asia.

These many parallelisms are too striking to be set aside by the few

instances of nonconformity, especially after it has been shown that irregularities or variations from uniform directions are an essential feature in the physiognomy of the world.

Both systems are very distinctly illustrated in Australia, and the facts there, were long since stated by Fitton.* All the great lines, both of mountains and bays, have either a course between northeast and north-northeast, or northwest and west-northwest. The mountains of the southeast coast; the east and west shores of the Gulf of Carpentaria, and the islands off its west cape; Cambridge Gulf and the coast a few degrees east; the northwest coast; and the bays in South Australia, have the former trend: while the south shore of Gulf Carpentaria, and the east coast of Australia in nearly the same line; the coast by Cambridge Gulf; the coast of South Australia; the Bay of Sydney or Port Jackson, and others, have the latter trend.

The subject might receive farther illustration by reference to the courses of cleavage joints, as brought out by Necker† and also illustrated by Darwin.‡ But it would add nothing confirmatory, since it is now an admitted fact that there is a general correspondence between the direction of these joints, and the mountain ranges or axes of elevation. The rectangularity of intersection between two systems of fissures in a region, is another branch of this subject, well illustrated by De la Beche,§ Phillips,|| Hopkins,¶ and other geologists, showing that the system which has influenced these smaller operations is the same that controlled the courses of the islands and mountain ranges of the globe.

The reader will not fail to observe that the facts, as well as principles deduced, accord in no respect with the hypothesis of M. Elie de Beaumont that the direction of a mountain chain is an index of its age.

VI. ORIGIN OF THE GENERAL FEATURES OF THE PACIFIC.

In the foregoing survey of the lands of the Pacific Ocean, we have considered the nature and origin of their features, internal and ex-

* Sketch of the Geology of Australia, *Phil. Mag.* lxxviii. 135.

† *Bibliothèque Universelle de Genève*, xliii. 166, 1830.

‡ Darwin on South America. 8vo. *London*, 1846, page 163.

§ *Geol. Rep. on Cornwall, Devon and West Somerset*. 8vo. *London*, 1839.

|| *Geology of Yorkshire*.

¶ *Trans. Camb. Phil. Soc.* vii.

ternal, the general arrangement of the islands in groups and ranges, and the evidences of change of level in different epochs. We may take a more comprehensive view of the facts, and inquire still farther into the origin of the great system of arrangement in the Pacific lands, and the connexion between the prime cause of this arrangement and the extent and position of the regions of subsidence which have been pointed out.

The several facts upon which our conclusions are based, may here be repeated :—

1. A general linear arrangement of the groups, and their subordination to ranges or chains, sometimes several thousand miles long.

2. A prevalence of northwest ranges (northwest by west, the average course) throughout the ocean, and consequently an approximate parallelism of the groups from New Holland across the Pacific to California. Also the existence of ranges nearly at right angles with the prevailing *northwest* system.

3. The linear groups based on a *series* of ruptures, instead of a single uninterrupted fissure, and forming “continued,” “advancing” or “receding” series; with frequent parallel ruptures in the same group, and occasional transverse lines.

4. A series of ruptures often largest at one of its extremities; and also, the several ruptures frequently largest at the corresponding extremity of each.

5. A frequent curved form to long ranges, and also to subordinate parts of ranges: the curves either proceeding from the position of the parts in “advancing” or “receding” series, or from a change of trend in the parts themselves, or from both these causes united.

6. When a curving range is met by transverse ranges, the latter vary in direction with the curve, so that the two are nearly at right angles with one another.

7. A parallelism of the groups of the Atlantic with those of the Pacific; and also a general parallelism between the two Pacific systems of trends, and the direction of coast lines and mountain ranges throughout the globe.

8. A tendency to curved directions in ranges and parts of ranges often modifies widely the courses of the earth’s physiognomic lines, although a prevailing northeasterly and northwesterly direction may be distinguished. The southwest lines may bend north on one side, and west on the other; and so the northeast may curve around from

north through northeast to east; and even greater variations of direction take place in a single range.

The truth forces itself upon the mind, in view of these facts, that some universal cause has operated in producing results so general, and so mutually dependent—a cause, through which, the very framework of the globe has received its characteristic features. We are also led to believe that it was in the early stages of the earth's history that the grand outlines of its structure were drawn which have been since filled up by subsequent operations. The prevailing uniformity of trend in the courses of ruptures of the earth's crust, must have proceeded either from the nature of the crust fractured, or the direction of the fracturing forces, and facts show that both causes have acted. For the occurrence of a linear series of rents, made up of a number of parallel ruptures oblique to the general line, proves that there was a fixed direction to the power causing rupture indicated by the direction of the line, and also a determinate structure indicated by the direction of the several rents.

The existence of such a structure in the earth's crust has been urged by Necker, Boase, De la Beche, Boué, Hopkins and others.* It has been attributed to the influence of magnetic or electrical currents on the process of crystallization while the earth's exterior was cooling from a state of igneous fusion, and also to the mechanical effect of an elevating force.†

The view that the earth has cooled from a state of fusion is generally admitted, and finds additional proof in the evidences, coextensive with the world, of a prevailing structure.‡ The influence of electri-

* M. NECKER, Bibliothèque Universelle de Genève, xliii. 180, 1833.—DE LA BÈCHE, Geological Report on Cornwall, Devon, and W. Somerset, p. 281, 8vo. London, 1839.—H. S. BOASE, Treatise on Primary Geology, 8vo. London, 1834, and L. and E. Phil. Mag. and Journ. of Sci. ix. 4, x. 14.—M. BOUÉ, Bull. Soc. Geol. de France, ii. ser. i. 355.

† W. HOPKINS, Esq., Trans. Camb. Phil. Soc. vii. 1.—C. DARWIN, on South America, 8vo. London, 1846, p. 163.—REV. A. SEDGWICK, on the Structure of Large Mineral Masses, Trans. Geol. Soc. London, ii. ser. iii. 480, March, 1835. Mr. Hopkins attributes the existence of parallel fissures in a region which has experienced elevation, and also of *transverse* lines, to the tension consequent on the elevation, and he shows by mathematical calculation that these are both necessary results of such a cause. Mr. Darwin, observing in western South America the general parallelism of cleavage lines to the Andes, suggests that the tension attending elevation, being unequal in different parallel lines, was the cause in this and other cases.

‡ W. Hopkins, Esq., has deduced from calculations based on the amount of precession

cal currents on the position of crystals in process of formation, is another fact established by modern science;* and the constant circulation of these currents about the earth has been ascertained, as well as the direction of isodynamic lines. As solidification would take place with extreme slowness after the first crusting of the surface began, and would continue afterward at a rate inconceivably more slow, the circumstances would be favourable through all ages, subsequent to the first step in the process, for a coarse crystallization of the material below, and for the general operation of electric currents.

It was first shown by Brewster that the isodynamic lines of the globe correspond with isothermal lines. Within a recent period, this relation of heat and magnetism has been mathematically investigated by Prof. William A. Norton.† The courses of electric currents, or rather the lines of equal intensity, would consequently be lines of equal heat or equal cooling, and therefore of equal tension as a result of the contraction attending refrigeration. Tension, heat, and electricity, therefore, would be at first combined in producing a common result, and we cannot doubt that some degree of structure would necessarily be thus impressed upon the cooling crust, and a structure analogous to that in the crystalline rocks of the surface. These crystalline surface-rocks illustrate well the result, although they must be viewed as distinct to a great extent from the cooled material which by a single long-continued operation has been gradually solidifying beneath the surface: and they should not necessarily conform to the latter in the direction of cleavage. The two transverse cleavages of granite due to its feldspar are well known; and it is also a fact, that feldspar is by far the most abundant mineral in igneous rocks. There is then a very probable cause before us for the structure which is shown to pertain to the solid material of our globe.

There is certainly a striking coincidence between the trends of many of the island ranges of the globe, and a chart of isodynamic lines, as may be seen by comparing our chart with the chart of magnetic

and nutation, that "the minimum thickness of the crust of the globe, which can be deemed consistent with the observed amount of pressure, cannot be less than one-fourth of the earth's radius."—Researches in Phys. Geog., in Trans. Roy. Soc. London, for 1839, p. 381, for 1840, p. 193, and for 1842, p. 43.

* R. HUNT, L. E. & D. Philosophical Magazine and Journal of Science, Jan. 1846, page 1; American Journal of Science, ii. Ser. ii. 116.—R. W. Fox, Report of the Polytechnic Society of Cornwall for 1837, pp. 20, 21, and 68, 69.

† Amer. Jour. Sci. ii. Ser. iv. 1, 207.

intensity by Major Edward Sabine, R. A., in the Report of the British Association for 1837.* A correspondence throughout, or even in the majority of cases, could not properly be expected, considering the changes that must have taken place during the progress of the earth's history, and also those other sources of influence bearing upon the direction of ranges of fissures.

With regard to the action of the rupturing force, (which in connexion with a specific structure has produced the features under consideration,) we observe in the first place that the great length of ranges or chains, and the relations of long systems of curves like those of Eastern Asia, and also the dependence of transverse lines as in the East Indies and Pacific, all show that this power has exerted its influence on a grand scale: for these are not the effects of accidental earthquakes or limited agencies, but a systematic result of a general cause. This cause we have elsewhere shown is to be found in the contraction that attends cooling. The reality of this force cannot be doubted; and the only question with us is whether the effects in view correspond or not with those that would proceed from this cause. As this subject is presented by the writer in another place,† we offer here only a brief statement of it.

After a cooling globe is incrustated over by refrigeration, the contraction still going on beneath as the cooling progresses places the crust in a state of tension; the contraction tends to draw it towards the centre, which effect its own rigidity resists. It is this power of tension in a Prince Rupert's drop (a drop of unannealed glass) that causes it to fly into a thousand fragments when the surface is merely scratched and the balance of forces disturbed: and the same principle operates on a scale of immensely greater magnitude in a globe of cooling rock. This tension, therefore, must necessarily produce fractures and displacements.

The direction of this force will depend on the rate of cooling in different parts, and also on that change in the earth's oblateness that would accompany a diminution of the earth's diameter. Large portions of the globe might cool before others, and this would modify the amount of force in different parts, as well as the mode or direction of its action.

Now we ascertain from the continents that they were early free

* Report of the Seventh Meeting of the British Association for the Advancement of Science, held at Liverpool in September, 1837, vol. vi. London, 1838.

† American Journal of Science and Arts, ii. Ser. ii. 335, and iii. 94, 176, 381.

from volcanic action, for throughout the whole interior of America we find no evidence of such fires, and the remark applies almost as strictly to the whole eastern continent; they were extinct even before the early silurian epoch. Igneous eruptions over these extended regions have since been confined to fissure ejections. But over the Pacific Ocean, volcanoes have abounded: every high island in Polynesia, excepting New Zealand, is of igneous origin; and even the coral islands probably rest on a base of similar character. In the Atlantic too, the islands are of the same volcanic nature. We hence naturally conclude that the continental portions of our globe first cooled, and became solid, and that the intermediate parts cooling at a later period or less rapidly, contracted most, inasmuch as the crust was here thinner:—just as a lead or iron ball is often found to have the surface depressed on the side that cooled last. The oceans were in general the more igneous portions of the globe, and the continents the parts which were first free from fires.

This view is confirmed by the fact that the continent of America is nearly cut in two by the ocean where volcanic fires prevail across its track from east to west, and where, consequently, subsidence from contraction was longest continued;—that the East Indies, properly a southeastern prolongation of Asia, is another archipelago abounding in volcanoes, instead of being a part of the continent: that New Holland* and Borneo, and all large bodies of land, are free from volcanoes over their interior, and that all volcanic regions are in or near the ocean.†

Our own investigations in the Pacific, following out the general deductions of Mr. Darwin relating to coral islands, have shown that this ocean has undergone a subsidence of several thousands of feet during the growth of coral. This would seem to be the close of the long period of subsidence which had been in progress from the remotest era. During the same period the continents have on the whole become more elevated than they were before, as tertiary beds

* The only volcanic tract is one in South Australia. So in Borneo there are no volcanic mountains known excepting those near the coast.

† This last fact has been attributed to the supposed importance of the ocean's waters in promoting volcanic action. But if this would account for the absence of volcanoes from the interior of continents at the present time, what was the reason in the silurian period, for the absence of volcanoes from these same regions, then beneath the sea, or bordering it? It is obvious that some other cause must be assigned for the proximity of volcanoes to the ocean.

and the various terraces show. Indeed, the continents from the earliest period have from era to era been rising, though subject to oscillations which may not now have entirely ceased. This will be gathered from any geological treatise.

If then the oceans were the regions of greatest contraction, these subsiding areas would be gradually deepening as long as contraction continued. Moreover, the tension, from its nature, would be exerted nearly horizontally. It would produce fractures over the subsiding surface until the strength was such as effectually to resist it. It would act also on the borders of the subsiding areas, with some mechanical advantage, and the effects of lateral pressure would therefore appear along the borders of continents, in fissures, disruptions, elevations and subsidences. These are necessary effects of the cause; they must have happened, if the earth cooled unequally.

Looking to the continents, we observe that these very effects have happened. Foldings, dislocations and lofty elevations, are common in the vicinity of the oceans, and make a crimped border to the great oceanic basins. The volcanoes of the globe extend in lines generally along the same region, and metamorphic and volcanic action have often been most rife on the oceanic side of the lofty mountain elevations bordering the sea. Illustrations of this fact have been pointed to in North America, whose interior is to a great extent a region of scarcely disturbed stratification, while on one side rise the Rocky Mountains, a lofty border to the Pacific, and on the other, the Appalachians, a corresponding border to the Atlantic; and the volcanoes of the former region as well as the metamorphic changes and foldings of the latter, are on the *oceanic* side of the mountains; moreover the direction and steeper west than east slopes of the Appalachian folds are just what lateral action over the Atlantic should produce.* The Andes also, have their volcanic action and principal dislocations on the side towards the neighbouring ocean. We observe too that the largest ocean, the Pacific, is encircled by volcanoes, the line extending from New Zealand, by the Philippines, Japan, and Kamschatka, around by the Aleutian Archipelago to Northwest America, and south by the Andes to Tierra del Fuego; and recent discoveries have shown that Deception Island is not the only volcanic region on the southern border of this ocean. Around the Pacific, moreover, we have some of the highest mountains of the globe. Bordering the Atlantic, on the contrary, we have on the western shores, no volcanoes and comparatively low mountains, and but few points of eruption on the eastern.

* American Journal of Science, ii. ser., iii. 182.

The Indian Ocean is another vast oceanic area; and it comports exactly with these views that over northern Hindostan, rise the lofty Himalayas.

We may conclude, therefore, that the subsidence of the oceanic areas has produced, to a great extent, the mountains of the continents. Until after the carboniferous era, we have little evidence of high mountains in America; for the Appalachians are of more recent date;* and the Rocky Mountains and Andes, although they had commenced to expand before, did not reach their present elevation till the tertiary period or later. We also infer that the oceans and continents of the globe have never changed places. The cause was at work from the beginning which resulted finally in producing the present oceanic depressions. During earlier times of igneous action, when the depression was still shallow, the oceanic area may have been largely covered with dry land. But as it deepened, these lands decreased in extent from the subsidence in general progress; the continents were more and more uncovered as the ocean cavity enlarged to receive the waters; and after various changes, the existing condition has resulted, in which nearly three-fourths of the globe† still present a surface of water. There is some evidence that no continent has occupied the present position of the Pacific, within any of the more recent geological epochs, in the absence of all native quadrupeds from its islands, and even from New Zealand. It hardly requires remark that minor changes of elevation that have taken place in both the oceans and continents, or along their borders, do not conflict with these general conclusions. The term continent should properly include all that surface of land which, whether submerged or not, is actually raised far above the great oceanic depressions. The outlines of continents may be greatly varied by slight changes of level; but not so the extent of these more elevated portions of our sphere.

In these operations we see a sufficient cause for those oscillations in the water level which the character of the rocks indicate. The changes of level in progress would be gradual or abrupt according as the tension produced a progressive yielding, or met with resistance which gave way only after an accumulation of force; moreover, during the earliest periods, variations in the places of igneous action would vary much the water level. There is hence an abundant cause for changes of level on the globe, without appealing to an incompre-

* American Journal of Science, ii. ser., iii. page 95, 181.

† Prof. S. P. Rigaud, Trans. Cambridge Philosophical Society, vi. 289, 1837.

hensible subterranean force. The lifting of the continents may have been only a result on the whole of the deepening of the ocean's bed.* The fractures attending contraction, would occasion *earthquakes* without the medium of vast cavities within the earth for the conveyance of vapour. The abrupt yielding of the earth's crust, after long ages of increasing tension, would cause vast agitations of the oceans, as well as changes of level; and *epochs* in the earth's history might thus be marked off.

It is a remarkable fact confirmatory of these views, that the axis of subsidence in the Pacific, as indicated by the coral islands, is very nearly identical with that which would be deduced from the positions of the ranges of islands. The author had previously laid down the former, and by an independent train of reasoning without connexion in the mind, arrived at almost the same position for the latter. The great central chain of islands, it is observed, curves with the convexity to the southwest. It seems like an outline of a vast elliptical area, or like a concentric line across such an area. The Hawaiian chain on the north, has a slight curvature in the opposite direction. The former consists of subordinate parts that are "advancing" successively toward the northward, while in the latter the parts are "advancing" to the southward; that is, the two have a reverse relation to the included area, although the Hawaiian line is much more nearly straight. We therefore conclude with reason that the axis of greatest subsidence for the central part of the ocean should be drawn somewhere between these groups. A consideration of all the circumstances bearing upon the question have led us to place it on our chart along a course extending from near Easter Island, towards the north of Nippon (Japan). This line (A' B') passes by the Marquesas and

* Some of the effects of this cause are presented by C. Prevost in the Bulletin of the Geol. Soc. of France, xi. p. 183. See also American Journal of Science, ii. ser. iii. 178.

The following authors have written more or less fully upon contraction as a dynamical cause in geology.—M. CORDIER, *Essai sur la Temperature de la Terre*, 4to. pp. 84; read before the Academy of Science, June 4 and July 9 and 23, 1827. American Translation, Amherst, 1828.

ELIE DE BEAUMONT, *Recherches sur les Revolutions de la Surface du Globe*, ib. 1829.

DE LA BECHE, *Researches in Theoretical Geology*, 12mo. London, 1834.

M. LEBLANC, *Bull. de la Soc. Geol. de France*, xii. 137, 1841.

W. W. MATHER, *American Journal of Science*, xlix. 284, 1845.

J. H. LATHROP, *ibid.* xxxviii. 68, xxxix. 90.

CHARLES BABBAGE, *Proceedings Geol. Society of London*, 1834. *Quarterly Journal of the Geological Society*, No. 10, May 1, 1847, p. 186.

Preceding all these authors, LEIBNITZ in his *Protogæa*, §§ iv. vi. xxii.

Fanning's Group, which lie nearly in a straight line. On the same chart, the green line (A B), from north of Pitcairn's towards northern Nippon, is that which I had before arrived at for the coral island subsidence. The close approximation of the two is a point of high interest. It strongly confirms the position that the subsidence in progress during the coral epoch was the conclusion of a long period of progressive subsidence. We have shown, moreover, that subsidence is probably still in progress at the northern Carolines, the islands which lie *nearest* this axis.

The *curving direction of ranges* is another result of the grand cause to which we have appealed. The curve in the central Pacific chain has already been alluded to. Its probable connexion with a vast elliptical area of subsidence is too obvious to require farther remark.

Large areas of non-contraction should occasion a similar result. The subsiding Pacific area, has to the southwest the semi-continent New Holland, where contraction was in much slower progress. The lateral tension would naturally produce fractures around this area; and in conformity, we observe the curving ranges which bend around its north and east coasts. The same ranges again bend north, as if modified in direction by the large island of Borneo, and the position of the Indian Ocean to the south and west.

The fact of unequal subsidence in different parts of the Pacific will be gathered from what has been stated on the preceding pages. Indeed, perfect equality is seen at once to be altogether impossible. In the coral epoch, as shown on page 399, the area of subsidence had an irregular southern border. This inequality is a necessary source of *curves* in the lines of fractures. The tension, exerted in parallel lines across an area, will usually have its line of maximum intensity, from which line it will diminish laterally. It could not, therefore, in this case produce a straight series of fractures; for as the fractures depend on the force, they will differ in position according to the amount of it, and any regular variation of the force not in simple arithmetical ratio, should produce a series of fractures having a curved form. There should, therefore, be long ranges of curves from the action across wide areas, and also subordinate curved lines from an inequality of tension in certain *parts* of these wide areas. Thus it is that the Pacific might be bordered with a series of grand curves, as from the Aleutian Archipelago to Borneo, having the relation to one another and close connexion which has been pointed out; and also other smaller curves might exist like that of New Ireland; that by the Sooloo Islands, and

another by Sanguir, and those of the Tarawan and Radack Islands, all of which are subordinates to main ranges.

Since Mr. Hopkins has shown that there are two systems of fissures, at right angles with one another and mutually dependent, produced as a necessary result of the elevation of an elliptical area, we are not surprised at the rectangularity of intersecting lines in the Pacific. They belong to the system of results proceeding from the grand cause upon which the features of the ocean depend. The transverse line, including New Zealand, the Kermadec Islands and the Tonga Group, (and which embraces in its course north, Samoa, Fanning's Group and the Hawaiian Islands,) crosses nearly at right angles the central elliptical area of the ocean.

From the various facts which have been presented, the early origin of the Pacific volcanoes or vents of eruption appears to be highly probable. We cannot rightly refer them all to a single era. The system in the arrangement of lines of islands, has not necessarily arisen from a cotemporaneous origin. On the contrary, it has rather proceeded, as the principles explained confirm, from a uniformity of origin and direction in the forces causing ruptures and displacements. We learn that the oceanic area has always been exerting tension laterally by contraction; and the identity of position between the central elliptical region of greatest subsidence, indicated by the trend of the islands, and that deduced for a late period from the coral reefs and islands, shows us that this area has preserved a singular uniformity of character, even from the epoch when its outlines first began to appear, till these recent times in geological history. Different fractures having a common direction, or constituting different parts of a curving range, may therefore be the result of distant ages. In other regions, the unequal progress of cooling may have changed somewhat the direction of tension, and therefore the striking uniformity seen in the Pacific is not everywhere to be expected. With all the irregularities, however, it is plainly perceived that the world has a system in its great features, the result of a single plan of development.

It is obvious from the views offered, if we have not been wandering in error throughout, that the earth has reached its present condition by gradual progress from a state of prolonged igneous action through epochs of increasing quiet, interrupted by distant periods of violence, to the present time, when even the gentlest oscillations of the crust have almost ceased.

A recapitulation of some of the topics that have been discussed is here presented, exhibiting briefly the origin of such of the grand features of the earth as depend on its gradual refrigeration and continued contraction.*

I. Solidification of the surface after the fluid material had lost its perfect fluidity.

a. The change inconceivably slow, and hence the rock formed having a coarsely crystalline texture:—the subsequent progress of solidification *beneath* the crust still more gradual, and therefore producing at all periods of the globe a coarsely crystalline texture:—the whole the result of a single immeasurably prolonged operation.

b. Hence, probably, a general uniformity in the crystalline structure, sufficient to give the crust apparently two directions of easiest fracture, whose mean courses are northwest-by-west and northeast-by-north; yet varying much, being probably dependent to a great degree on the early direction of isothermal and isodynamic lines.

c. In the progress of this cooling, commencing with its first beginning, the surface necessarily presenting large circular or elliptical areas that continued open as centres of fluidity and eruptive action.† Subsequently, a gradual reduction in size of these centres of igneous action and their frequent extinction.

d. A boiling movement or circulation (up at centre and down around the sides) in the vast circular areas of igneous action, owing to escaping vapours, and dependent mainly on the temperature being greatest below at centre and least at the surface and laterally. As this circulatory or cyclosis movement occurs in material whose mineral ingredients or products differ in the temperature of solidification or of formation, it determines to some extent the distribution of these mineral constituents, and of the rocks which are formed. In later periods, this cause producing a feldspathic centre to volcanic mountains having basaltic sides.

e. As refrigeration went on, the centres of eruption becoming mostly extinct over large areas, and remaining still active over other areas of as great or greater extent:—for cooling, wherever commenced, would extend somewhat radiately from the centre where begun, (yet with some relation to the structural lines,) and so gradually enlarge the solidifying area and encroach upon the more igneous portions.

II. Contraction, as a consequence of solidification, attended by a diminution of the earth's oblateness.

a. Rate of contraction in different parts unequal, according to the progress of refrigeration; and after the formation of a crust, greater beneath the crust than in the crust itself.

b. Contraction beneath the crust causing a subsidence of the surface.

c. Subsidence greatest where the crust was thinnest or most yielding, and least in those parts which were thickest from having been first stiffened by cooling:—the large areas that continued to abound in igneous action therefore becoming in process of time more depressed than those areas that were early free (or mostly so) from such action.

d. Subsidence of the surface progressive; or, if the arched crust resisted subsidence, a cessation, until the tension was such as to cause fractures, and then a more or less abrupt subsiding.

e. Frequent changes and oscillations in the water level, either gradual or abrupt, arising from the unequal progress of subsidence in different parts, and also in early periods from extensive igneous action.

* For a fuller exposition of several points touched upon, we again refer to volumes ii. and iii. (ii. ser.) of the American Journal of Science.

† Well illustrated on the surface of the moon, as also are many of the points here mentioned. (Amer. Jour. Sci., ii. ser. ii. 335.)

III. Fissures and displacements of the crust, owing to the contraction below it drawing it down into a smaller and smaller arc ; also, from a change in the earth's oblateness.

a. Fissures influenced in direction by the structure of the earth's crust,—because of the existence of such a structure, and also because the tension causing fractures would be exerted with some reference to the structural lines, the tension and the structure being both simultaneous consequences of cooling.

b. Direction of fissures modified by the relative positions of the large areas of unequal contraction, and whatever the actual course, frequently attended by transverse fractures.

c. As the force of tension acts tangentially in a great degree, (like the pressure of stone against stone in an arch, and that of the whole arch against the supporting or confining abutments), the effects will appear either over the subsiding area, or on its borders ; and they will be confined to the latter position whenever the surface is strong enough to resist fracture.

d. The borders of large subsiding areas sooner or later experiencing deep fissurings and extensive upliftings through the tension or horizontal force of the subsiding crust ; these upliftings frequently in parallel series, of successive formation, or constituting a series of immense parallel folds ; *that* side of the fold in general steepest which is most remote from the subsiding area.

e. Fissures formed having the character of a series of linear rents either in interrupted lines or parallel ranges, instead of being single unbroken lines of great length, and this owing to the brittle nature and structure of the earth's crust ; ranges sometimes curved, either from having a general conformity to the outlines of contracting areas, or because proceeding from an inequality of force along parallel lines of tension over a subsiding area.

IV. Escape of heat and eruptions of melted matter from below through opened fissures.

a. Igneous ejection of dikes an *effect* and not a cause of displacements.

b. Some points in the wider fissures continuing open as vents of eruption. The outlines of large contracting areas being liable, from the cause just stated, to deep fissurings, these therefore likely to abound most in volcanic vents.

c. Heat from many fissures giving origin to hot springs.

d. Distribution of the heat attending submarine action, causing metamorphic changes.

V. Earthquakes, or a vibration of the earth's crust, consequent on a rupture, internal or external, and causing vibrations of the sea besides other effects.

VI. Epochs in geological history.

VII. Courses of mountains and coast lines, and general form of continents, determined to a great extent by the general direction of the earth's cleavage structure, and the position of the large areas of greatest contraction.

Thus the existence of continental areas determined the existence of the mountains they contain ; and also the mountains in their turn determined to some extent the position and nature of subsequent deposits formed around them, effecting this either directly, or by influencing the courses of ocean currents during partial or entire submergences, or by determining the outlines of ancient seas of different epochs. According to this view, the general forms of continents, and those of the intermediate oceanic depressions, however modified afterward, were to a great extent fixed in the earliest periods by the condition and nature of the earth's crust. They have had their laws of growth, involving consequent features, as much as organic structures.

CHAPTER VIII.

GEOLOGICAL OBSERVATIONS ON NEW ZEALAND.

THE three islands included under the general name of New Zealand form a broad strip of land, running in a direction from southwest to northeast, and having a narrow northwest prolongation at the north extremity. The whole is included between the parallels of thirty-four and forty-seven and a half, south latitude. In general form, it is similar to that of Italy reversed. In size, it is four times as large as the Italian peninsula, the body of the boot being eight hundred and fifty miles long, and the foot nearly five hundred miles. Cook's Straits is a passage twelve to sixty miles wide, cutting irregularly across the leg of the boot, three hundred and fifty miles above the heel, and thus separating the northern and middle islands. The middle island is four hundred and eighty miles long, and has an average breadth of ninety miles. The third or southernmost island lies near the south angle of the middle island, and is but fifty miles in diameter. The three form parts of one system, and but for a break of *twelve* miles in two places, would constitute a single continuous chain. The aggregate area is about equal to that of England and Scotland.

A range of lofty mountains traverses the whole length of the middle island, and continues its northeasterly course through the northern island. In the former they rise in many places into the regions of perpetual snow, and contain talcose and granitic rocks, besides sandstone and argillaceous strata. In the latter there are some lofty peaks, the highest of which are volcanic cones; of these, according to Dr. Dieffenbach,* Mount Egmont, situated at the southwest angle, is nine thousand feet high, and Tongariro six thousand feet. In the interior there are many lakes, besides boiling springs or geysers, which have resulted from volcanic action. The northwestern

* Dieffenbach's New Zealand. He makes 7204 feet the limit of perpetual snow.

prolongation or foot of the boot is a region of hills and mountains, some of which are three thousand feet in height, and here also there are several extinct craters and hot springs. This part of the island is remarkable for its deep irregular bays, which nearly divide the peninsula into an archipelago.

The Bay of Islands is one of these indentations, though by no means the most remarkable. It is an irregularly branching area of waters cutting deeply into the coast, and sending coves in every direction far among the hills. It is about twelve miles long, and averages three in breadth, though varying from one to twelve miles. On account of the many extensive coves, a walk of five miles or more is often required to accomplish a distance of a single mile along the shores. Its waters are studded with islands, which well entitle it to the name it bears. Rude sugar-loafs, truncated cones and rugged peaks of rock, either barren or with an occasional spot of green, diversify the water scenery. Nearly every point has its half a dozen islets, with boat passages between them; and there are places innumerable where the sea dashes wildly through narrow channels among the isolated rocks, or roars in the deep caverns it has excavated. The neighbouring country is a succession of hills and deep valleys, and in every direction the traveller finds tedious ascents, occasionally leading up a thousand feet. A dense growth or thicket of ferns has succeeded the former forests which have been burned.

We have already remarked that the portion of the group trending northwest is parallel with the grand ranges of the Pacific, while the other portion has the transverse direction of the Tonga Islands, and along with the Kermadec Islands, is part of one and the same north-northeast and south-southwest chain.

The rocks of New Zealand include the granitic with their associated beds, and those of more modern igneous origin, with the most recent volcanic: also arenaceo-argillaceous deposits and shales, besides limestone, and beds of coal. The most prevalent in the northern island is a sub-argillaceous rock, in general scarcely schistose, and apparently of ancient date. This is the rock of the Bay of Islands and the adjoining country, the only part of New Zealand examined by the writer; and we learn from Dr. Dieffenbach that it is the most abundant deposit in other parts. It is intersected by basaltic dikes; and volcanic cones are occasionally isolated in regions of it, as at Waimate and Taiamai, twelve miles west of the Bay.

Coal has been observed at Wangarrie, on the west coast of the

middle island, on the southern coast of the northern island in Cook's Straits, in the Bay of Thames, at Wanganui on the west coast, and elsewhere.

Owing to the prevalence of the argillaceous rock, the country of New Zealand about the Bay of Islands is covered with a poor soil of a hard clayey nature, producing but little without great labour. And I was informed by the Rev. Mr. Williams that the same was the general character of the northern island even to its southern extremity. There are, however, volcanic tracts, which, though small, afford a rich soil, strongly contrasting with the unproductive clays. There is no natural pasture-land in the group, and this has been a great obstacle to the introduction of horses and cattle. Where the forests are cleared away, the fern springs up, and covers thickly the land. Both common and sweet potatoes are grown by the natives, and these, with Indian corn, have been their main dependence for food.

Vicinity of the Bay of Islands.—The arenaceo-argillaceous rock of the Bay of Islands is singularly compact, seldom showing any appearance of lamination or stratification. It is fine in texture, or almost impalpable, with no traces of pebbles or even coarse sand. The general colour is grayish-yellow, passing into grayish-brown. It is rather soft, but is intersected, in many places, by veins which are more siliceous and hard, and more or less ferruginous; and these veins are often so numerous as to cut up the rock into small irregular blocks. The blocks readily separate, and show that the veins are properly lines of fracture, and that they owe their appearance and character to a silico-ferruginous solution, which hardened the walls either side.

This arenaceo-argillaceous rock passes into an extremely hard, siliceous rock, apparently of the same constitution as the softer variety. These siliceous portions do not constitute distinct layers, alternating with others that are soft; on the contrary they are local, arising seemingly from an alteration of the other rock, and graduating into it laterally, instead of vertically. They cover, however, large areas, and are prominent in producing the peculiarly rugged scenery of the coast. Seams or veins of pure quartz are numerous.

The general colour of the siliceous cliffs is a dirt-brown or grayish-black; sometimes, however, it presents a dirty white, grayish-blue or pale flesh-red colour. These varieties may be seen on the shores of the harbours of Parua and Tipuna. At the latter locality, the rock contains layers of red and brown chert, and also nodules one to six

inches in diameter, of white and coloured quartz, which have much the appearance of imbedded boulders. They are penetrated, however, to a depth of half an inch with the material of the enclosing rock. At the same place, there are small seams of black or greenish shining shale, which cleaves readily, affording curved laminæ. The rock in these parts has much resemblance to some chlorite beds, and the slate, where green, is actually a variety of chloritic slate. A hand specimen would be taken without hesitation for a fragment from a true chloritic rock. The metamorphic changes here indicated are hence of great interest; and we regret that so little opportunity was offered us for following them out.

The *stratification* of the formation we are describing, is occasionally indicated by distant parallel lines along the cliffs of a coast, though seldom distinguishable, even when a cliff is forty or fifty feet high. These parallel lines, when apparent, vary from six inches to as many feet in width of interval; they are most distinct where the surface is water worn, and are thus brought out when not seen on a fresh fracture. The dip is in all directions from 90° to 30° , but generally varies between 45° and 90° . There are other lines or fissures crossing those just referred to, and equally distinct, which throw doubts on any conclusions as to the stratification.

Within a few yards at the head of the Bay, near the mouth of the Waikate River, the dip varies from 60° to the southwestward, through verticality to 70° to the northeastward. Passing over a few rods of the coast to the northward of this place, I took down the following:—

Dip to the southeast, 70° .

Numerous parallel fissures dipping to north-northeast, 75° .

One, near by, dipping to northward, 80° .

Two large fissures dipping to the northwest-by-north.

Numerous parallel fissures to east-northeast, 80° to 85° .

One fissure dipping to east-by-north, 60° .

Another crossing the last, dipping to the southeast-by-south, 70° .

Several parallel fissures dipping to northeast-by-north.

The same diversity in direction is common. The general direction, however, in the region just referred to, is to the northward and eastward. In many parts of the Bay, there is too great a confusion of lines to make out any general direction; and in many others no fissures whatever could be detected. At the mouth of the Kirikiri River I found a dip of 40° to the north-northeast, though seldom distinguishable; and across the river, at Mataroa, the layers were from one to five

feet thick, and inclined to the east 60° . Yet I could not satisfy myself that these were planes of deposition.

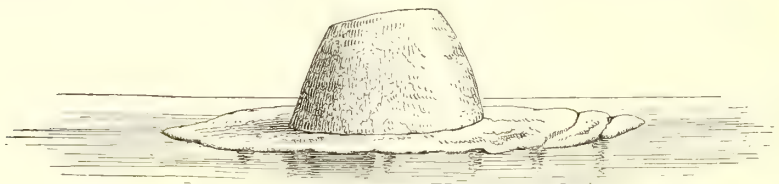
No *fossils* were observed in this rock. A single *Pecten* was handed me by Mr. Swain, who picked it up on the Pahia beach, on the west side of the Bay; but he could not be certain of its locality. A few other imperfect specimens were received from Mr. Waterford; but these also were of undetermined locality. Although we suspect the rock to be one of the earlier deposits, belonging in the geological series below the coal, we have no decided evidence on this point from organic remains. Dr. Dieffenbach places the formation in the silurian period.

The rock afforded us few minerals. With the exception of the quartz and iron referred to, and some pyrites, nothing was found in the neighbourhood of the Bay. Specimens of manganese are brought, it is said, from the Thames; but we know nothing of its position. Copper mines have recently been opened in New Zealand; but we are not informed as to the containing rock.

Decomposition and Degradation of the Rocks.—The soft argillaceous portions of the rock described, undergo rapid decomposition when exposed to the action of air and water. Some fresh sections had been lately made by cutting a road over the hills leading from the Messrs. Williams's farm, near Taiamai, towards the Bay: and at the time we travelled that road, hardly two years afterward, the rock was altered and crumbling to a depth of two feet. Blocks, two or three cubic feet in size, lying on the roadside near where they were thrown out at the time of the excavation, were so decomposed as to fall to pieces when struck lightly with a hammer. The altered rock appears fissured in every direction, and is divided by thin ferruginous seams into pieces about the size of the fist. The decomposition in progress sometimes changes the light yellowish colour to a bright red, owing to the included iron.

The hard siliceous varieties of the rock produce nearly the same results of decomposition. Over the hills, the peculiar character of the rock beneath can seldom be distinguished in the soil, as its character is so uniform; though along the cliffs the difference is very apparent. Alteration takes place more slowly in these harder rocks, and the cliffs are therefore abrupt rugged heights, decomposed only at the summit; while those consisting of the softer rock, are less steep, with a more rounded contour, and usually covered nearly to their foot with the crumbling clayey soil.

Throughout this region, we have instructive examples of the protection afforded by the sea against decomposition. The whole coast of the Bay, and of nearly all its islands where the rocks are not interrupted by a beach, is bounded by a rocky platform twenty to eighty feet wide. This platform is very regular in height, lying near the level of two-thirds flood tide, that is, between five and six feet above low water, the tide being eight feet in this region. The existence of this platform is owing to this protection of the sea from wear and decomposition. Above, the material has disintegrated and been washed away by the action of streamlets and the waves; but beneath the water, these effects do not take place. The cause for the particular height of the platform has already been explained (p. 109); and we have alluded to the singular forms of some of the islets. We repeat here the figure of "The Old Hat," with its broad brim. As the rock is not



stratified, the sea does not, under any circumstances, tear off and throw up large masses on the shores. The surface of the platform is generally covered with a muddy coat, a fourth of an inch thick, which is very slippery under foot, owing to its clayey nature. This coat is the softened exterior of the rock. Notwithstanding its softness, it is too adhesive to be easily washed away by the surf.

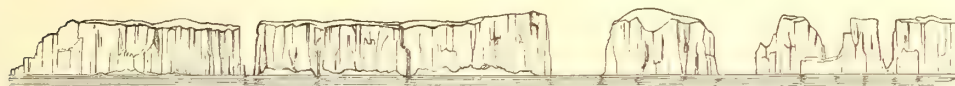
The soil which covers the country for several miles around the Bay of Islands, has arisen entirely from the rocks beneath.

Igneous Rocks and Volcanic Phenomena.

In the vicinity of the Bay of Islands, there are basaltic rocks, and several extinct craters.

Several low tabular islets occur off Tipuna, in the Bay of Islands, which consist of a dark compact basalt. They constitute a cluster by themselves, unlike the rocks of either shore, and stand with abrupt sides, and an even height of about thirty feet. The low cliff which forms their outline shows a columnar structure, in some places quite perfect and regular. The rock is very solid in texture, scarcely glistening on a surface of fracture, and contains disseminated crystals

of feldspar, besides a few small grains of chrysolite. Its colour is dark bluish-gray or grayish-black, from which fact they are generally designated the *Black Rocks*.



"BLACK ROCK," BAY OF ISLANDS.

Other similar islands lie not far distant up the same portion of the Bay, near the mouth of the Kirikiri River, and the whole appear to have had a simultaneous origin, as may be inferred from their uniformity in height and other characters. The siliceous hardness of the rock of Tipuna Bay, and also of Parua, to the southward, is probably due, in some way, to the heat of the injected basalt, and the silica which might have been dissolved at the time by the heated waters within and around these rocks. The quartz veins and chloritic beds may have had the same origin.

The *volcanic cones* of this part of New Zealand lie twelve to sixteen miles to the westward, in the district of Taiamai. There are here four regular cones, standing upon the same broad plain, besides regions of hot springs and sulphur exhalations.

The largest of the cones, called *Ahuahu*, stands about nine hundred feet above the plain. It has very evenly sloping sides, inclined at an angle of thirty-five or forty degrees, and terminates above in a narrow truncated summit. Its regularity and perfection of form lead us to infer that its fires were gradually extinguished, after a period in which cinders were quietly thrown out.

Mount Turoto is much smaller, its height not exceeding three hundred feet. The sides are more sloping than those of *Ahuahu*; the opening of the crater is very much broader, and has an undulated outline, with one side a little the highest. From a neighbouring eminence we had a glimpse of the interior of the crater, and of the large forest trees, which thrive well in the moist volcanic soil.

Poerua stands farther to the south, and is about twice the height of *Turotu*. It appeared in the first view to be an unbroken cone, perfect in symmetry; its smoothly sloping sides were overgrown with ferns, among which there was rarely a shrub to be seen. Farther to the westward the view changed. A deep gorge was seen to intersect the western side of the cone, exposing the interior of the crater, as shown in the following sketch. On the ascent, we passed over a fine black

soil of volcanic cinders. At the summit we left the dry fern beds of the exterior, and passing over a narrow lip, plunged down the decli-



EXTINCT VOLCANO, POERUA.

vity among the forest trees of the crater. By a very steep descent over loose earth, gradually changing to coarse fragments of lava, we soon reached the cool shady depths of this seat of ancient fires. Here were huge blocks of lava, fifty to a hundred cubic feet in size, lying loosely piled on one another; and among them large trees were thickly planted, whose massy foliage shut from view the height from which we had come, and all but a few points of the blue sky over head. The soil was damp, and nourished numerous succulent plants; but there was no standing water, although in a region of frequent rains. Many of the trees appeared to be as old as the forests of the plains, and nothing indicated very recent action in the volcano.

We estimated the breadth of the crater across the summit at fifteen hundred feet. The break on the west extends rather more than half way to the base of the cone, but we may infer from the exterior view, that when formed, it opened through to the very bottom, and that the lavas which then escaped by this opened passage, together with subsequent accumulations of cinders and volcanic fragments, have restored it to half its original height. The plain surrounding the volcano was strewed with blocks of lava, which the natives had collected together into heaps, to prepare the land for tillage; but on the west, where the gorge opens, the fragments so completely covered the plain that improvement was not practicable.

Small pieces of porous lava were very abundant towards the bottom of the crater. The large blocks are comparatively compact, or very sparingly cellular.

No continuous stream of lava was observed, as the region is covered with soil or the loose blocks alluded to. Near the foot of Ahuahu, at one of the villages of Taiamai, the rock appears in place for a short distance. Near Poerua, the ground in some places sounded hollow as we walked over it; and there is a small tepid spring in its vicinity, from which, as I was informed, bubbles of gas are continually escaping.

The small extent of this volcanic region is quite remarkable. Ahuahu and Poerua are only seven or eight miles distant, and Turotu lies to the west, at nearly equal distances from the two, though a little nearer the latter. The volcanic soil appears to be included within a circle of ten miles diameter; and from it, we pass abruptly to the light-coloured clays of the argillaceous formation, which are not at all blackened by their proximity to this scene of igneous action.

There are other regions of volcanic rock in this part of New Zealand, and two of small extent were passed by us on the way between Taiamai and the Bay of Islands. One of these is four to six miles from Poerua towards the Bay. After leaving the volcanic soil pertaining to the vicinity of Poerua, and travelling a mile over clays, we entered again upon a similar tract, and crossed, at the same time, a low ridge. Fragments of lava were thickly scattered around, and the soil evinced its fertility in its noble forests. Beyond were sterile clays as before, and these continued to the Bay. No distinct cone was seen; but we had too little time to study thoroughly the place. The ridge was one hundred and fifty or two hundred feet in height.

The other region referred to lies upon a more northern route to the Bay of Islands, just south of the Waitanga River, and is about seven miles from the Bay. The volcanic soil covers a space about three miles long and one and a quarter broad. A hill of steep and irregular outline, about three hundred feet high, stands near the northern side of this area, which is apparently the remains of a cone. A deep soil covers the region, and no bed of rock is exposed; but loose blocks of lava lie thickly over the plain, as in the district of Taiamai. The transition was abrupt from the yellow clayey soil to the black volcanic; and we were as surprised here, as about Poerua, at the small extent to which the volcanic material had been distributed.

The volcanic cones which have been described, are all of them cinder cones, or the result of fragmentary ejections, which probably followed an eruption of lava. Poerua is the only one in which our cursory examinations detected evidence that an outburst had taken place after the existing cone was completed.

Hot Springs.—There is a large area of hot springs (Waieri, of the natives), about four miles beyond the cone of Turoto, to the westward. On the way there, we left the rich soil around Turoto, about a mile from this cone, and travelled for three miles over an undulating country, underlaid by the prevalent argillaceous formation, and finally arrived at a broad plain enclosed by low hills, near the centre of which

lay a small lake about a hundred yards across. The shores of the lake were flat and marshy, and clumps of wiry grass and rushes covered them, excepting on the western side; here a wide flat beach runs back into a small winding valley, from which a shallow streamlet flowed to the lake, and over its surface, as well as in the valley, steam was issuing from many a pool and crevice. Some of the pools were in violent ebullition, and sent up a thick cloud of steam, and though generally clear, a few stirred up the mud at bottom by their violent action. This ebullition is produced by the escape of some gas, and not vapour of water, for the highest temperature observed was 168° F. A quantity of the gas was collected, but an accident deprived us of it before we had ascertained its composition. As no smell of sulphur was perceived, excepting a very faint trace, and the gas extinguished a taper at once, it was probably nitrogen.

The rocks and soil up the little valley are variously mottled with yellow and reddish incrustations, some of which consist of pure sulphur in layers an eighth of an inch thick. Around the boiling fountains there were also efflorescences of alum, and on the sides of one deeply seated among the rocks, there were small patches of muriate of ammonia. The water had no peculiar taste, and but a slight pyroligneous smell, which probably arose from decayed wood buried in the soil.

The features of the region afforded no evidence that the lake occupied the crater of a volcano, for there were no volcanic ejections of any kind. An area of twenty acres had apparently subsided fifteen or twenty feet, as was obvious from a terrace that surrounded the lake and the sides of the valley. We may also believe, judging from a line of elevated land that encircled the plain, that there had been a more extensive subsidence of at least a thousand acres.

Half a mile before reaching the boiling springs, we passed a larger lake of similar features to the one just described. There were no hot springs about it, though a smell of sulphur was perceived. About the shores there were piles of fallen trunks of trees, appearing like an artificial embankment. The trees lay with their tops directed outward, and formed a pile twelve feet high above the general surface of the plain; we had no means of ascertaining to what depth they extended. The region, at some former period, must have been covered with forests: and it is probable that the opening of a source of heat or hot water prostrated the trees, and gave rise to the lake. There are the same evidences of subsidence here as at Waieri.

The volcanic region which has been thus briefly described, is very inferior in extent to that of the interior of the island, of which we have an excellent description by Dr. Dieffenbach. The lofty volcanic summits of Egmont, Tongariro and Mount Edgecomb are evidence of what has been accomplished in former times on the island; and this action is still going on, to some extent, at certain points in the line. White Island, farther north, in this line, is still smoking, and is said to afford abundant supplies of sulphur. Tahua, an island in the same bay, consists of rugged basalt and obsidian. On the coast near the Thames, between Waitemata and Manukao, there are numerous extinct cones, many consisting of loose scoria.

Mount Egmont abounds in cinders, slags and lavas, though, according to Dr. Dieffenbach, not active; its summit is a plain of snow about a square mile in extent. Tongariro stands near the centre of the island, about equally distant from the east and west coasts. Innumerable boiling springs, solfataras and lakes are connected with it, and stretch along the northeast volcanic line. This crater, though still smoking, is not known by the natives to have been the scene of any recent great eruption, beside showers of ashes; it is described as an abyss a fourth of a mile in diameter. Lake Taupo is the largest of the boiling springs of this neighbourhood: it measures thirty-six miles by twenty-five in breadth, and is twelve miles distant from Tongariro, and thirteen hundred and thirty-seven feet above the level of the sea. Several streams flow into it from the snowy peak of Ruapahu and other heights to the eastward. On the western shores vapours arise from a hundred crevices or pools having a temperature of 200° to 212° F., and subterranean noises are heard, like the working of a steam engine. Near Lake Terapa, there are two square miles covered with springs of hot water; around the sides of some, siliceous sinter and magnesite are constantly forming; and about one of them saucer-shaped aggregations of silica shoot up, compared by Dr. Dieffenbach to fungi. Deposits of chalcedony are also found, resembling flint in compactness. Some of the springs are strongly saline, while others contain sulphate of iron, and evolve sulphuretted hydrogen. On the river Waikate there are numerous steam-holes and hot springs, some of which have the power of petrifying wood. A part of Rotu Mahaina, or Warm Lake, imperfectly separated from the rest by a ledge of rocks, is in constant ebullition, and steam issues from countless openings among the foliage of the hills around. Siliceous deposits form numerous steps, one to two feet broad, which in texture

are firm like porcelain, and have a pink tinge. Mammillary concretions of milk-white chalcedony and pendent stalactites also occur here. Lake Rotuma is surrounded by a low flat of pumice and earth, and is two feet in diameter; and around, there is a deposit which, in some places, is soft like chalk, and in others forms porcelain jasper and magnesite.* Some of it adheres to the tongue when applied, and is used for making pipes. The wonders of this region, as detailed by Dr. Dieffenbach, make it of scarcely less interest than the better known volcanic geysers of Iceland.

The siliceous solutions of this region instruct us on this important point, that waters highly heated by volcanic action decompose the rocks in contact, and take up silica in solution, along probably with the alkaline ingredients of the feldspar. This fact aids us in understanding the siliceous character of portions of the argillaceous rock on the Bay of Islands, and the numberless siliceous seams in the same rock there and elsewhere. The similar effects in the older sedimentary strata of our globe, and many of the metamorphic changes which are described, require no other explanation. That this should be fully appreciated, we must consider that submarine eruptions are necessarily attended by vast siliceous solutions, far exceeding in extent the pools of New Zealand or Iceland; and, moreover, the permeating waters which enable the rocks to conduct heat from its source, have the same faculty of dissolving the silica of the rock, when heated, and will deposit it again on cooling. We may believe that this cause in its different modes of operation, has been the great agent in metamorphic operations on the globe.

New Zealand, through its coal beds and copper veins, promises to be a better mining than agricultural region. The geology of the islands has been recently much enhanced in interest by the discovery of the remains of the gigantic *Dinornis*, and other birds of remarkable characters. On these points we can add nothing from personal examination, as our excursions were limited to the vicinity of the Bay of Islands.

* This magnesite is probably a soft, *aluminous* material, (instead of *magnesian*,) proceeding from the decomposition of the volcanic rocks by the action of hot gases and steam.

CHAPTER IX.

GEOLOGICAL OBSERVATIONS ON NEW SOUTH WALES.

A SANDSTONE bluff, from one hundred and fifty to two hundred feet in height, forms the North and South Heads of Port Jackson.* The rock lies in nearly horizontal beds, brought out in bold relief by the partial removal of occasional softer beds, or by natural excavations along the junction of the several layers. Passing the narrow entrance between the capes, the same light gray or grayish-yellow sandstone is seen bordering the bay throughout its extent, stretching far away around its deep sinuous coves, and advancing into prominent headlands that often confine the view to a small portion of this large expanse of waters. The sandstone usually presents a low bluff front to the bay : the upper layers retreat either by terraces or a gradual slope, into rounded elevations covered with a sparse growth of shrubbery or forest trees. These slopes continue in many places to the water's edge, especially at the head of the coves, where they terminate below in a broad sand-beach, or a small marsh, more or less changed to meadow-land by washings from the adjoining declivities.

On reaching the higher grounds about Port Jackson, which nowhere exceed four hundred feet above the sea, the eye ranges over extended plains, gently undulating, or meets occasionally with narrow gorges appearing like deep channel excavations through the general surface of the country and the subjacent sandstone. With the exception of some few ornamental trees cultivated about the handsome mansions adorning the vicinity of Sydney, there is little to relieve the dull sameness of the sterile fields around. A scanty growth of grass, with thin patches of gum trees,† and shrubbery seems to contend with the

* A view of these Heads is given beyond.

† Species of the genus *Eucalyptus*, many of which occur over New South Wales, and give a peculiar character to the forests.

sands for pre-eminence. A few agreeable exceptions to this may be found about some of the coves of Port Jackson; and the ride from Sydney to the South Head or Cape, may be recommended as offering strong attractions to the lover of the beautiful in nature, especially as the noble bay throws its own life into many of the fine views.

Such are the prevailing features of the neighbourhood of Sydney. The same, if we enlarge the undulations of the surface, and deepen the gorges, are the predominating characters of the scenery within a circuit of sixty miles or more around Port Jackson, through which the sandstone prevails. In some parts the plains are more extended; the ridges, which in the distance may seem like mountains, melt away when approached, into rounded elevations of gradual ascent. The surface, in other portions, is a succession of high rolling hills. These pass again into precipices, one to three thousand feet high, which front extensive plains, or enclose deep secluded valleys and winding defiles.

The Blue Mountains,* running nearly north and south, forty or forty-five miles west of Sydney, and attaining, in some parts, an elevation of four thousand feet, are among the most remarkable examples of these barely accessible heights. In the distant view from Port Jackson Heads, this ridge skirts with a tame outline the western horizon. But near by, it rises abruptly before the traveller, and appears to discourage any attempts at farther progress towards the interior. Indeed, for many years it was actually an insurmountable barrier to migration westward. Profound gorges intersect this sandstone range, impassable below, and offering scarcely a point of access up their mural sides. Mr. Hale of the Expedition, travelled over these mountains in his excursion to the Wellington Valley, and remarks, in his journal, that in the fifty miles passed in crossing them, "there were but five or six miles of level ground, and these were due chiefly to the labour of the engineers. The road was constantly

* See the map of New South Wales facing this chapter. These mountains stretch north towards the northeast cape, and south to Van Diemen's Land, having in general a north-northeast and south-southwest trend, but with several large curvings which are convex eastward. South of latitude 36° they are called the Australian Alps, and one peak, Mount Kosciusko, according to Strzelecki, is 6500 feet high. (N. S. Wales, p. 52.) To the northward they are named the Liverpool Range, and some of the greenstone peaks are 4700 feet high. Among the peaks of the part called the Blue Mountains, Mount Adine, according to Strzelecki, is 4050 feet high, Mount Clarence, 3500 feet, Mount King George, 3620, Mount Tomah, 3240, Mount Hay, 2400, King's Table Land, 2790, Mount York, 3440 feet. This chain of mountains has been laid down on the map from Strzelecki's chart.

ascending or descending, and on every side, as far as the eye could reach, extended a sea of mountain ridges intersecting one another in all directions, their summits rising in detached peaks, and their declivities terminating in deep and narrow gorges. The sides of these eminences were generally clothed with a scanty growth of dark evergreen, but in some places presented only bare and rugged precipices, or masses of brown sandstone rocks. The whole scene, for the first forty miles, was wild, dismal and monotonous beyond description." "From Mount Lambie, the last, and one of the highest of the eminences in this range, the summit of the lighthouse of Port Jackson is visible at a distance in a direct line of sixty miles."

Similar precipitous heights and depths were met with by the writer on an excursion from Illawarra into the "Kangaroo Grounds," a secluded valley to the southwest of this district.* A few incidents of the way may be mentioned in illustration of the peculiar sandstone scenery of New South Wales. The Illawarra Mountain bounds on the west the seashore district of the same name, and is about two thousand feet in height. It rises from below with a very rapid slope covered with dense vegetation, till near the summit, where a perpendicular face of bare rock, made up of the edges of horizontal layers, finishes off the upper three hundred feet. As we approached the top, on the ascent, the path wound through narrow breaks in the rock, and after much climbing, especially difficult for our horses, we at last landed on the wide plain of the summit. Proceeding about three miles upon this elevated plain, we reached a small stream, flowing on in gentle rapids. We were led by our guide a few rods down the stream, and suddenly came upon the verge of a narrow gorge two hundred and fifty feet deep, presenting, in its abrupt sides, the usual succession of horizontal sandstone beds, with occasional clayey layers. From the sunny plain above, the streamlet made the venturesome descent. Too small to clear the whole height at a single leap, although very nearly perpendicular, it went skipping on from one projecting rock to another, now sliding down a mossy surface, and then leaping again to another point below; and finally the exhausted waters reached the bottom in a thin spray, falling too lightly into the limpid pool to ripple its dark surface. Deep down in the narrow gorge there were a few large trees and luxuriant shrubbery growing from projecting shelves of

* A dotted line on the map shows the route taken by the author over the district of Illawarra and its vicinity.

rock ; and smaller plants formed an open network of green over the whole walls, dripping with dew-drops, though at mid-day. This shaded recess opened to the westward into a branch of the Kangaroo Valley.

Some miles beyond this interesting spot, we left the mountain plain, to descend into the Kangaroo grounds, which we finally reached by a precipitous path like that on the ascent from Illawarra. The valley we found to be a narrow patch of land, as shown on the preceding map, scarcely averaging three miles in breadth, lying between abrupt mountain walls, from one thousand to eighteen hundred feet in height.

The features we have described are common through the sandstone region. The valleys are profound gorges, often intricate and gloomy, occupied at bottom by a narrow plain, and the bed of a stream ; and although the minor elevations have often rounded summits, or they give rise to an undulating country, the higher declivities have steep sides, and usually terminate above in a mural front of rock, if not precipitous from their very bases.

Going west from Sydney, vegetation somewhat improves, and there are extensive tracts producing a slender growth of grass, and affording profitable sheep pasturage. There are miles too of arid wastes within the circuit of sixty miles, which will long lie in a state of nature. Tall gum trees generally cover the plains ; but their thin and dry foliage is scarcely sufficient to cast a shadow below. The groves are called forests ; but the trees are generally so sparsely scattered over this natural pasture-land that a horse and carriage may drive through with good speed, and rarely meet with an obstacle. I have travelled for miles on roads through these forests, in making which it was not found necessary to fell a single tree. Some lands, especially where wet or marshy, are covered with thick brush ; but these form but a small portion of the country.

Occasional summits of basalt appear through the sandstone, and these regions may usually be distinguished by their denser forests long before reaching them. They are in general remarkable for their fertility.

Beyond the circuit of sixty miles, to which our remarks thus far particularly apply, there are similar features to a great extent, but modified in some degree by the appearance of other rocks, as limestone, clay slates, and granite, and also by a greater proportion of

basaltic ridges. We add only, and that from the statements of others, that granite appears to the west in the Clywd Valley near Mount Victoria, eighty miles from Sydney, and at other points north and south in the Blue range:—to the north, one hundred miles, and beyond in the Liverpool range, through the district of *New England*, where the granitic mountains present characteristic needle crests and sharp edges:—to the southwest, on the Wollondilly, in the district of Argyle:—and farther south, granitic and syenitic rocks, and others allied, prevail through the Australian Alps, which are continued also into Van Diemen's Land. Clay slates are said to occur beyond the Dividing range towards Bathurst, and at other places to the north and south. The limestones are met with to the west in the Wellington Valley, and other regions in that direction, and also to the southwest about Yass Plains and beyond, and south on the Shoalhaven River; serpentine occurs between Bathurst and Molong, and south of Yass Plains.

There is a single volcanic region on the Australian continent, south of the Grampians near Port Philip, where there are a number of volcanic cones and vast sheets of lava.

In the preceding remarks we give no very flattering picture of the fertility of New South Wales: and in our excursions, we saw little material for such a picture. Major Mitchell, an extensive explorer of Australia, and for some years Surveyor-General, in speaking of the recurrence of the Sydney sandstone through the southwestern portion of the colony, says,† “We again find here that ferruginous sandstone which desolates so large a portion of the territory of New South Wales, and to all appearance, New Holland, presenting in the interior desert plains of red sand, and on the eastern side of the Dividing range a world of stone quarries and sterility. It is only where trap, or granite, or limestone occur, that the soil is worth possessing.” Again he says, “Sandstone prevails so much more than all these (trap, limestone, or granitic rocks) as to cover about six-sevenths of the whole surface comprised within the boundaries of nineteen counties, (from Yass Plains on the south to the Liverpool range on the north.) Whenever this happens to be the surface rock, little besides barren sand is found in place of soil. Deciduous vegetation scarcely exists there; no turf is formed, for the trees and shrubs being very inflam-

* Strzelecki's *New South Wales and Van Diemen's Land*, London, 1845, 8vo. p. 56.

† *Expeditions into Australia*, 2 vols. 8vo. London, 1838, ii. 321.

mable, conflagrations take place so frequently and extensively in the woods during summer, as to leave little vegetable matter to turn to earth." There are, however, some fine regions, which afford a relief to the dry scene. Such are the valley of the Hunter, the plains of Argyle, Port Stephen, and Illawarra. The Illawarra district is laden with the foliage of the tropics, for palms mingle among the trees of the dense forests. There are many fine farms along the Hunter and some of its tributaries, though of limited extent.

It is well known and generally admitted among the citizens of New South Wales, that the territory is not agricultural, and consequently the attention of the inhabitants and the capital of the country has been largely given to wool-growing, an excellent material being afforded. Wool is therefore the staple product. A farther obstacle to successful tillage is encountered in the frequent droughts which, once in seven or eight years, are so excessive that the largest rivers are dried to a string of pools, and it is with difficulty that water can be obtained for land or cattle. When Oxley made his exploring tour beyond the Wellington Valley he found the whole region under water; it had been a season of floods, which are of occasional occurrence. Major Mitchell passed over the same region some years afterward and found the water of the rivers too scanty to form a running stream, and his party was finally compelled to turn back for want of water.* Mr. Hale states in his journal, on the authority of the missionaries of the Wellington Valley, that the crops of their region have wholly or in part failed for six years out of seven, and that the settlers were obliged to transport their flour and other provisions from Sydney, a distance of two hundred and fifty miles.

The *rivers* of Eastern Australia, east of the Blue or Dividing range are small streams, the largest, like the Hunter, navigable but twenty miles from the sea; and the smaller quite dried up during the summer weather. From the map of New South Wales, it might be supposed that no country in the world was better watered: but the greater part of the rivers sketched on the map are only beds of streams, which are wet or dry according to the season of the year. West of the Blue range, the streams collect from many sources over an area five hundred miles north and south, and flow towards the southwest, combining to form the Darling, Lachlan, and Murrumbidgee, and these again unite into the Murray, a hundred miles above

* Oxley inferred from his observations that the interior of New Holland was a wide sea; and Mitchell, that it was a desert.

its mouth in South Australia. But notwithstanding the large extent of surface drained by these water-courses,—not less than 250,000 square miles,—the main branches, as the Darling for example, are often reduced to mere streamlets, or pools of standing water. Some of the rivers become subterranean in the limestone region west of the Dividing range. This is the case with the Macquarie west of Bathurst, which was visited by Mr. Hale. Though a large stream, it entirely disappears in ordinary seasons by sinking into the caverns of the country.

It is a remarkable fact that many of the pools to which the rivers become reduced in dry weather, consist of brackish or saline water.

The interior of Australia is still 'terra incognita.' The early supposition that the whole was a vast internal sea, had been seemingly confirmed by the explorations of Mr. Eyre over the northern parts of South Australia.* But the later journeys of Captain Frome (1843), and Mr. Poole (1845), have made deserts of the fancied lakes. Some small pools were all the water found. It appears to be the most probable conclusion, therefore, that the interior is mostly an arid waste.

The peculiar dryness of the climate and soil of a large part of Australia,—a fact which cannot be doubted, as it is abundantly proved by observations,—admits of ready explanation on established principles in meteorology. For this semi-continent lies to a great extent within the *desert latitudes* of the globe. In Africa, and on the west coast of the Americas, both north and south, the latitudes 18° to 30° or 35° are remarkably dry, and are occupied by complete or partial deserts. The desert of Atacama, between Chili and Peru, the semi-desert of California, and the far-famed Sahara are the regions referred to. Sahara stretches across Africa, and the arid territory is continued on over Arabia.

In Australia, the same condition as regards surface exists as in Africa, though varied by the more insular character of the land. Mr. W. C. Redfield has satisfactorily explained the existence of deserts on the western side of continents in the latitudes referred to, on the principle that the winds reaching these coasts blow from a colder region, and are passing to a warmer, and, consequently, with the increase of heat, their capacity for moisture is increasing. They are therefore

* Mr. Eyre first stated the existence of the so-called Lake Torrens in South Australia, near latitude 30° and longitude 139° or 140°. Captain Frome found that the appearance of water was due to mirage.

drying winds. On the opposite or *eastern* coasts, the reverse takes place; the prevailing winds come from a warmer region, and being already surcharged with moisture, they are yielding it in the shape of rain, as they travel away from the tropics to colder regions. The winds of the west coast, unless prevented by a high mountain barrier, will affect largely the whole continent, a fact to which Africa bears sad testimony. Australia in the same manner suffers from the drying winds, through its whole width from west to east. But the characteristic weather of eastern shores, as well as the insular character of the land, throws in a modifying element, and the consequence is that there are alternations of wet and dry through ordinary seasons, and also every few years alternations of floods and droughts.

The character of the streams should be partly attributed to the soft, porous nature of the sandstone, and the near horizontality of the stratification. Owing to the latter cause, there are no inclined planes for gathering together the waters that may be absorbed from the surface, and guiding them into channels. These waters are taken up and dissipated without benefit to the country; being spread every way, instead of collecting together, they evaporate from all points of exposure, or gradually pass into the rocks to a depth below the river valleys. These remarks apply generally to the whole of the sandstone portion of the colony.

The mineral resources of New South Wales, thus far laid open, consist of mines of lead in the Yass region, and valuable beds of coal on the Hunter and in Illawarra. South Australia contains copper and lead mines of great productiveness, and gold mines are said to have been discovered.

I. GEOLOGICAL FORMATIONS OF NEW SOUTH WALES.

In the foregoing observations on the general features of New South Wales, we have comprised under the term *sandstone*, strata of different ages, as their influence on the topography of the country is strikingly similar. These rocks are naturally divided as follows:

1. Sandstone above the coal, including subordinate layers of argillaceous shale. We shall name this the *Sydney Sandstone*.
2. The coal formation, with its shales and sandstones.
3. Argillaceous sandstones below the coal.

These were the only rocks of sedimentary origin examined by the writer; and they are the predominating rocks of the country. Clay slates, and limestones of older formation, with granitic and allied rocks, have been mentioned as occurring in some parts, especially about and beyond the Dividing range, and south towards the Australian Alps.*

The igneous rocks which have come under observation are basalts or greenstone, of several varieties, including syenitic, porphyritic, and amygdaloidal basalt. These rocks occur of all ages corresponding with the eras of the above sedimentary rocks, or are even anterior to all of them; and some may be of more recent date.

In the following pages, we may first consider the sedimentary deposits, commencing with the uppermost, dwelling in detail on their mineral characters and stratification, their structure, fossils and imbedded minerals, which particulars comprise the original peculiarities of the rocks; and afterwards on the changes they have subsequently

* We add a few facts with regard to the rocks of other parts of Australia, derived more especially from the accounts by Fitton, (*Phil. Mag.* lxxviii. 135,) Strzelecki (*N. S. Wales and Van Diemen's Land*), and J. B. Jukes, (*Rep. Brit. Assoc. for 1847*, p. 68.)

North of Cape Melville, on the northeast coast, the country consists mostly of porphyritic, feldspathic and quartzose rocks, with basalt or trap and some granite. From Cape Melville southward nearly to the East Cape, the prevailing rock is granite, with some talcose slate, and serpentine. At Port Bowen, in latitude $22^{\circ} 30'$, there are schists, porphyries and basalt; and near Port Curtis, a degree farther south, syenite and red sandstone are said to occur. On the southeast coast, there are palæozoic schists and sandstones, with granites, mica and argillaceous slates in the mountains. Mount Kosciusko, six thousand five hundred feet high, consists of granite, with mica slates and siliceous and argillaceous slates in a vertical position. Van Diemen's Land contains granites, syenites, mica slates, serpentine, quartz rock, palæozoic limestones, shales and sandstones, and the coal formation; also basalt, showing magnificent displays of columns, in many places. In the district of Port Philip, there is coal at Western Port. The Grampians, four thousand feet high, consist of the Sydney sandstone; and south, there is a tract of volcanoes. From Port Philip to the Murray, tertiary covers the country along the sea. About Adelaide, Cape Jervis, in South Australia, there are mica slate, gneiss, clay slate and chlorite slate; and in the various ranges, veins of copper and lead abound. Tertiary and sandstone extend westward over the country bordering the Great Bight. At King George's Sound, in this same tertiary, there are ramified concretions, formerly taken for corals. Granite occurs in the mountains to the north; but along the shores, from the Southwest Cape to Shark's Bay and beyond, the same tertiary beds are found. About the northern shores, east and west of Cambridge Gulf, the rock is a red ferruginous sandstone, in horizontal layers, apparently the same as the Sydney rock. A sandstone of similar characters, but of unascertained age, occurs around the Gulf of Carpentaria. This rock has been supposed to be tertiary, and to extend over Central Australia.

undergone, as shown in fissures, dislocations, decomposition, abrasion. We may next proceed to the igneous rocks, tracing out their several varieties and transitions,—their positions, as in dikes or layers,—their decomposition or waste by abrasion. These facts will prepare the way for various deductions relating to the geological history of the land in past and recent times.

The results to which we shall arrive have been deduced from a study of the sandstone formation in the neighbourhood of Sydney and Paramatta; from an examination of the various rocks in the Illawarra and the adjoining Kangaroo Grounds, fifty to eighty miles south of Sydney, with a rapid glance over the country from Illawarra through Appin and Campbelltown to Paramatta; from an investigation of the coal formation of Newcastle at the mouth of the Hunter River, and a journey up the valley of the Hunter through Maitland, Patrick's Plains, and Muswellbrook to Puenbuen, one hundred and twenty miles from Newcastle. As the time spent in these investigations was short—about two months—we can gratify but partially, in a geological point of view, the curiosity which so strange a land may well excite; and perhaps give increased interest to the results of some future labourer in the field, who shall make more extended examinations into the condition, causes and changes of its physical features and peculiarities of structure.

Before proceeding farther, I may be permitted to acknowledge many grateful remembrances of kindness received wherever our explorations led us, and especially our obligations to Major George Barney, Surveyor-General of New South Wales, Captain Westmacott of Bulli, Illawarra, Dr. C. Nicholson of Sydney, W. Stephens of Puenbuen, Rev. C. P. N. Wilton and George Brooks, M.D., of Newcastle, Mr. Robert Scott of Glendon, Rev. Mr. Mears of Wollongong, and the Rev. W. B. Clarke of Paramatta. To Major Barney, Rev. Mr. Wilton, Mrs. Robert Scott and Dr. Brooks, our cabinet is indebted for large and valuable collections of the rocks and fossils of New South Wales.

RELATIONS OF THE SEDIMENTARY FORMATIONS.—The relations of the several sedimentary formations enumerated are well exhibited in the district of Illawarra, as shown in the following cut, and also on the preceding map. Going inland from the seaport Wollongong, we leave on the shores the fossiliferous deposit of *argillaceous sandstone below the coal*. Approaching the Illawarra range, two miles back, we come upon the outcropping edges of the *coal series*, and ascending the bluff

mountain just beyond, we soon reach the Sydney sandstone, which continues to the summit, where it stretches far to the northward and westward in a gently inclined plane, though broken in many parts by



EAST AND WEST SECTION THROUGH ILLAWARRA, FROM WOLLONGONG.

deep valleys or gorges. The several deposits are conformable, and constitute an unbroken series. Similar sections, including the coal and the Sydney sandstone, are in view near Newcastle; and at Greenhills, seventeen miles west, there is an argillaceous sandstone abounding in fossils, apparently identical in age with that of Wollongong.

II. SYDNEY SANDSTONE FORMATION.

Geographical Extent.—The Sydney sandstone is the prevailing rock of New South Wales, and probably, as Major Mitchell states, of all New Holland. It extends from Shoalhaven River on the south to the Hunter River on the north, and west some distance over the Dividing range, only occasionally interrupted by basalt or granite, or the outcropping inferior deposits. North of the Hunter it occupies many valleys as far up as the Liverpool range of mountains. Beyond these mountains, it is said by Major Mitchell to occur again on the Nammoy and the head waters of the Darling; west of the Dividing range it does not appear to predominate until approaching the valley of the Darling, three hundred miles or more in the interior, where a similar rock is described as common. These few facts may give some idea of the sameness that characterizes the geology of New South Wales.

The thickness of the sandstone above the coal may be deduced approximately from the elevation of the Illawarra heights, and the altitude of the main range of the Blue Mountains. The former vary from eight hundred to eighteen hundred feet, and consist at base of the coal layers; and if four hundred feet be allowed for the subjacent deposits, we have fourteen hundred for the Sydney sandstone. Nearly the same thickness may be inferred from the sections observed in the Blue range. North, towards the Liverpool range,

which is apparently away from the centre of the region of sand depositions, the thickness is but four hundred or four hundred and fifty feet; below this, coal layers occur. Approaching Newcastle, at the mouth of the Hunter, the sandstone becomes very thin, and at the cliffs is represented only by a single layer of conglomerate, of which we shall speak particularly when describing the coal deposits of Newcastle. As this conglomerate appears to belong to the upper portion of the Sydney sandstone series, it is probable that it presents us with nearly the whole thickness which the sandstone has ever had in the vicinity of Newcastle.

Lithological Characters and Stratification.—The sandstone of this formation is mostly a soft friable rock, of fine texture and light sandy colour. It consists of minute grains of quartz, with particles of decomposed feldspar of an opaque white colour, and scales of light-coloured mica. The quartz usually predominates. The mica is at times wanting, though small scales may generally be detected; in some cases it is so abundant as to increase much the glistening lustre of the rock.

The colours of the layers are white, grayish-white, and yellowish, like ordinary sand; also varying to light blue and grayish-blue, which characterize a variety used as a building material at Paramatta, where it occurs. There are also reddish shades. The colours are very often arranged in curved parallel bands, or waving lines, and concentric oval figures. A very pretty variety occurs to the south, at a place called the Cowpastures. Owing to the delicate arrangement of the layers of deposition, and the dissemination of mica scales in patches, the slabs, which are of a grayish colour, are marked with short waves or curls of a darker tint.

The finer varieties of the sandstone contain an occasional rolled pebble of milk-white quartz, three-fourths of an inch to an inch in diameter; now and then, small fragments of an argillaceous schistose rock, either white or some light shade of colour; and rarely black siliceous pebbles. Small masses of soft clay of a dirt-brown colour are occasionally met with imbedded in the sandstone, and some are several inches long, though generally small. They are much like lumps of clay, and may be kneaded by the fingers when moist.

Besides the ingredients already enumerated, minute scales of graphite are found disseminated through a large portion of the rock, like the scales of mica. Iron ore in the form of sand is common, and it also occurs in seams. The disseminated iron is so abundant in some parts that exposure to the air and moisture soon rusts or reddens the

surface, staining the rock to a depth of some feet. Magnetic iron-sand is met with along the roadsides and on the sea-beaches.

This fine variety passes into a grit, and also into a well-characterized puddingstone. The *grit* consists of pebbles of quartz disseminated thickly through an arenaceous or sub-ferruginous base. The quartz is mostly white, but occurs also of various tints, as red, bluish, greenish, black, &c.; and it is sometimes intermingled with argillaceous pebbles. This variety of the rock constitutes thick layers in the upper part of the formation. It also occurs in thin patches, extending for a few rods between the layers of the finer sandstone. On the summit of the South Head of Port Jackson, the upper layer is covered in some places for a few yards or rods with these thin patches of pebbles, which appear as if they had been pasted to the surface by some process of modern date; but in the face of the cliff, near the top, the same may be seen in layers of an inch or less in thickness, proving them contemporaneous in formation with the sandstone, and a constituent part of it.

The *puddingstone* is the upper member of the series. Its pebbles average an inch in size and are often very closely compacted. In the valley of the Hunter, near Puenbuen, some deposits consist of rolled stones, eight or ten inches through, presenting a variety of colours, which give considerable beauty to the rock. They rest on a fine-grained sandstone, resembling the Sydney rock. A large proportion of jasper pebbles with chalcedony, agates, and carnelians occur in some beds, as near Harper's Hill, and the agates are often of great delicacy. Ferruginous varieties of both the grit and puddingstone are found in many parts of the territory. Major Mitchell mentions that they abound through the valley of the Darling.

A *schistose structure* is assumed by the rock as the proportion of clay increases, and slaty argillaceous layers alternate occasionally with the sandstone. The gradual passage of the one into the other may be often seen, as at a locality near the residence of A. McLeay, Esq. Some thin layers might be properly called a micaceous shale, as the slaty structure is wholly due to the mica contained.

Where the argillaceous layers are most largely developed they possess the ordinary characters of such slaty rocks, chipping off in thin fragments, and often coarsely crumbling. The colour is the usual dull blue-black, or grayish-black. It often passes above to a white or grayish-white colour, and the rock then becomes more arenaceous, approximating to the sandstone of the region.

The argillaceous deposits, though generally thin, (being often but a few inches, and of little lateral extent,) are also at times largely developed. On the river opposite Paramatta, there is a perpendicular bank, one hundred and ten feet thick, resting on the sandstone which crops out below, a short distance up the stream. The upper portion of the bed shows a gradual passage vertically into the sandstone layers, as it changes the blue-black colour for a whitish sandy tint several feet from the top, and becomes less perfectly schistose and more arenaceous. A similar bed occurs along the road two miles south of Appin. The rock is white and crumbling, resembling the upper portion of the deposit at Paramatta. In a section of this formation at the waterfall of two hundred and fifty feet, visited on the elevated plain between Illawarra and the Kangaroo Grounds, (page 451,) a similar argillaceous layer, about thirty feet thick, lies below twenty-five feet of sandstone; and the same is seen seven miles beyond, on the descent of the mountain into the Kangaroo Valley. We have no reason to believe that these different beds are in any way connected, excepting possibly those of the two last-mentioned localities.

Structure.—The layers of sandstone average eight feet in thickness, but vary much even at short intervals. Two layers, quite distinct from one another, unite so as to leave no trace of their former line of separation. Again, a new place of disjunction appears a foot or so above the other, and after running on for a few rods loses itself in the sandstone layer. This remarkable irregularity, which is exhibited even in the subordinate parts of a layer, may be seen at any of the quarries or in exposed natural sections. The annexed figure repre-



sents a section on the borders of a cove half a mile east from Port Jackson, near the bathing houses. The layers are constituted as follows :—

A. 10 feet.—Grayish-white sandstone, in part clouded with red; layers of deposition thin. Increases in width to the right encroaching on that below.

- B. 7 feet.—Similar sandstone, in some parts clouded with red; layers of deposition rather indistinct. Six yards to the northward, reduced to a thickness of *two* feet. The horizontal lines in this layer are planes separating portions of it.
- C. 3 inches.—Blue clayey shale, micaceous. Disappears a few feet to the north.
- D. 3 feet.—Similar to B. Discontinues abruptly, fifteen feet to the northward.
- E. 4 inches.—Blue shale, similar to C, with a distinct slaty structure. Increases to three feet to the northward, where it replaces D. The layer is more arenaceous above; it contains some vegetable impressions.
- F. 4 feet.—Gray sandstone, with brownish or black stripes in some parts; micaceous. Layers of deposition one-tenth to one-sixteenth of an inch thick.
- G. 2 feet.—Blue micaceous shale; arenaceous; cleaves readily into thin plates or laminæ.

The following figure was taken at a quarry adjoining the same cove, but higher up the bank. The irregularity of the lines of stratification is still more apparent in this figure. The rock is wholly sandstone, excepting one thin argillaceous layer which disappears to the northward, but again appears ten feet beyond. The sandstone layers are generally marked distinctly with parallel lines. They are the edges of layers of deposition, and are seldom over an eighth of an inch apart. They are best seen on a worn surface.



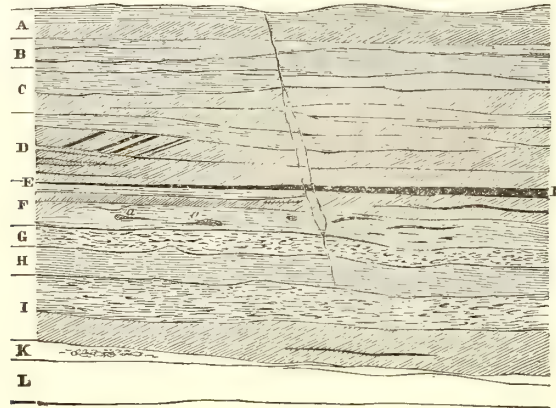
The upper portion of the figure on page 462 affords an example of *oblique deposition*, of very frequent occurrence in the sandstone. Similar facts have been described as occurring elsewhere, but I know of no instance of their prevailing to so large an extent as in this formation. The upper layer in the figure referred to, though horizontal itself, consists of oblique subordinate layers, dipping at an angle of about eighteen degrees to the northward and eastward. The next layer below is horizontal in structure as well as position.

A section of only twenty feet in height at one of the quarries contains *three* alternations of these peculiar layers, with others of ordinary structure. They are as follows:—

- A. 6 feet.—Sandstone, composed of thin oblique layers of deposition.
- B. 4 feet.—Sandstone, with the ordinary horizontal layers of deposition.
- C. 3 feet.—Similar to A.
- D. 4 feet.—Similar to B.
- E. 3 feet.—Similar to A.; and below this horizontally deposited layers occur.

Look where we may, scarcely a cliff of twenty feet can be found

around Port Jackson, or a quarry anywhere, in which these anomalous layers cannot be distinguished. In many parts of the city of Sydney, the same may be seen by the roadside; and about the Parramatta quarries, and in the Illawarra range, similar facts are exhibited. The following figure, taken at a quarry near the residence of Alexander McLeay, Esq., is a very common case. It consists as follows:—



- A. $4\frac{1}{2}$ feet.—Fine, light sandstone; the lower part composed of oblique layers of deposition, while the upper part has no traces of this structure.
- B. 4 feet.—Same sandstone appearing in some parts to consist of two or three distinct layers, which become united again a few yards to the north, where others commence.
- C. 5 feet.—Same sandstone: but imperfectly separated from B; the lower portion is formed of two or three small layers, each distinct, and consisting of *oblique* layers; this part of the layer widens to the right, and contains a central portion, having horizontal lines of deposition. The oblique lines below in some places curve and become horizontal.
- D. 6 feet.—Same sandstone: narrows rapidly towards the right (or to the northward); above, its lines of deposition are horizontal; below this there is a central portion in which these lines are *oblique*, and between some of these subordinate oblique layers there are thin coaly seams, as represented by the black lines in the figure. The lower part of the layer is also composed of *oblique* layers; but they occur in *three or four series*.
- E. 3 inches.—A thin layer of argillaceous shale, about three inches thick to the right, but running out to the southward; it also disappears to the northward, after continuing a few rods. It contains several thin seams of bituminous coal, one of which is half an inch thick, and is very fine coal, with no vegetable structure apparent to the naked eye.
- F. 5 feet.—Same sandstone as above: near the upper limit there are some fine wavy lines of deposition, which run into a thin layer composed of *oblique* layers; and a

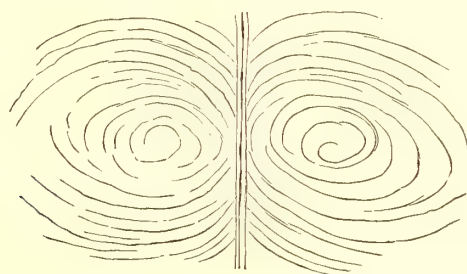
few inches below there is another similar case. To the right there are a few elongated coaly impressions, four and five feet long. Cavities in this layer contain masses of soft clay, some of which (*a*) are six inches long.

- G. $2\frac{1}{2}$ feet.—Blue-black argillaceous shale; extends to the right, gradually narrowing.
- H. $2\frac{3}{8}$ feet.—White sandstone, argillaceous and schistose, crumbling; loses the most of its argillaceous character to the left, still is distinctly marked with horizontal lines of deposition about an eighth of an inch apart, and the laminæ are separable.
- I. 5 feet.—Argillaceous sandstone; fragile; above, horizontal planes of deposition, in lower part, oblique.
- K. 2 feet.—White argillaceous.
- L. 4 feet.—Sandstone similar to the upper layers, more or less discoloured by iron.

It is observed, in this section, that even layers but three or four inches thick are composed, independently of the large layers in which they are contained, of *oblique* layers; and the changes are frequent and various. Another example of the structure of these layers is shown in the view taken at the South Head of Port Jackson (p. 467).

The inclination or dip of these oblique layers, in the vicinity of Port Jackson and Paramatta, is almost invariably to the northeastward. I have observed some instances of different directions in other parts of the colony, but as far as examined, they are uncommon. The amount of dip varies from fourteen to twenty degrees, but usually it is quite uniformly eighteen degrees.

Concentric Structure.—A concentric structure is of much rarer occurrence in this formation than in the coal series and sandstone below. One remarkable example of it was observed along the road from Wollongong, ascending the Illawarra range, about two-thirds up the ascent. A fissure bounded by parallel walls, two inches thick, here intersects the rock nearly vertically, having a small inclination to the eastward. Either side of this fissure and its walls, the sandstone is concentric



in structure, the two concentric areas being about twenty feet in diameter. The figure here given represents the general character

of the rock. The coats of sandstone in the concentric mass are from half an inch to two inches in thickness: they have a fine granular texture and a light gray colour; they peel off readily, and some large masses have fallen down into the road. The thin walls of the fissure project a little, the layers either side having fallen away, owing to their less compactness. This is the only instance observed by the writer of concretions in the Sydney sandstone on so large a scale; and even those of small size are not common.

In the argillaceous shale near Paramatta, there are fine examples of this structure, as is well laid open to view along the river's edge opposite that city. The rock is intersected by fissures dividing it into irregular polygonal areas, generally not exceeding two feet in diameter. These fissures, as in the case above described, are bounded by walls about a third of an inch thick; and within the areas, the concentric structure is neatly developed. The surface of each is a portion of a large flattened sphere, approaching the curvature of a lunette watch-glass: the layers are thin, (averaging a fourth of an inch,) and separable. The rock has a dark colour, and does not differ in any apparent characters from the horizontally laminated shale.

Other particulars respecting this structure are described on a following page, in our remarks on the inferior formations, where figures are given.

Dip of the Sydney Sandstone.—The layers of this formation are in general, as already stated, nearly or quite horizontal. An inclination amounting to twelve degrees is very rarely met with, and no instance was observed in which this dip was exceeded.

Near Port Jackson, an inclination to the westward or northward and westward is barely apparent. At the North Head it is more distinct than at the South, but does not exceed *five* degrees. Near the mansion of A. McLeay, Esq., there is a dip of *one and a half* degrees to the southward and westward. At Paramatta, the argillaceous schist along the river dips *two* degrees to the east-northeast, in which inclination the sandstone below it partakes. But at the quarries, half a mile distant, no dip was apparent. The sandstone of the Illawarra range inclines slightly to the westward, or northward and westward. Near Greenhills on the Hunter, there is a dip from the valley of the river to the southeast or south-southeast at an angle of *ten to twelve* degrees. At Puenbuen, the dip of the ridge to the west-southwest of the plain is *six* degrees to the west-southwest; other portions of the same ridges are nearly horizontal.

These isolated observations indicate little more than the general fact that the variation in the dip is local, being often some way related to the position or direction of valleys or fissures. Major Mitchell remarks that from the Blue Mountains to the seashore, there is a general dip of *one* degree to the eastward. On this point, we had no means of judging. The statement establishes the important fact, that the variation from horizontality is in general very small, and on this depends much that is peculiar in the topographical features of New South Wales.

Fissures.—The sandstone is fissured in most places with remarkable regularity in two directions at right angles with one another, and producing rectangular blocks which occasionally look like an artificial pavement on a vast scale. The directions are nearly uniform, being



VIEW AT SOUTH HEAD, PORT JACKSON.

north-by-east and west-by-north, compass courses, or, allowing for a point variation, *north-northeast* and *west-northwest*. The various cliffs and quarries about Port Jackson and also the region of Parramatta afford abundant illustrations of the statement here made. I have also observed the same in the Illawarra range to the south, and northward at Greenhills, on the Hunter. These courses sometimes vary a point, inclining to north-by-east, (true course,) and west-by-north. I noted down the latter on the Illawarra range near the Kangaroo Grounds. A northwest course is at times met with, and also a north-east. I observed the former in the sandstone between Newcastle and Maitland.

The view above given, shows the rectangular pavement which borders the sea at the foot of the cliff at the South Head of Port

Jackson, arising from the fissures alluded to. There are also other fissures, having the same direction, that intersect the whole cliff from top to bottom.

The harbours and bays along the coast correspond in direction nearly with these fissures, running generally north-northeast and west-northwest. Major Mitchell mentions this as their direction, and without any reference to the courses of the fissures, which he had not observed. It is also worthy of note, in connexion, that the main mountain range has in general a northeast to north-northeast course, while some parts have a transverse direction.

Organic Remains.—This sandstone formation is remarkable for the paucity of its organic remains. I am not aware that a fragment of a single animal relic has been detected in it. A few vegetable impressions and some thin seams of bituminous coal occur in some of its more argillaceous layers. In the micaceous shale of the section represented in the figure on page 463, there were some fragments of leaves, extremely thin, having a yellowish-brown colour and easily peeling from the surface of the layers of shale. When detached, they were translucent, and appeared like dried *Ulvæ*, though showing longitudinal ribs when seen under the microscope.

In the section represented on page 464, there is a coal bed three inches thick, consisting of thin layers of bituminous coal and argillaceous shale. The coal layers vary from half an inch to a sixteenth in thickness, and consist of perfectly formed coal, entirely destitute of all vegetable structure. This thin seam continues for a few rods only.

Coaly impressions occur in the sandstone, some of which are four feet long, and are evidently parts of single plants or leaves. They are thin, not exceeding an eighth of an inch, but several inches in width. They are so perfectly carbonized as to have lost all traces of their original structure, and afforded no clue to their original character. About Port Jackson and at the Paramatta quarries, these impressions are not uncommon.

This brief account includes all the information we have on the sandstone fossils: and we have reason to infer from the statements of several scientific gentlemen resident in the colony, that this subject will always form a short chapter in New South Wales geology.

Imbedded Minerals.—This formation is nearly as barren in minerals as fossils. Excepting the ferruginous cement prevailing through the

sandstone of some districts, there are a few sprinklings of galena and iron sand, and thin seams of argillaceous and hematitic iron; these are all the metallic minerals it is known to contain. Some masses of brown hematite were detected by the writer in the hills southwest of Puenbuen, lying loose in the side hill, though evidently from some source near by. They are sufficient to warrant at least a few hours' exploration. Galena is said to cover the surface of a bluff called Hassen's Wall, yet only in trifling quantities.

The prevalence of salt springs in New Holland was noticed by the early navigators. This is the predominant character of the inland waters throughout Australia; it is stated that more than half the wells sunk in New South Wales afford brackish, unpalatable water. Many of the northern tributaries to the Hunter are described as brackish, except when flooded by the rains. The Darling, west of the Dividing range, is in the same manner brackish at low water. Most of the waters, both eastern, western, and southern, where this sandstone formation prevails, are more or less saline in the dry seasons.

The salt, however, is not uniformly diffused; for streams rising in the same region are unlike in this respect, one being pure, while the other is saline. This is true of two rivulets in Illawarra a few miles north of Wollongong, whose sources are near one another on the Illawarra range. There are some accredited instances of the discovery of mineral salt in the sandstone. Some of the salt lakes of the interior have their waters denser than those of the ocean, and their shores are covered with plants peculiar to salt regions.

III. COAL FORMATION.

Although in our general division of the subject we have separated the sandstone above the coal from the coal formation, this separation is hardly apparent in nature. In all portions of the country, where examined by the writer, the two form an unbroken series, differing only in the interpolation of distinct coal beds in the latter. The division is deemed convenient for description, and is, therefore, adopted, although the whole properly belongs to one prolonged epoch.

Geographical Extent.—The coal series appears in view in the neighbourhood of Newcastle, at the mouth of the Hunter, and occurs at numerous localities along the valley or plain bordering this river, as

at Glendon, Patrick's Plains, Ravensworth, and as far northwest as Puenbuen, and the vicinity of Mount Wingan. Ten miles south of Newcastle, near Lake Macquarie, the coal has also been opened.

This region, which may be called the Hunter River Coal District, is upwards of one hundred and twenty miles long, and varies in width from six to twenty miles on either side of the river; and farther exploration will probably extend these limits. Although we thus name this region, the coal throughout it is generally covered with the upper sandstone, and outcrops only at intervals. It is quite possible that coal may be found in most parts of the district by boring; and the scarcity to the southward may be owing to the thickness of sandstone which covers it.

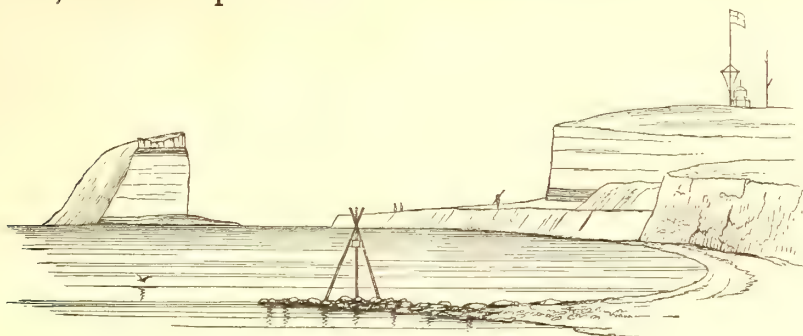
A *second* coal region extends through the greater part of the district of Illawarra. Coal is first seen at the northern extremity of the district in the low cliffs at the base of the main mountain range, and near where this range commences to diverge from the coast. From this place (called Bulli) the coal formation may be traced through the district to the southward, following along the base of the mountain, as shown in the map of the district.

Beside these two districts, the Hunter River and Illawarra, I am not informed of any other beds opened in Eastern Australia. Mr. Darwin met with coal fossils, (the *Glossopteris Browniana*,) at Wolgan at the foot of the Blue range; and the formation, according to the Rev. W. B. Clarke, outcrops in other places. Coal has been described as abundant in some parts of South Australia, and in Van Diemen's Land.

Stratification and Characters of the Beds.—The cliffs of Newcastle exhibit a much fuller development of the coal series than those of Illawarra, and it will be most instructive to study first the details of stratification at the former place.

NEWCASTLE COAL DISTRICT.—The village of Newcastle lies to the south of the Hunter, just back of a small promontory forming the southern cape at the mouth of this river. A hill, a hundred feet in height, rounded above and with a bluff face to the sea, occupies the promontory; and to the southward on the coast there are other cliffs alternating with short sand-beaches, which are successively of greater elevation, and in the course of half a mile become two hundred feet high. Near the middle of the river's mouth stands the small islet, Nobby, facing the ocean on the east and southeast with an erect front of bare rock, and sloping rapidly in the opposite direction. Nobby, and Tele-

graph Hill or the South Cape, are shown in the following sketch. The coal beds are finely displayed in the several cliffs alluded to, and on this island. North of the Hunter, the shores are sandy for a long distance, with no exposed rocks.



NOBBY AND TELEGRAPH HILL, NEWCASTLE.

These cliffs contain in all five distinct seams of coal, separated by twenty to fifty feet of sandstone and argillaceous shale, and are shown as sections at the foot of the map facing the present chapter. The following section was taken at the highest cliff referred to above—the only one which includes, above the sea level, the whole number of coal beds. We begin with the upper layers.

- 15 feet coarse grit or puddingstone, containing quartz pebbles and hard opaque argillaceous pebbles (A).
- 3 feet (I.) COAL; upper six inches clayey, the rest good coal.
- 4 feet.—Dark blue clay, with thin black coaly layers (C).
- 2 feet.—Argillaceous sandstone, whitish and hard (D).
- 4 feet.—Clay, soft and crumbling (E).
- 1 foot.—Clayey sandstone; crumbling; easily acted upon by the weather, but a little harder than E (F).
- 6 inches.—Similar to E.
- 6 inches.—Similar to F.
- 2 inches.—Same as E; uniting a few feet off with the following.
- 1 foot.—Same as F.
- 6 inches.—Same as E.
- 2 feet.—Same as F.
- 3 feet.—Same as E.
- 5 feet.—Same as D; fine, grayish-white; not much altered by exposure; some ferruginous seams running southeast.
- 3 feet.—Same as F, but containing thin layers of E and D.
- 5 feet.—Same as D, with three or four thin layers of E; finely crumbling.
- 3 feet.—Same as D for the upper foot; below, mostly like E, with thin layers of D.
- 3½ feet.—Same as D, with thin layers of E; upper part schistose, lower mostly very crumbling; colour light gray; some thin ferruginous seams or layers.

- 2 feet.—Same as D.
- 3 feet.—Same as E.
- 6 feet.—Thin alternations of D and E, E predominating.
- 1½ feet.—Same as E, with thin layers of D.
- 1 foot.—Same as F.
- 6 inches.—Same as E.
- 5⅔ feet (II.) COAL. 10 inches, bituminous coal.
 4 inches, clay.
 18 inches, coal.
 2 inches, clay.
 2 inches, coal.
 2 inches, clay.
 2 inches, coal.
 18 inches, clay.
 10 inches, black coaly shale.
- 2 feet.—Soft clay.
- 18 feet.—Grayish-blue sandstone, containing clayey layers, one or two thin seams of coal in clay, ferruginous nodules, and fissures lined with ironstone. The sandstone is a little argillaceous, and crumbles on exposure; some of it breaks into concentric laminæ.
- 6 feet.—Same bluish sandstone as preceding, but more fissured; the ferruginous walls to fissures are from a fourth to half an inch thick.
- 5 feet.—Fine and soft clayey sandstone.
- 6 feet (III.)—COAL, with thin seams of clay; one layer of two feet, clear coal.
- 5 feet.—Same as E, with layers of F.
- 4 feet.—Mostly same as D; with numerous ferruginous fissures and thin beds of clay ironstone. This layer passes into—
- 12 feet.—Same as D, with thin ferruginous layers; hard, but becomes clayey and soft, for eighteen inches over the following layer.
- 5¼ feet (IV.) COAL. 1 foot, bituminous coal, shaly above; lower six inches pure.
 2 to 3 inches, dirt-brown clay.
 8 inches, coal.
 6 inches, white clay, very soft.
 4 inches, good coal.
 12 inches, clay, with thin seams of coal.
 18 inches, good coal.
- 20 feet.—Bluish clay, schistose, passing into bluish argillaceous sandstone, which is more or less schistose. A few thin beds of ironstone and trunks of trees, mostly ironstone.
- 6 feet.—Compact hard sandstone.
- 6 feet.—Bluish sandstone with clayey layers; thin layers of deposition apparent; imperfectly schistose.
- 10 feet.—Compact hard argillaceous sandstone of a bluish colour.
- 3 feet (V.) COAL; situated at low-water mark.

In this section we have,

Grit,	-	-	-	-	-	-	-	15 feet.
Coal (I.),	-	-	-	-	-	-	-	3 feet.
Argillaceous and arenaceous layers,	-	-	-	-	-	-	-	58 feet.
Coal (II.),	-	-	-	-	-	-	-	5 $\frac{2}{3}$ feet.
Argillaceous and arenaceous,	-	-	-	-	-	-	-	29 feet.
Coal (III.),	-	-	-	-	-	-	-	6 feet.
Argillaceous and arenaceous,	-	-	-	-	-	-	-	21 feet.
Coal (IV.),	-	-	-	-	-	-	-	6 feet.
Argillaceous sandstone,	-	-	-	-	-	-	-	42 feet.
Coal (V.),	-	-	-	-	-	-	-	3 feet.

We have been thus particular in noting down the alternations of rock in the cliff, especially the upper part of it, in order to give some idea of its varying character: and this peculiarity is farther evident from the fact that a section a few rods to the right or left is quite different in its minor layers. The argillaceous and sandy layers often coalesce, or subdivide and change in character, even at short intervals. The sandstone is generally quite soft and crumbling, though harder in the lower layers. The ironstone beds increase below, and become quite numerous; yet they seldom exceed four inches in thickness, though extending laterally to ten or twenty feet, or as many yards; they either lie between the layers of bluish sandstone, or are imbedded in the middle of them.

The clayey layers, near the coal beds, are remarkable for their softness. When first laid open, the clay may be kneaded in the hands; and after a short exposure, it crumbles into small fragments, showing commonly no schistose structure, unless in consequence of imbedded vegetable impressions. They more resemble recent deposits of clay than the usual argillaceous shales of the carboniferous era. The soft character of all the rocks distinguishes them from those of most other coal regions; and were we hastily to judge from this character alone, we might place these formations high in the geological series.

The several layers of coal are similar in all the cliffs through the half mile examined, excepting a difference in the proportion of clear coal and clayey layers. The uppermost bed of coal is an extraordinary exception to this remark. The layer, without varying in thickness, gradually changes, a few hundred feet to the northward, to a layer of dark-brown clay, coloured with carbonaceous matter, and with no pure coal included; two hundred feet from where the above

described section was taken, the coal bed had so lost its coaly character, that when first met with, I had no suspicion that a bed of coal existed in that vicinity. The upper part of the cliff is removed to the southward, and it was therefore impossible to trace out its variations in that direction.

In Telegraph Hill, the south cape of the river, there are two coal beds visible corresponding with the *third* and *fourth* in the above series. The following alternations were there observed, commencing above.

- 4 feet.—Fine gray argillaceous sandstone, widening to eight feet a few rods to the northward; lower part consisting mostly of clay.
 8½ feet.—Puddingstone; pebbles varying from one-fourth to one or two inches in size; the layer has a clayey bed near its centre, which soon thins out both to right and left.
 15 feet.—Clayey shale; very soft below. Vegetable impressions abundant, consisting mostly of a species of *Glossopteris*.
 6 feet.—Coal (III.); only the lower twenty inches are clear of clay-shale, and this part is worked.
 5 feet.—Hard grayish-blue sandstone; stands the weather.
 1¼ feet.—Grayish clayey sandstone.
 12 feet.—Fine grayish sandstone, containing some softer layers which are thin schistose.
 2 feet.—Soft clay, of a light dirt-brown colour.
 6 feet.—Coal (IV.) and coaly shale.
 At water's edge.—Sandstone of a grayish-blue colour.

This section also exhibits the inconstant character of the layers which alternate with the coal.

For the following section I am indebted to Mr. James Steel, superintendent of the coal works at Newcastle. It was taken down by him when sinking the shaft to the second or "B" coal pit.

- 17 feet.—Yellow sandstone: moderately hard, crumbling.
 15 feet 2 inches.—Soft blue stone.
 5 feet.—Coal shale, black.
 10 feet.—Soft blue stone.
 2½ feet.—Bad coal.
 7 inches.—Fine white clay. }
 12 inches.—Bad coal. } Coal bed, 5 feet 9 inches.
 20 inches.—Best coal. }
 24 feet.—Soft blue stone.
 6 feet.—Hard blue stone.
 6 inches.—Soft stone.
 20 feet.—Hard blue stone, containing impressions of leaves.

12 inches.—Bad coal.	}	Coal bed, worked; 4 feet 1½ inches thick.
18 inches.—Good coal.		
1½ inches.—Band of stone.		
18 inches.—Good coal.		
<i>Below</i> , hard blue stone.		

In this section, the two layers of coal are separated by fifty feet six inches of rock; they correspond to numbers IV. and V. in the first section. The lowest affords the best coal, and is at present the only one explored, excepting the small workings on Telegraph Cliff.

The island of Nobby is capped by a layer of conglomerate eighteen feet thick. Below this there are two layers of coal, separated, according to estimate, by fifty-five feet. The view on page 511 shows their positions. The upper coal bed, with its shales, is eight feet three inches thick, and consists as follows:—

18 inches.—Coal.
18 inches.—Argillaceous shale.
12 inches.—Coal.
36 inches.—Argillaceous shale, in part arenaceous.
15 inches.—Coaly shale.

The lower coal bed, which is near the water's edge, is nearly eleven feet thick, and contains as follows:—

15 inches.—Coal.
20 inches.—Clay, indurated.
2½ feet.—Coal.
8 inches.—Indurated shale.
5 feet.—Coaly shale.

The two layers in Nobby are separated by the same interval nearly as the layers I. and II., and also layers IV. and V. It is uncertain to which they correspond. The whole island of Nobby has been altered by the action of heat from a basaltic dike which intersects it; but we reserve our remarks on this subject for a following page.

The coal of the beds we have been describing is of the bituminous kind, and the best of it is of fair quality. It is evident, however, from the facts, that it is quarried with considerable difficulty on account of the thinness of the beds, and the very soft nature of the rocks associated with it. It is, however, quite extensively worked, and is of great value to the country.*

* The principal explorations at Newcastle are carried on by sinking shafts. Large excavations have been made in the cliffs; but the difficulties arising from the thinness

The following are the results of four analyses of the coals, of different qualities, by Prof. B. Silliman, Jr.

	NEWCASTLE. Sp. gr. 1·2759.	NEWCASTLE. Sp. gr. 1·3082.	BULLI. Sp. gr. 1·459.	NEWCASTLE. Sp. gr. 1·633.
Coke or fixed carbon, -	57·775	59·46	65·125	38·308
Volatile carbon, - -	39·225	34·71	15·850	19·367
Ashes, - - - - -	3·000	5·81	19·025	42·325
	100·000	100·00	100·000	100·000

Faults in the Newcastle Coal Region.—A few of the faults in this region are illustrated by the section on the map of New South Wales, representing the series of cliffs at Newcastle. Fractures appear to have taken place between each of the bluffs, though most apparent in those to the right of C. In D, the bed of coal which is nearly horizontal in C, inclines at an angle of five degrees: at one end of the cliff the coal is twenty feet above the water, while at the other end it falls to eight feet. A basaltic dike intersects the shore rocks at *m*; but whether the fault has taken place in this line or not, could not be ascertained. In the following cliff, E, the same layer of coal lies at the water's edge with a dip not exceeding *two* degrees to the northward and westward, and about *one* degree in the line of the cliff. The cliffs are so far disjoined that the exact amount of the fault between the two cliffs is not easily ascertained without levelling: it does not exceed a foot. Towards the north end of Telegraph Hill (E), a small fault is seen dislocating the coal layers about ten inches, in a line running southeast-by-east.

Through the section in the figure referred to, the whole amount of of the bed and the slight coherence of the roof rock, must soon put a stop to these quarryings. Up to the time of the writer's visit (in 1840), operations had been carried on by means of a single shaft, from which excavations had been extended around over twenty-four acres. A second shaft was just completed, and preparations were making to commence mining. In the working, as much coal is left to support the roof as is quarried out, and props of wood were required every three or four feet. Through the long narrow passages, small railways were used for bringing the coal to the shaft, in doing which, convict labour was employed. A steam engine was used both for raising the coal from the pit, and for clearing out the water. At the time of the writer's descent, they were removing the coal which had been left to support the roof, and preparing thus to desert the mine for the new shaft.

fault or subsidence, from A to E, is about fifty feet. Between Nobby Island and the shore (E) there is a fault of fifty or sixty feet, for this must have been the case whether the lower layer be number II. or number V. The character of the rock in the lower layers of Nobby (which must have been a fine clay before baking) inclines me to believe that the lower bed is probably number II. The dike intersecting this island has produced a dislocation not exceeding three inches.

Interesting examples of faults are brought out in the excavations of the coal pit, which have uncovered them laterally for three or four hundred yards. The following cut (figure 1) is a ground-plan kindly

Fig. 1.

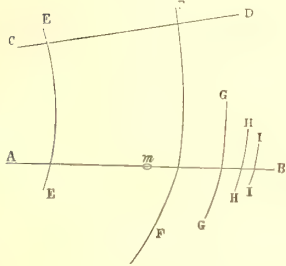
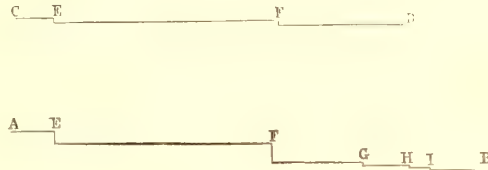


Fig. 2.



furnished by Mr. J. Steel. It appears from the figure that in the short space of two hundred and sixty yards there are five faults following the same course, that is, curving around gradually from a north-northwest to a north direction. Along the transverse line A B, figure 2, (running east-northeast,) these faults are as follows:—

- | | | | | | | | | | |
|-------|----------------------------|---|---|---|---|---|---|---|----------|
| 1. E. | - | - | - | - | - | - | - | - | 6 feet. |
| 2. F. | —180 yards to the westward | - | - | - | - | - | - | - | 10 feet. |
| 3. G. | —50 yards farther west | - | - | - | - | - | - | - | 2 feet. |
| 4. H. | —20 “ “ “ | - | - | - | - | - | - | - | 1 foot. |
| 5. I. | —10 “ “ “ | - | - | - | - | - | - | - | 1 foot. |

The rock here falls to the westward by a series of dislocations, and the inconvenience arising from water collecting in the natural basins thus formed, has prevented farther mining in that direction. Two hundred and fifty yards to the southward, along the line C D, the faults E and F cause a displacement of only a foot each. The other faults have not been exposed on this line. The rock at this place has a slight dip to the westward or northward and westward.

ILLAWARRA COAL DISTRICT.—The most convenient and instructive

places for examining the coal series of Illawarra, are the Bulli Cliffs, and the sides of the road running west from Wollongong, near the foot of Mount Keerah, one of the principal peaks in the Illawarra range.

In the Bulli coal cliffs, as shown on the map of New South Wales, the three southernmost contain near the middle a horizontal black stripe, which is the coal layer; and farther north, there are two such stripes, one just at the water's edge. The coal extends about eight miles beyond Bulli to the northward.

At the second of these cliffs I took down the following section, which differs but little in its general characters from those at Newcastle.

20 feet.—Fine sandstone; mostly white or gray, but in some parts having a reddish tinge.

11½ feet.—COAL.

2½ feet, black coaly shale.

1 inch, clay.

3 feet black coaly shale.

4 inches clay.

2 feet black coaly shale.

6 inches clay.

1½ feet, coaly shale.

1½ feet pure bituminous coal.

3 feet.—Grayish clay; soft and crumbling when dry.

1 foot.—Argillaceous shale.

2 feet.—Soft clay.

1 foot.—Argillaceous shale.

5 feet.—Grayish clay, as above.

6 feet.—Schistose sandstone, stained red and brownish-red with iron; fine and somewhat friable.

10 feet.—Hard compact sandstone, extending to water level.

On the second cliff beyond, the second or lower layer of coal lies below the section just given, and is separated from the upper bed by about twenty-five feet of clay, argillaceous shale, and sandstone.

The clay in these deposits is very soft, and kneads readily when moistened; it is neither more compact nor more schistose than ordinary clay. Vegetable impressions occur through a great portion of it, though less abundant than at Newcastle. The coal from the lower part of the section is quite pure and burns well. It crumbles on exposure to the weather. It is much intersected by thin seams of charcoal, which make the coal dirty to the hands, as well as fragile.

The coal formation continues south on the coast to Point Tow-rudgi, two and a half miles north of Wollongong, where coal fossils

may be obtained. Farther south, commences the Wollongong rock, which appertains to our *third* division, or sandstone below the coal, and the coal formation retreats inward, continuing along the base of the Illawarra range, as shown on the map of the district.

On the road running west from Wollongong, the following alternations were observed, commencing above.

- 20 feet.—Argillaceous shale, greenish, containing numerous impressions of *Glossopteris*; alternates with a light gray arenaceous schist.
- 1 foot.—Black coaly shale, more or less argillaceous.
- 3 feet.—Clay, imperfectly schistose; crumbling.
- 1 foot.—Argillaceous shale, greenish.
- 2 feet.—Clay, as above.
- 1½ feet.—Argillaceous shale.
- 3 feet.—Black coaly shale.
- 4 feet.—Clay, as above; crumbling; passing into argillaceous shale below.
- 3 feet.—*Coal*, with layers of clay four to eighteen inches thick.
- 4 feet.—Dirt-brown argillaceous shale.
- 10 inches.—Coaly shale, black with thin layers of coal.
- 2½ feet.—Argillaceous shale, a little arenaceous.
- 2 feet.—Poor coal; argillaceous above and interlaminated with clay layers six inches thick.
- 5 feet.—Gray sandstone, having a concentric structure.
- ½ foot.—Blue argillaceous shale.
- ⅔ foot.—Clay as above.
- 1 foot.—Grayish-green clay shale, soft above.
- 2½ feet.—Blue shale.
- 1 foot.—Blue shale and impure coal.
- 1 foot.—Hard argillaceous shale, somewhat arenaceous.
- 3 feet.—Dark green argillaceous shale.
- 4 feet.—Dirt-brown argillaceous sandstone; schistose.
- 12 feet.—Grayish-white argillaceous shale.
- 6 feet.—Grayish sandstone.
- 20 feet.—Shale and sandstone, containing vegetable impressions, trunks and branches of trees.

The layers dip to the westward under the mountain at an angle of six degrees, diminishing below to three degrees. The road has a slight ascent, and the different layers come successively in view.

To the south of this locality, the coal has been observed at several places, through Keelogue, Depto, &c., as far as the latitude of Red Head, where the mountain, as seen on the map of Illawarra, makes towards the shore. Beyond this, farther south, the mountain again diverges from the sea, but no coal had been detected in this part

of the district. I collected a few impressions of leaves descending into the Kangaroo Ground, which indicated that the coal series existed there, although there may be no beds of coal in the region.

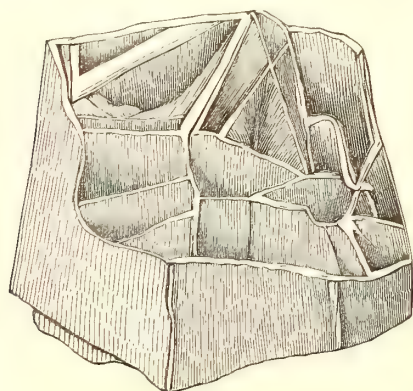
The sections examined do not seem to promise profitable explorations for coal in this district. The beds are too thin to be worked. We cannot speak, however, with certainty of the Bulli region to the north of the part explored by us. The beds seem to be less productive as we go south from Bulli.

Fissures, and Concentric Structure.

The fissures in the coal formation correspond in direction with those of the sandstone above, and in general have the courses north-northeast and west-northwest. Other directions are, however, met with. At Telegraph Hill, Newcastle, the fissures run northwest, and the same extend through the coal. One hundred rods to the southward there are two distinct lines of fissures, one east by north and the other north by west. Near the Bulli coal cliffs, there are two systems, one north by east, and the other northwest by west.

In some of the sandstone layers there are numerous and irregular fractures or seams, dividing the surface into small polygonal areas, which have a concentric structure, with walls bordering the seams. The walls are from half an inch to two inches thick, thus varying with the thickness of the layers or coarseness of the rock, and the size of the included areas.

This structure is carried to the most minute perfection in the thin beds of ironstone. The accompanying figure represents a fragment from one of these beds. The areas here are often less than a square



inch, and the walls, which are double, as usual, rarely exceed a twelfth of an inch in thickness, and in some parts are but a twentieth. The specimens break in the line of the fissures between the walls with the feeblest stroke, falling into polygonal fragments, bounded on each side with smooth even surfaces. The layer which afforded the specimen figured, averages two and a half inches in thickness, and extends over several

square rods, covering the lower layer of bluish sandstone, which is not at all fissured to correspond with the ironstone. Below three inches of the sandstone, there is another layer of ironstone similar to the one just described, and lying upon a thick layer of the same solid bluish sandstone. The walls of the larger areas extend through the whole thickness of the ironstone layer; but not so those of the smaller, which are often very irregular; and hence the upper and under surfaces generally have but little resemblance.

Within the areas, the rock is laminated and slightly concentric; it is rather soft, and is worn out to a considerable depth, (often nearly an inch,) producing a honeycomb texture. The walls are hard, and consist of clay ironstone.

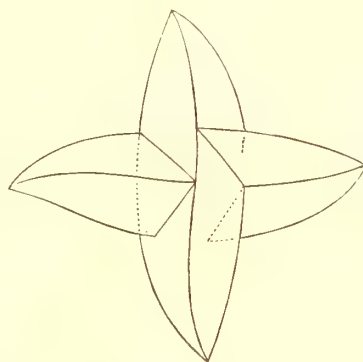
Calcareous Prismatic Concretions.—Various specimens of remarkable prismatic forms of lime were presented us by Mrs. Robert Scott of Glendon. They were described as occurring in clay; but whether they pertain to the sandstone rocks under consideration is not yet determined. As these rocks occur at Glendon, this is their most probable source, and we therefore mention them in this place. The facts as to their characters are the same, whatever be their place of origin.

Two of these singular crystals are represented in the following figures, much reduced. Some of the crystals are twenty inches long;

Fig. 1.



Fig. 2.



three or four inches is the average size. They have a rhombic form, and taper towards each extremity, the two ends curving slightly in

opposite directions. Stars of four and six rays, (figure 2,) and also globular masses, bristled on all sides with the ends of prisms, are common among them. They have a very rough, brownish exterior, like a fragment of sandstone; and within, instead of the regular cleavage structure of a proper crystal, the texture is crystalline granular. A surface of fracture glistens like a fine-grained statuary marble, though less bright. An attempt was made to burn them for lime, but they crumbled, and so clogged the fire that it was abandoned.

At one of the localities the specimens are coated with minute crystals of gypsum: they were probably formed through the decomposition of iron pyrites, this mineral giving rise to the sulphuric acid which united with the lime of the concretions. The rough surface of these rhombic concretions may have arisen from erosion by this process, or by the action of water percolating through the clay.

The discovery of concretions of the same kind in Oregon shows that these prisms actually consist of a series of rhombohedrons, as illustrated by figures in the course of our remarks on the Geology of Oregon.

Fossils of the Coal Regions.

We make in this place only a few remarks on the general character of the fossils, as they are particularly described in an Appendix at the close of the volume.

With the exception of a single fossil fish, the organic remains observed in this formation belong to the vegetable kingdom.

The specimen of fossil fish referred to (see Plate I.), was obtained by Mr. James Steel from the B or *second* coal pit of Newcastle, and was presented by him to the collections of the Mechanics' Institute of the place, where it was deposited in October, 1837. It was found about ninety feet from the surface, in a layer of bluish sandstone.

I was informed by Mr. Robert Scott of Glendon, that another fossil fish was formerly obtained from the rocks near his residence,—about forty miles above the mouth of the Hunter. But as the specimen had left the country, I had no means of ascertaining its characters.

The Flora of the carboniferous era of New South Wales has afforded comparatively few species. No true Calamites, Sigillariæ, Lepidodendra, nor any of the genera of tree-ferns which characterized the carboniferous era of Europe and America, were observed by the author. Instead, the prevalent species were small ferns and Equis-

tacea, and the remains of Coniferæ allied to recent pines. The simple-leaved *Glossopteris Browniana* constituted more than four-fifths of all the vegetable remains at the localities examined. The leaves are beautifully preserved in the clayey layers, and the black colour contrasts handsomely with the light tint of the clay in which they are imbedded. They give the rock a schistose structure. Large slabs may be broken out, covered with the black leaves, and these slabs may often be split for the same reason into laminæ as thin as a wafer. Besides this species, four or five others of the genus *Glossopteris* were collected, a compound-leaved fern (but of rare occurrence) of the genus *Sphenopteris*, leaves that have been referred to *Zeugophyllites* (or *Noeggerathia*), a species of *Phyllothea*, and some confervoid fossils; in all, exclusive of the Coniferæ, not over twenty species. In the examinations of Strzelecki, the same genera were observed.

The investigations since more extensively made by the Rev. W. B. Clarke, have brought to light many others, and he reports the discovery of *Sigillariæ*, *Stigmaria*, and *Lepidodendra*.*

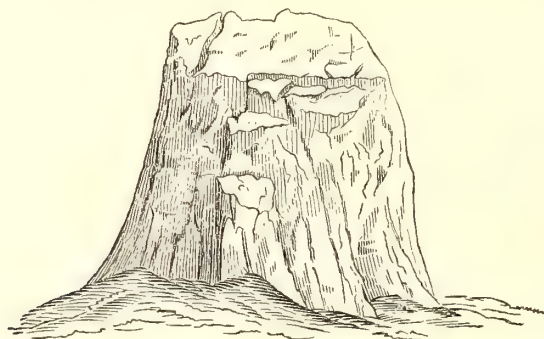
The remains of Coniferæ occur in fragments, disseminated through the sandstone layers, especially the inferior of the series. These fragments are of all sizes from a few inches to many feet in length, and occasionally large stumps are met with: they are usually more or less flattened, the shorter diameter being but a third or one fourth the larger. The masses are generally a siliceous clay ironstone, of a brownish-red colour. Many are simply silicified or agatized, and others are partly siliceous and partly carbonaceous. The examinations of Wm. Nicol, Esq., have determined satisfactorily their coniferous character.†

At the Newcastle cliffs, on the platform of rock at the water's edge, many of the fragments of wood are six feet long and a foot broad. Similar fragments are seen along the surface of the cliffs, with their ends extending out for a few inches. In Illawarra, on Point Towrudi, two and a half miles north of Wollongong, there are fragments twenty inches in diameter, which, though siliceous, are black in colour, (owing to some contained carbon,) except when bleached in consequence of exposure; they give out a bituminous odour when struck with a hammer. At Bulli, similar fragments are not uncommon: they are also abundant at Keelhogue and throughout the Illawarra coal region. On the side of the road west of Wollongong, near

* Quart. Journ. Geol. Soc. of London, No. 13, 1848, p. 60.

† Fourth Rep. Brit. Assoc. p. 660, and Jameson's Journ. xvi. 137, 1834.

the foot of the mountain, there are two large stumps standing erect, one of which is here represented. The diameter exceeds two and a



half feet. Some fragments of the trunk of a tree lie in the rock on the opposite side of the road. Many a passing observer has fancied that he distinguished the different parts of a single tree in these remains, and has pointed out a supposed resemblance to wood of the present forests.

On the coast, a few miles to the south of Newcastle, near Lake Macquarie, as we were informed by the Rev. Mr. Wilton, there is a large number of upright stumps standing in the sandstone, and appearing like the remains of a former forest. The region has since been described by the Rev. W. B. Clarke, in a memoir before the Geological Society of London;* he states that "one can form no better notion of their aspect than by imagining what the appearance of the existing living forest would be if the trees were all cut down to a certain level." One of the stumps was five or six feet in diameter. They are imbedded below in sandstone, which has in part a cherty character; and the occurrence of a specimen of the common *Glossopteris* proves that the rock belongs to the coal series of Newcastle.

IV. SANDSTONE STRATA BELOW THE COAL.

We have remarked upon the gradual transitions which connect the coal rocks with the series above it. The same observation may be extended to the strata below the coal; the two are conformable, and so pass into one another, that we can distinguish no distinct line of separation.

* Proceed. Geol. Soc. London, iv. 161, 1843.

These sub-carboniferous beds are well developed in Illawarra, where they extend with some interruptions from Wollongong southward to Shoalhaven, (see map,) through which region they were examined by the writer. From Shoalhaven these rocks extend inward along the Shoalhaven River; but to what extent we cannot say. To the north of Port Jackson, strata nearly identical in age outcrop at Harper's Hill, and others, perhaps somewhat older, farther west at Glendon, and again at Mount Wingan, one hundred and twenty miles up the Hunter. This wide range will undoubtedly be found more extensive when the country is farther examined, and other intermediate points may be made out, wherever the Sydney sandstone does not overlie and conceal them.

Characters and Structure of the Beds.

Lithological Characters and Stratification.—The layers, where I have had an opportunity of examining them, are light grayish-blue, grayish-red, and red sandstones. They are generally very argillaceous, and are properly called argillaceous sandstones.

At *Harper's Hill* the rock is a bluish or greenish compact sandstone, not at all schistose, containing an occasional pebble of greenstone, amygdaloid, or granite. Much of it is composed of fine earthy grains, as if from the decomposition of greenstone; there is rarely the glistening lustre derived from grains of quartz. Some portions of the rock contain carbonate of lime sparingly disseminated; but this is mostly confined to the layers in which the fossils are most abundant. The fossils themselves are calcareous instead of siliceous.

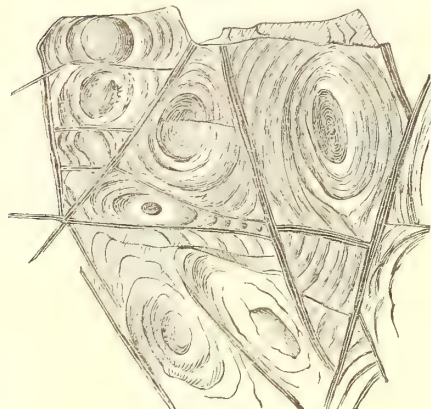
The rock at *Wollongong* is very similar in appearance to that of Harper's Hill, and like it encloses occasionally rounded masses of amygdaloidal, syenitic, and porphyritic greenstone, some of which are very large, amounting to ten or fifteen cubic feet. In general the texture is fine-grained, and the colour light grayish-blue. The layers are thick and compact, and rarely exhibit any planes of deposition. They vary a little in hardness, and in some parts of the Wollongong Point, softer layers alternate with others which are harder and more siliceous, the silex having been infiltrated in solution. South of Wollongong, from Kiama to Black Head, the rock, where it appears in view, has either the same characters as at Wollongong, or is a *red*

sandstone; and in some places the passage of the red into the gray may be observed. Through much of the distance, however, beds of basalt constitute the shore bluffs. The relations of the sandstone and basalt will be particularly described in the pages on the latter rock. At Black Head the rock is identical in appearance with that of Wollongong. Between this point and Shoalhaven, a distance of nine miles, the coast is a sand beach. But near the latter place stands Mount Coolomgata, an isolated elevation, five hundred feet high, which consists of the same rock, but having a grayish-red colour and a rather coarse texture, approaching to pebbly.

The greenstone or basaltic boulders and pebbles of this rock in Illawarra, may be traced to the basaltic rocks of the same region. The porphyritic variety contains tabular crystals of feldspar half an inch square, so thickly disseminated as to form at least one-third of the whole mass. In the amygdaloid, the ovoidal nodules were so numerous as to make it resemble a puddingstone; and its nature was farther disguised by a bleaching of the surface to a light grayish-green. These nodules were calcareous and averaged half an inch in length, though some were two or three inches.

This amygdaloid actually occurs in place at Keelhogue, presenting the same characters in every particular; and a porphyritic rock is also met with in the same region, similar to that above described, excepting a smaller proportion of imbedded feldspar crystals. This locality is situated to the west of Wollongong, not far from the foot of the Illawarra range, near the residence of the Attorney-General.

The imbedded minerals of the rock, as far as known, are few and unimportant. Some small nodules or crystals of pyrites occur at Wollongong; and chalcedony, quartz crystals, and calc spar are met with, constituting fossils and occasionally filling seams.



Concentric Structure.—A concentric structure is more frequent in these rocks than in those of the coal series above, and in some places the examples of it are quite remarkable. The general character of it when connected with cracks or fissures in the rock is

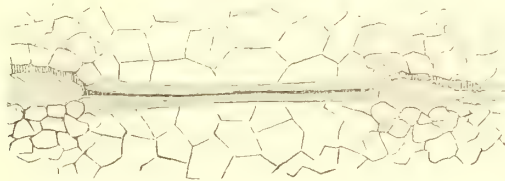
similar to what has been explained. The preceding figure was taken at Wollongong, and represents on a reduced scale, the usual appearance of the layers where they have been worn by the sea. In general the enclosed area is very low convex. The centre has a compact structure, and is enveloped by layers which diminish in thickness towards the sides. In some examples the whole is composed of layers, while others have the compact central mass more than half the whole diameter. The latter, when worn by the sea, have a flattened convexity as the centre of the concretion; and this convex surface is in some places singularly eroded, as in the annexed figure.

Fig. 2.



The connexion of the concretionary structure with the fissurings or cracks of the rock, (which is apparent from the fact that each area is a separate concretion,) is well shown along certain large fissures which follow a single course, independent of any areas. The following sketch represents a part of the seashore layers, about thirty feet in length, just north of Wollongong Harbour. Along the centre runs a

Fig. 3.



narrow fissure, which enlarges irregularly in two places, and then contracts again to a narrow crack, that nearly disappears and branches in different directions. On each side of this fissure there is the same schistose structure as in the regular concretions: six to twelve layers, about half an inch thick, run parallel with the fissure, and are brought out in relief by the wearing away of the intermediate portions, which appear, as elsewhere, to be softer than the centre of the layer. Around the *enlargements* the schistose structure is interrupted; and instead of it, the rock is collected into rough shapeless masses, cracked in every direction, which, on account of their hardness, have resisted abrasion, and stand out as a prominent boss on the surface of the rock. On each side of the fissure, for many yards, there are irregular cracks, some of which are continuous with those of the boss, and appear to be of the same origin. The fissure is nearly lost to the right, where it

subdivides, but to the westward it continues for several rods. Some other peculiarities might be remarked upon, but we refer to the figure for a knowledge of them.

The walls bordering a fissure between concretions have mostly a reddish or ferruginous aspect, while the areas they enclose are grayish-blue. It was somewhat surprising, after finding the fact just stated very generally true, to discover that in a few places where the rock was a little reddish, the walls, for an inch each side of the fissure, were a light grayish-blue like the ordinary sandstone,—just the reverse of the previous statement.

These fissures or cracks are various in their directions. They cross at all angles, and often abut against one another without crossing.

The concentric structure passes into the *globular*, and occurs where there are no cracks or fissures. Around Wollongong Point, the wide platform of rock, lying at high water mark along the shores, presents singular examples of these globular concretions. They appear as if large cannon-balls had been dropped into a bed of mud, and sunk, some half their diameter, others three-fourths or more; and subsequently the mud had hardened around them. The water, by removing the softer portions of the layers, has left the spherical balls projecting generally a hemisphere above the surface. More regular spheres than many of them could hardly be formed by art. The average size is about four inches; but they occur from an inch, and even smaller, to a foot in diameter. They are extremely compact and hard, requiring smart and repeated blows to break them, while the adjoining rock yields with little difficulty; a few blows will readily detach them from the rock, in which they lie like foreign masses.

These natural cannon-balls generally contain some foreign body, and in one-third of them, at least, it is a fossil; in this case they easily split in the direction of the fossil. In some there is a fragment of carbonized wood or a pebble. In many no nucleus could be detected; and often the foreign body, when present, was far from the centre. The texture generally is equally hard throughout, though occasionally having the centre soft. Along the shores they may be sometimes found hollow, with a single small hole by which the water entered and gradually hollowed them out.

These concretions are mostly confined to particular layers. Some of the layers in the cliff near the extremity of Wollongong Point appear to be wholly composed of flattened globular masses, united laterally into a continuous bed of large extent: and this structure

passes gradually into layers, in which no traces of curved surfaces can be detected, showing that the hard siliceous texture of the firmer layers has arisen from the influence of silica deposited from solution.

The concentric structure is also well seen at Harper's Hill on the Hunter. It is confined to the upper layer, in which the concretions have the form of a flattened sphere, and are from four to six feet in horizontal diameter. They consist of concentric layers, which readily separate and peel off. In the bed of a stream near Glendon, farther up the Hunter, there are other examples, as I am informed, on a magnificent scale. The concretions average ten feet in diameter, and cover the surface like artificial domes; in the distant view they look like a village of rounded huts. They consist of separable concentric coats, and contain seams of quartz or chalcedony, often half an inch thick, lying between some of the layers.

Dip—Fissures—Faults.—The dip of the layers in Illawarra is small, and varies from one to twelve degrees. In the cliff to the north of Wollongong, it amounted to five degrees to the northwestward, and increased to ten degrees two hundred yards beyond. In the Wollongong Cliff, it was two to four degrees; in the cliff north of Kiama, three degrees; in Rocky Cove, three miles south of Kiama, three degrees; at Black Head, two degrees; and in each of these cases, as in the first, the inclination was to the northwestward.

Notwithstanding this dip, however, there is a little difference in the elevation above the sea, of the layers of rock along the coast south of Wollongong. At Shoalhaven, however, nine miles south of Black Head, the same layer which lies at the water level of the latter place, is found at a height of one or two hundred feet in Mount Coolomgata.

At Harper's Hill the rock dips to the northward and westward twelve degrees.

The smaller fissurings of a layer with which a concretionary structure is often connected, have no system of uniformity in their arrangement. There are larger fissures, which are more uniform in their courses, and correspond in general to those of the Sydney sandstone, though less constant, and not of so frequent occurrence.

At Wollongong, the fissures vary from *northeast-by-north* to *north-northeast*.

At the top of the cliff there is a fissure running *northeast-by-north*, exposing a surface of fracture twenty feet in height.

At the cliff north of Wollongong Harbour, the course of a fissure is *east-by-north*, and becomes a short distance beyond east and west.

At Kiama, a fissure runs for one hundred yards *north-by-east*; in the second cliff to the northward, the general direction of the fissures is *east-by-north* and *northeast*; in the second cliff to the southward, *north-by-east* and *northwest*.

At Black Head, near the extremity, there are fissures running *north-by-east* and *northwest*. They are more numerous than usual, and divide the layers into large blocks.

Decomposition.—The sandstone of this formation undergoes rapid alteration when exposed to the influence of air and water. Both at Harper's Hill and Wollongong, the upper portion of the cliff for eight feet is changed from its usual grayish-blue to a rusty yellowish colour, and is very fragile. This layer might be mistaken for a subsequent deposit of different composition from that below, especially as its limits are distinctly marked; but the fossils and obvious transitions prove its identity with them.

Along the road, half a mile west of Wollongong, where the rock is exposed in a quarry, the outer surface facing the road is altered in the manner just described, and is quite soft and crumbling; but, when quarried out, the layers present the usual characters.

The upper layer at the Wollongong Cliff appears to be altered throughout; for the quarryings in it, which have already been extensive, do not open to any unaltered rock. The fossils, moreover, are mere casts; the shell which, before the alteration, appears from those below to have been siliceous, has been dissolved out, and removed during the progress of decomposition.

Decomposition in some places makes rapid progress. At Harper's Hill, the rock during the two years past has been altered to a depth of a foot, and become a black granular material, too tender to bear handling. It resembles the soil from greenstone rocks, and is actually of the same nature, as the sandstone is made up largely of basaltic material.

In much of the rock at Wollongong, exposure to drying developes a concentric structure, not before apparent, and the masses fall to pieces by peeling off in layers. Large blocks, quarried out for use, thus undergo a natural destruction. If kept under water, however, the rock is durable; and it has been successfully used for building a basin at that place. We might suppose that the salt of the sea-water, or of the spray from the surf, has much to do with this peeling process, and probably it does promote it. Yet the same effect takes place in the interior of the country, where the sandstone is not exposed to the sea.

Fossils of the Sandstone below the Coal, and Age of the Deposits.

Fossil shells, along with some corals, occur at many localities of the argillaceous sandstone. They abound at Wollongong Point, and at various points on the shore, to Black Head and Shoalhaven. At Wollongong the specimens usually occupy the interior of globular concretions, and some of these imbedded bivalves are eight inches long. At Black Head, and also between this place and Rocky Cove, and three miles south of Kiama, they are scattered through the rock, in great numbers. Harper's Hill and Glendon are localities on the Hunter already somewhat noted in the colony.

The shells throughout the formation are well preserved, the valves are united with unbroken edges or angles, (except from pressure,) and the ridges or markings are distinct and apparently unworn. The bivalves usually lie with the valves somewhat gaping, though sometimes closed. Numbers of the same species are often clustered together.

The shells are fossilized either with lime or silica. The former is the case at Harper's Hill; and the shells look as fresh and white, and as natural, as if just from the water. They are so neatly preserved, that, judging from this character alone, they might easily be mistaken for fossils of a modern date. When broken across, a cleavage structure is often exposed, showing that the original lime of the shell has been recrystallized. If, as the writer has suggested in another place, the lime of shells is in the condition of arragonite, we may understand how a molecular change should take place, producing the ordinary calc spar and its cleavage. The striæ or markings of the original shell are perfectly retained.

The fossils of Black Head are either calcareous or siliceous. They sometimes consist of chalcedony, with the interior more or less perfectly filled with calc spar.

The remains of plants are few in number, and are badly preserved. Flattened fragments of trees, like those of the coal series, are occasionally met with. At Black Head, a portion of a silicified trunk of a tree, seven inches in diameter, projects three feet from the face of the cliff. The structure of the wood was beautifully preserved, and resembled that of the layers above. There are also coaly impressions of irregular form and large size, one of which measures twenty inches by six. They present no traces of their original structure;

they are equally thin throughout, not exceeding an eighth of an inch, and many are much thinner. No distinct leaves were observed.

The fossil animal remains embrace a variety of genera, including some that have hitherto been considered as widely distant in geological age.

The whole number of species obtained by us is eighty-six, of which there are nine or ten of corals, two of *Conularia*, one of *Theca*, sixty-four of bivalve molluscs, and eleven of univalves.

The corals pertain to the genera *Favosites*, *Stenopora*, *Fenestella*, and *Hemitrypa* (?). There are none of the *Cyathophyllum* family, and no other *Radiata* were observed either at Harper's Hill or in Illawarra, excepting some plates possibly of an encrinital character, which we have referred to the new genus *Pentadia*. Encrinital remains occur at Glendon.

The Brachiopoda include species of *Productus*, *Spirifer*, *Terebratula* and a *Lingula*. Among acephalous molluscs, there are species of *Pholadomya*, (*Allorisma*,) *Solecurtus* (?), *Astarte*, *Cardinia*, *Nucula*, *Cypricardia*, *Pecten* and *Avicula*. There are also the genera *Eurydesma* and *Pachydomus*, instituted by J. D. Sowerby and J. Morris for New Holland fossils; and still other genera the author has found it necessary to introduce.

All the species are peculiarly plain in their markings. It is also remarkable that they should pertain almost exclusively to genera in which the shells have no sinus to the palleal impression. The species referred to *Pholadomya* have the external characters of that genus; but the specimen, an external cast, does not show whether there was a palleal sinus or not. Neither can we say, from the specimens of the species referred to *Solecurtus* (?), that there was a palleal sinus. The genus *Mæonia*, proposed by the author, contains species closely resembling the *Myidæ* in general appearance, and especially the *Homomyæ* (Agassiz), yet having a very strong *entire* palleal impression, and belong to the family *Astartidæ*.

The following catalogue gives the genera and number of species, at each of the three localities referred to. The specimens of these localities may generally be distinguished by the nature or colour of the rock accompanying them.* Those of Harper's Hill are calcareous fossils, and the rock has an olive green colour, generally appearing some-

* I suspect that the localities of Strzelecki's fossils are often given wrong in his work, as I made careful search at the localities, and the facts observed do not always correspond with his statements.

what granular. Those of Glendon, seen by the author, have mostly a rusty ferruginous look, and the rock is somewhat schistose. Those of Illawarra occur in a dull bluish or dark grayish argillaceous sandstone; or else in a rock of a light sandy aspect, a colour and appearance derived from partial alteration; and very many of the shells are contained in spherical concretions, as already described.

The species of fossils of the different genera, are as follows:—

FROM ILLAWARRA.—2 of *Pleurotomaria*, 1 *Natica*, 2 *Platyschisma*, 1 *Theca*, 1 *Lingula*, 2 *Terebratula*, 2 *Productus*, 5 *Spirifer*, 1 *Solecurtus*, 1 *Cardium*, 3 *Pholadomya*, (or *Alloisma*), 1 *Astarte*, 6 *Astartila*, 3 *Cardinia*, 1 *Nucula*, 4 *Cypricardia*, 7 *Mæonia*, 1 *Eurydesma*, 1 *Avicula*, 1 *Pecten*, 1 *Pterinea*, 2 *Chætetes*, 1 *Pentadia* (crinoidal?).

FROM HARPER'S HILL.—3 species of *Bellerophon*, 3 *Platyschisma*, 2 *Pleurotomaria*, 1 *Conularia*, 1 *Spirifer*, 1 *Solecurtus*, 1 *Mæonia*, 1 *Nucula*, 2 *Eurydesma*, 2 *Cypricardia*? 3 *Pecten*, 3 *Pachydomus*, 1 *Chætetes*, 1 *Hemitypa*?

FROM GLENDON.—1 *Conularia*, 1 *Spirifer*, 1 *Astarte*? 1 *Pholadomya*, 1 *Cypricardia*, 5 *Fenestella*, 1 *Nucula*, 1 *Avicula*, and Encrinital remains of one or two species.

No species of Harper's Hill and Illawarra proved to be identical, excepting the *Pleurotomaria Morrisiana* and the *Spirifer glaber*. The *Conulariæ* are peculiar to Harper's Hill, and the genus *Theca* was found only in Illawarra. The genus *Pachydomus*, (as properly restricted,) is confined to the former locality, and *Cardinia*, *Productus*, *Terebratula*, *Cleobis*, and *Astartila* to the latter.

These differences, though based on our partial examinations, are too striking to be passed without remark. The Glendon fossils are also peculiar; of them, only a single *Spirifer* was found also in Illawarra.*

Age of the Coal Beds and the subjacent Sandstone.—The question of the age of these deposits is discussed with much learning and good judgment by Mr. J. Morris, in the work by Strzelecki. The carboniferous character of the animal remains is obvious. The transverse

* According to Strzelecki, there are other species common to Illawarra and Harper's Hill; but we may doubt his accuracy, for reasons already stated. We hesitate at receiving all the facts regarding localities stated in M'Coy's article. The "*Pleurohynchus australis*" he attributes to "sandy schists of Wollongong;" whereas the Wollongong rock is not schistose, and we have the same fossil from Glendon, where the rock is "a sandy schist." On account of these uncertainties, we have not instituted a comparison between the statements of these authors and our own observations, although we believe in their general accuracy.

Spirifers, with strong costæ, are carboniferous forms.* The *Spirifer glaber* occurs in the coal beds of England, Europe, and America, and also extends into the Devonian. M'Coy mentions also as Australian fossils, the *Spirifer calcarata* and *Sp. attenuata*, British carboniferous species.† The *Terebratula hastata* has its representative in the *T. amygdala*. The *Cypricardia siliqua* is near the *C. modiolaris* of M'Coy,‡ and may be the same. The species of *Pleurotomaria*, *Conularia*, *Productus*, *Pholadomya* (*Allorisma*), *Pecten*, *Astarte*, *Nucula*, and *Bellerophon*, as well as *Fenestella*, are carboniferous in character. The absence of *Orthocerata* and *Cyathophylla*, and the rarity of *Crinoidal* remains, is all in favour of the deposits being as recent as the carboniferous epoch. A few genera are peculiar, but not as many as might have been supposed in the antipodes of Europe.

The coal fossils of New South Wales, where examined by us, are of more uncertain chronology. They differ from those of the American and European carboniferous beds in the following points:—

1. Abundant remains of coniferous wood, in logs and stumps.
2. Absence of arborescent ferns. *Stigmaria* and *Sigillaria* are rare, though recently reported to exist there by the Rev. W. B. Clarke.§
3. The rarity of compound leaved ferns, and the great quantities of *Glossopteris*, the *Browniana* constituting nine-tenths of all the buried leaves.
4. Absence of true *Calamites*, and the presence of the thin and fragile *Phyllotheceæ*.
5. The close relation of the species of *Pecopteris*, *Glossopteris*, and other genera to the Oolitic coal plants.

The same or allied fossils occur at the coal basins of Van Diemen's Land, and also at the Burdwan coal field, India. It is not known

* The *Spirifer antarcticus* of the Falkland Islands, described by Morris and Sharpe, (*Quart. Jour. Geol. Soc.*, No. 7, ii. 274, and plates 10 and 11,) is quite near the *Sp. avicula* or *vespertilio* from Illawarra; and the *Sp. Hawkinsii* of the same region resembles a Glendon species.

† *Foss. Bot. and Zool. Aust.*, in the *Ann. Mag. Nat. Hist.*, xx. 232, 1847.

‡ *Carb. Limestone and Foss. of Ireland*, 4to. 1844, pl. viii. fig. 27.

§ *Quart. Jour. Geol. Soc.*, iv. 60, No. 13.—Mr. Clarke states that the same coal beds probably occur on the Mackenzie, lat. 30°, 600 miles north of Newcastle; also at Port Essington in North Australia, as observed by Leichardt.

Lepidodendra are reported by him as occurring on the Paterson, and in "the hard siliceous metamorphic rocks of Colacola on the Allyn, with a multitude of *Orthidæ*, *Atrypæ*, *Trilobites*, *Strophomenæ*, &c.," fossils which indicate a greater age for the associated plants than that of the Newcastle coal.

whether the same characterize the coal beds of New Zealand, Chatham Island, Borneo, Labuan, Luzon, and other East India localities.

Morris concludes from the facts that the Flora of the southern hemisphere differed from that of the northern at the "carboniferous period." M'Coy infers that the coal beds are of the Oolitic epoch, and the sandstone below, of the lower carboniferous. Rev. W. B. Clarke ranks all with the Devonian or lower carboniferous.

The opinion of Mr. Morris we believe to be most nearly correct. The fossil fish described indicates, according to Agassiz, the upper carboniferous era, or a transition to the Permian; and this age appears to accord best with the observed facts. This is confirmed by the resemblance of the *Noeggerathia* to species found by Tchihatcheff in Siberia, in rocks corresponding probably "au todliegende des Allemands," lying above the coal and immediately succeeding it.*

While the coal plants point to the upper carboniferous, or still higher, the fossils below the coal seem to correspond most perfectly with the lower carboniferous epoch. Yet the conformity and continuity of the series of beds, (including the sandstones below the coal, and the coal layers,) observable in various places, the frequent occurrence of coniferous logs, like those of the coal beds, in the fossiliferous sandstones at different localities,† together with the characters of the fossil fish, leave little doubt that the whole is of one prolonged age, referable to the upper carboniferous, or partly the lower Permian era.‡

V. BASALTIC AND ALLIED ROCKS.

Basaltic ridges appear here and there over most parts of New South Wales, isolated in the sandstone, or associated in ranges. But these ridges increase in number as we pass the Hunter on the north, or reach the Blue Mountains on the west, or Argyle on the south. In the Liverpool range some peaks exceed four thousand five hundred feet in height; others in the Blue range are between three and four

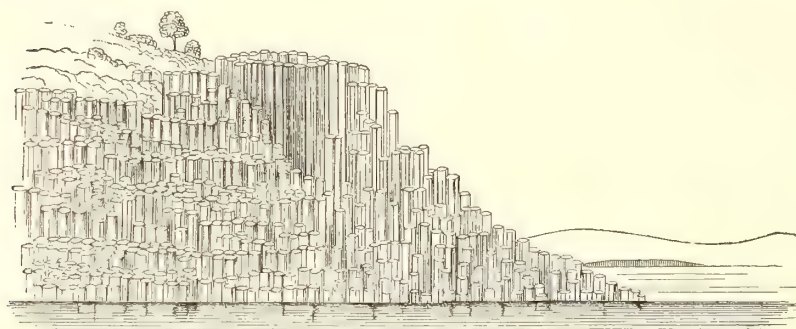
* L'Altai Oriental, p. 378.

† For other facts, see Rev. W. B. Clarke, loc. cit. p. 61.

‡ The existence of older fossils in Australia, both animal and vegetable, is well known. The *Lepidodendra* and associated fossils alluded to in a note on page 494, are of this character. Trilobites, according to the Rev. W. B. Clarke, are found on the Paterson, also at Yarralumla and Yass Plains, and at Burragee, north of Port Stephens. *Cyathophylla*, species of *Orthis*, and other old fossils, occur in the same regions and elsewhere. —W. B. Clarke, *Jour. Geol. Soc.*, loc. cit. p. 63.

thousand feet. My own excursions have enabled me to study the rock in the Hunter Valley at Newcastle, and at Puenbuen, near Paramatta at Pennant and Prospect hills, and at various points in Illawarra and the adjoining country towards the Kangaroo Grounds.

Illawarra afforded the most interesting views of basaltic cliffs; and some of the basaltic scenery about Kiama will bear comparison with the rocks of Staffa. The following sketch is from that region.



There are many similar scenes along the cliff to the north of that place, exhibiting the character of the rock and the effects of the sea. At one place, where the prevailing rock is sandstone, there is a deep channel, but eight feet wide, cutting into the shore bluff about one hundred and fifty yards, like an artificial canal of great depth. The sea swashes along at bottom, and with every tide is beating in surges against the rocks at its head. It was made by the removal of a basaltic dike through the action of the waves. At another place, a dark cavern, eight or ten feet wide, extends into the cliff a hundred yards or more. The sea dashes in below, and may be heard hurrying on, for a while—becoming nearly still,—when suddenly, a sound like thunder roars through the cavern, as the water strikes the farther walls, and a few rays of light are seen amid the darkness, sparkling from scattered foam. At the entrance, the cave is sixty feet high, and half-way up, the rocks have fallen together and made an upper story or chamber, into which the traveller may venture, and looking down through the openings enjoy the exhilaration of the scene.

One of the most interesting spots to the amateur occurs in the cliff of Kiama Point;—it is a *blow-hole* like those of the Pacific, though peculiarly grand when in full blast. The entrance to the subterra-

nean passage, and its columnar rocks are shown in the sketch here given. The channel is about twenty feet broad and eighteen high. The



ENTRANCE TO THE KIAMA BLOW-HOLE.

advancing sea enters and swells onward with only a gentle murmuring for a distance of about two hundred feet; there a wall of prismatic basalt stands before it, against which it throws itself with a deafening roar, and then dashes upward through an opening forty feet deep, rising in a column to a height at times of a hundred feet, and falling around in a thousand changing arches.

The basaltic scenery of Illawarra is said to be exceeded by that of Van Diemen's Land, where these rocks occur under very similar circumstances.

Lithological Characters.—It is yet doubtful whether the igneous rocks under consideration are wholly *basalt*, or are in part *trap*, that is, whether they always contain augite with the feldspar, or sometimes hornblende. Some ambiguous rocks might be referred to either variety. But on tracing out their transitions, I have often found them graduating into coarser rocks in which the augite could be readily distinguished; and no instance was met with affording satisfactory evidence of the occurrence of hornblende. The fact that these minerals, augite and hornblende, are so nearly related in composition and differ principally in the temperature of crystallization, or rather, in rate of cooling, renders it more important that they should be distinguished by the geologist. The following varieties of rock were observed.

A. The basalt is in some places a tough compact black rock with

no traces of crystallization, scarcely glistening lustre, almost impalpable texture, and affording a smooth sub-conchoidal surface of fracture. A few grains of *chrysolite* may with difficulty be distinguished. This is its character at Prospect and Pennant Hills near Paramatta, where it is quarried for macadamizing roads. The same variety was met with at Puenbuen.

B. A similar rock to A, but breaking with a rough fracture. It is the prevailing rock at Kiama.

C. A similar rock to A, but containing more *chrysolite*. It occurs at Puenbuen.

D. A similar rock to B, but of a light grayish-blue colour. This is met with near Broughton's Head, Illawarra, and to the northwest of Kiama.

E. A dark bluish rock, finely porphyritic, with small points (not tables) of feldspar. It occurs at Prospect Hill.

F. A compact porphyritic basalt, with distinct crystals of feldspar, but none of augite. It occurs to the north of Kiama, in Coolomgata, at Shoalhaven, and also at Keelhogue.

G. A porphyritic basalt, in which the augite and feldspar are both distinct, and some of the crystals of the augite are a fourth of an inch long. It occurs at Prospect Hill.

H. A feldspathic rock, consisting almost purely of thin tables of feldspar aggregated into a moderately compact rock, with occasional geodes of smaller feldspar crystals. Some small specks of augite appear disseminated through it, and more resemble green earth than augite. It occurs at Prospect Hill.

I. Compact basalt, more or less vesicular, and containing geodes of chalcedony and other amygdaloidal minerals. Met with at Puenbuen and in Illawarra.

K. An amygdaloidal basalt, consisting of nodules of calc spar, thickly disseminated through a compact base. The calcareous nodules compose, in some parts, more than half the material of the rock.

These varieties graduate into one another. At Prospect Hill, the compact black basalt changes to a compact rock, with disseminated points of feldspar; next, to a porphyritic basalt, with distinct crystals of both augite and feldspar; and next, to the feldspar rock (H), in which augite is almost wholly wanting. Near Kiama, the dark compact basalt (B) passes into a subporphyritic variety, containing rarely a light brownish crystal of feldspar, and then into a coarsely porphyritic basalt, containing large tables of feldspar. It varies in colour from

a dirty black to a dirty green, and the feldspar crystals have usually the latter colour. The porphyritic rock of Keelhogue passes into the amygdaloid of the same region (K).

Position of the Basalt.—The basaltic rock occurs both in layers interstratified with sandstone, and in dikes. By its occurrence, both underlying some layers below the coal, and also protruding through the Sydney sandstone, it appears to be of different ages.

In Layers alternating with Sandstone.—The alternation of sandstone and basalt may be seen in many of the cliffs from Black Head to Point Bass, six miles north of Kiama, as shown in the line of cliffs represented on the map of New South Wales. At Black Head, the basalt does not occur in the cliff itself, but may be seen overlying the argillaceous sandstone a few hundred yards back. Going to the northward from this cape, the basalt soon appears capping the bluffs, and dipping with the sandstone below to the northward and westward. This layer of basalt, farther north, dips to the water just north of Stony Cove, three miles south of Kiama, where the lower sandstone layer is no longer in sight. The next bluff north is wholly basaltic. The next beyond is capped with red sandstone; this rock does not appear on the following cliff (at Kiama), which is very low, but composes the whole of the next one, with the exception of a small basaltic portion near the water's surface at the south end. The basalt thus dips beneath the water like the layer of sandstone before mentioned. Continuing our course northward, in the next cliff, the sandstone becomes capped with a second layer of basalt. Farther on, the sandstone disappears, and leaves the basalt alone.

There are hence, in this coast section, two distinct layers of sandstone, and two of basalt interstratified with them; and they disappear in succession as we go northward from Black Head, excepting the upper basalt. The following is a general view of them, with the thickness of each.

Upper basalt,	-	-	-	-	-	-	80 feet.
Red sandstone,	-	-	-	-	-	-	60 "
Second layer of basalt,	-	-	-	-	-	-	100 "
Blue argillaceous sandstone of Wollongong and Black Head,							150 feet thick in Coolomgata.

The first of the following figures represents the north cliff of Gerin-gong Boat Harbour, and the second the corresponding one on the

Fig. 1.



NORTH CLIFF, GERINGONG BOAT HARBOUR.

Fig. 2.



SOUTH CLIFF, GERINGONG BOAT HARBOUR.

south side. In both there is a layer of basalt overlying a layer of red sandstone, and this rests on a bluish-gray sandstone. The south cliff consists of the following layers :—

Basalt, above,	-	-	-	-	-	18 feet.
Red sandstone,	-	-	-	-	-	25 "
Gray Wollongong sandstone containing fossils,	-	-	-	-	-	37 "

Figure 3 represents a section of the south cliff of Stony Cove; and figure 4, a portion of the second cliff south of Kiama. The former

Fig. 3.



SOUTH CLIFF, STONY COVE.

Fig. 4.



SECOND POINT, SOUTH OF KIAMA.

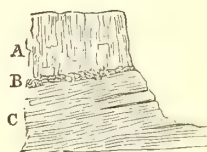
consists of basalt above, lying upon hard sandstone, containing numerous vertical fractures, passing into grayish sandstone, with shells and concretions like that of Wollongong. The latter is composed of eight feet of red sandstone, overlying eighty feet of basalt.

Fig. 5.



FIRST POINT, NORTH OF KIAMA.

Fig. 6.



SECOND POINT, NORTH OF KIAMA.

Figure 5 is a section of the first cliff north of Kiama, and figure 6, of the next beyond. The first, towards its north extremity, consists

wholly of red sandstone, excepting a layer of basaltic conglomerate below. Near the middle of the cliff, at one place, the sandstone has the ordinary gray colour of the Wollongong rock. The other shows the basalt overlying the sandstone, and separated from it by three feet of basaltic conglomerate.

The red sandstone, which in these sections lies between the two beds of basalt, appears to be an upper layer of the Wollongong sandstone, while the grayish rock below the basalt is identical in characters and in its fossils with the fossiliferous layer of Wollongong Point.

This stratification is well seen also at Keelhogue. The porphyritic and amygdaloidal basalt form a bed which may be traced for half a mile along the bed or margin of a stream. At either end we find it overlaid nearly horizontally by sandstone; and five hundred yards farther up the stream the coal shale and its fossils are abundant.

Between Black Head and Shoalhaven there was no exposed section in which the relations of the basalt could be studied. But in Mount Coolomgata, it appears in a bed, and overlies sandstone containing fossils like that of Black Head. This fossiliferous layer is seen at a height of three hundred and fifty feet. Above it, the basalt continues for eighty or one hundred feet, and then there follows sandstone again. The rocks correspond apparently to the lower sandstone layer, the lower basalt, and the second sandstone layer.

When first examined by the writer, the basalt was supposed to form a dike; but on examining the other side of the hill, I found the same alternation of sandstone and basalt, and could not discover any appearance of the latter cutting through the former. The case appeared anomalous, for the coast of Kiama had not then been studied. But afterwards it was obvious that we have in Coolomgata only a continuation of the stratification at Black Head, interrupted by a fault of one or two hundred feet.

Descending towards Shoalhaven, from the height called Broughton's Head, (see Map,) back from the coast ten miles, we passed over some outcropping basalt, which for sixty or eighty feet intersected the sandstone. Whether a dike or not was not ascertained.

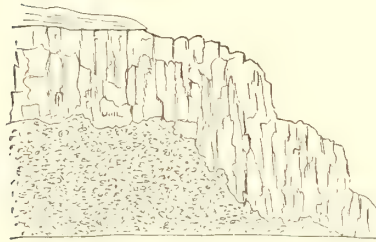
This alternation of basaltic beds and sandstone has been described as occurring in Van Diemen's Land, and the rocks present there the same characters as in Illawarra.

The beds of basalt, which we have followed along the shores, cover, with small exceptions, the whole region between Black Head and Point Bass, and compose the mountain spurs which here radiate from

the range. The sandstone intervening between the two layers appears as a surface rock only near Stony Cove, as it has been mostly worn away, leaving the harder basalt at the surface.

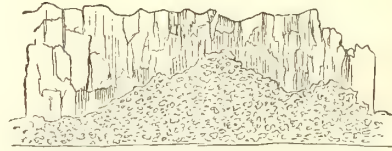
The basaltic conglomerate, where occurring, forms an irregular layer from one to ten feet thick, between the basalt and the sandstone. In some places it is piled up in hillocks and ridges twenty feet high, over which the basalt has spread itself, or the sandstone has been deposited. On the shores south of Kiama the transitions from basalt to conglomerate are very numerous, and in some instances, the latter rises in extensive beds into the basaltic cliff. Figures 7 and 8 illus-

Fig. 7.



SECOND POINT SOUTH OF KIAMA.

Fig. 8.



FIRST POINT SOUTH OF KIAMA.

trate this statement. The first was taken in the second cliff south of Kiama, at the entrance to a deep cavern which runs a hundred yards into the cliff. A thin layer of sandstone overlies the basalt, below which is the basaltic conglomerate. The second is from the first point south of Kiama. Other peculiarities are represented in figures 9 and 10.

Fig. 9.

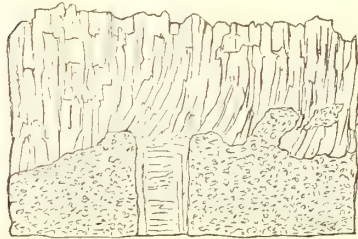
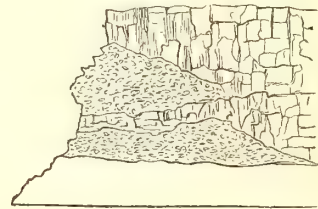


Fig. 10.



In figure 9, from the second cliff south of Kiama, the overlying basalt is connected with a dike. In figure 10, a layer of sandstone is overlaid by basalt and basaltic conglomerate, part of the latter being included between portions of the former.

The basalt and basaltic conglomerate are sometimes so closely

united, and the latter so irregularly permeated and intersected by the former, that considerable difficulty is experienced in tracing out the line of separation.

The character of this conglomerate may be well studied at the foot of the first cliff north of Kiama Point. It is exceedingly rough and ragged in its features. It generally consists of a clayey base tinged of various light shades of colour, either red, purple, green, flesh-tint, or yellow, and containing imbedded fragments of the several varieties of basalt. Large masses are occasionally scattered through it; one observed was fifteen feet square and five feet high, and seemed to be a knoll projecting from the solid basalt below. In some parts the fragments seem to be entangled in the solid basalt, and appear to have been enveloped during the fusion of the latter; and they are often three or four feet in diameter, though generally about as many inches. The exterior is rough and sometimes scoria-like; rarely they are somewhat rounded.

The clayey base is often baked to a flinty chert or jasper, which is usually of a deep-red or brownish-red colour, but in some places is striped with gray and brown. In the annexed figure, the conglomerate is intersected by a network of veins of jasper; it was taken on the first point south of Kiama. The four principal veins are from three to seven inches wide and nearly parallel; yet they are extremely irregular in form and vein-like in their branchings.



When this baked conglomerate has been worn by the sea, as is well shown near the Kiama blow-hole, it sometimes presents all the cavernous structure and rough points of a volcanic scoria; and the resemblance is so close, that in hand specimens they could hardly be distinguished.

The heat of the layers of basalt has produced important changes in the sandstone below. The red colour of the rock near Kiama is evidently an effect of this heat. At Geringong Boat Harbour, a layer of red sandstone, twenty-five feet thick, lies below the basalt; and beneath the whole, there is the common gray Wollongong rock. At Rocky Cove, the continuation of the same red layer is scarcely at all altered from the gray colour, although much hardened and vertically fractured.

In contact with the basalt it is horizontally slivered, or broken into thin chips, for an inch or two, and the surface of the layer is much excavated or honeycombed. It is a striking fact that the sandstone at one place should have a gray colour near the middle of a cliff, though red above and below. In Mount Coolomgata there is red sandstone under the basalt, and this rests upon the usual gray rock.

The change of colour here indicated must depend on the iron in the rock; and where, under similar circumstances as to position, the heat has not produced it, we may infer that the iron was too sparingly disseminated. The distribution of heat required for the effect would take place readily by means of the water penetrating the rock under the pressure of the sea above. The extent to which the necessary heat operated is shown by the usual thickness of the red layer.

The reverse effect of the sandstone on the basalt is also distinct in some places. At Rocky Cove, the basalt, for two or three inches above the sandstone, breaks into small fragments as large as a walnut. In one of the bluffs north of Kiama, the prevailing dull grayish-green colour of the basalt, gradually changes to dirty olive-green six feet from the sandstone, and nearer the sandstone is almost black,—a change which may be attributable perhaps to iron from the sandstone. The rock, moreover, is very much fissured horizontally. Six inches of basaltic conglomerate separate the basalt and sandstone.

From the facts stated, especially the occurrence of the basaltic conglomerate with the basalt, and this graduating into the sandstone, it is evident that the basaltic beds were overflowings of the rock in fusion before the upper sandstone layers were deposited, and were not the result of intrusion. The same conclusion is deduced from the red colour of much of the sandstone below the basalt, and the breaking of it immediately adjacent. The occurrence also of pebbles and masses of basalt in the Wollongong rock indicates the existence of other beds of still earlier age, though probably of the same epoch.

A few narrow seams of baked conglomerate occur in basalt at an elevation of one thousand two hundred feet on the Illawarra range, just to the south of Broughton's Head, on the road leading from the Kangaroo Grounds. The surface of the basalt was exposed for a few square yards, and through it run irregular seams half an inch to three inches wide, which were filled with this conglomerate. The seams appeared to occupy fissures produced by contraction on cooling; but when or how filled and baked, we could not conjecture, without a

farther examination of the surrounding region. No other traces of basaltic conglomerate were observed in that region.

Courses of Basaltic Dikes.—The dikes of Illawarra are numerous and present interesting peculiarities. Their courses and characters are various, as shown in the following table.

	Course.	Width.	
1	N. E.	40 feet.	On Point Towrudgi, two miles and a half north of Wollongong. Disappears on one side in the sea, and on the other under the beach.
2	N. E. by N.	3 feet.	Rocky shores just north of Wollongong beach. The dike is interrupted for a short interval, and the adjacent parts run nearly parallel for some distance (fig. 1, p. 506).
3	N. by E.	6 feet.	Two miles west of Wollongong on the road running south. Only seen on the north side of the road; it disappears under the soil.
4	N. W.		On the same road as last, north of Illawarra Lake.
5	W. N. W.	6 feet.	North extremity of second cliff north of Kiama.
6	W. N. W.	4 feet.	Same locality.
7	W. by S.		Same cliff farther to the southward. The dike has been removed by the sea for one hundred yards or more, and leaves a deep narrow channel entered below by the sea.
8	W. by S.		Same cliff; similar to the last.
9	W. by S.	6 inches.	Same cliff farther to the southward; forms one side of a deep cavern excavated in the cliff.
10	N. N. E.		Same cliff; cuts through the sandstone that forms the base of the cliff, but does not intersect the basalt above.
11	N. W.	40 feet.	Same cliff. There is a broad fissure cutting through the rocks of the shore, which is evidently a dike, though the rock is concealed by the soil.
12	E. N. E.	5 feet.	First cliff south of Kiama Point.
13	N. E.	5 feet.	Same cliff as last.
14	E. by S.	16 inches.	Same cliff, near south end.
15	W. N. W.		Kiama Point near Blow-hole, intersecting the basalt of the cliff.
16	W. N. W.		At the Kiama Blow-hole, cutting through the rock over it.
17	W. by N.	40 feet.	Second cliff south of Kiama; cuts through the basaltic conglomerate, and above forms a bed overlying it.

	Course.	Width.	
18	W. N. W.	20 inches.	Same cliff; very irregularly faulted.
19	W.	6 feet.	Rocky cove, three miles south of Kiama; follows the whole western side of the cove, and runs into its southeastern corner.
20	W. by N.	2 feet.	Extremity of Black Head. On the other side of the Point, the same dike runs W. $\frac{1}{2}$ N.
21	N. E.	5 feet.	South side of Black Head.

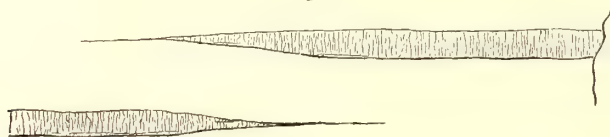
In addition to the above we may state that on the ascent of the Illawarra range near Mount Keerah, the high peak west of Wollongong, I observed a few fragments of basalt on the surface towards the top, showing that a dike probably intersects the sandstone in that vicinity, though concealed by the soil. On the Illawarra range, where the summit was first reached on the way to the Kangaroo Grounds, numerous blocks of basalt afforded the same evidence of a dike, probably several feet in width. We were compelled to hasten on without a thorough exploration. In the same range, just to the south of Broughton's Head, the summit was found to consist wholly of basalt.

In other portions of New South Wales, but few dikes were met with. The island of Nobby (page 511) is divided vertically by one, eight feet wide, which runs northeast, coinciding in direction with the fissures in the rock adjoining. Another dike intersects the rocks of the shores just south of Telegraph Hill, Newcastle; its width is three feet and direction north-northwest.

At Paramatta, in the bed of the river, a narrow dike runs to the northeast, and has a slight inclination to the west-southwest.

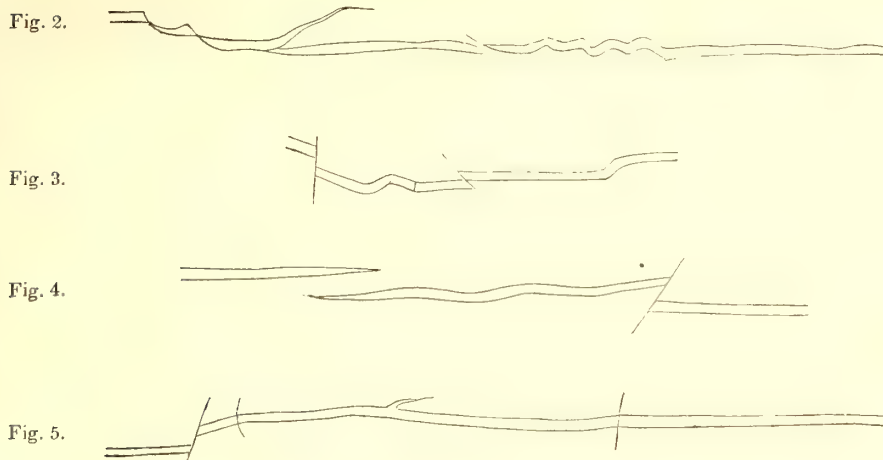
The *flexures*, *curvatures* and *faults* in many of the dikes are unusually numerous. Sometimes a dike contracts rather abruptly till it closes, and then its continuation appears some distance to the right or left, beginning with a mere line where the other part commenced to

Fig. 1.



contract, and attaining its full width where that disappeared. The dikes 2, 10 and 18, exemplify this fact. In the first of these, which is here represented, the two parts are five feet distant.

The faults and curvatures in a few dikes are represented in the following figures. The faults in some instances take place every few



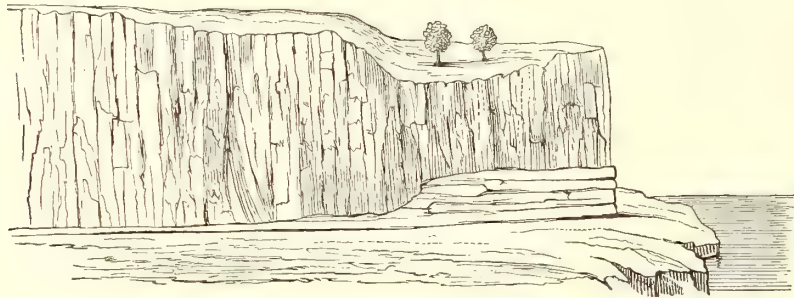
feet, and vary in amount from a few inches to some yards. These faults show that the enclosing rock has undergone greater disturbances than would be inferred from other appearances.

These dislocations are more striking in dikes intersecting the basalt, which is the fact with those represented in figures 2 to 5; and it evidently arises from the tendency of the basalt to fracture irregularly in all directions, instead of in long straight lines, like the sandstone.

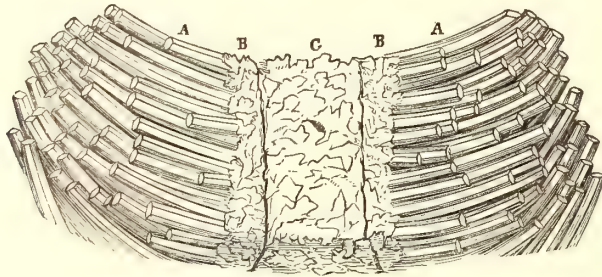
Prismatic and Concentric Structure in the Basalt.—The regularity and magnitude of the basaltic columns in some portions of Illawarra have been alluded to on a former page, and a figure of the Kiama Causeway has been given.

The columns of Kiama are surprisingly perfect, and vary from five to eight feet in diameter. They are mostly hexagonal; yet there are a few four, five, and seven-sided prisms among the others. The top of the cliff is like a flat pavement formed of large hexagonal blocks closely fitted together. The columns are imperfectly jointed, and break across with a flat surface, instead of a convexity. In certain parts of the cliff the top plane of the prisms is set obliquely, and the adjacent prisms over a large extent are alike and uniform in this obliquity. These oblique terminations are in general confined to places consisting of oblique columns; the terminal planes are in all cases nearly horizontal.

Along all the cliffs near Kiama, and beyond to the southward, the structure of the basalt is more or less columnar, though seldom as perfect in symmetry as above described. The cliff figured on page 497 represents more nearly the ordinary character. The following sketch gives another view of the basalt, and also exhibits its superposition upon the sandstone.



In the same cliff here figured, there is a fine exhibition of columns, and although inferior in extent to the place just described, the curvatures they present give great interest to the scene. These curved columns radiate from either side of a bank of basaltic conglomerate, which is twenty to twenty-four feet wide. Immediately adjoining the bank, the basalt is massive, with no traces of a columnar structure. Beyond this, as shown in the sketch here given, the columns become at once



perfect, being scarcely less regular below at their first appearance than above at their extremities. They are at first horizontal, and after extending thus a few feet, they gradually curve upward, and twenty feet distant are nearly vertical, inclining but ten degrees from a perpendicular. The whole curvature is not seen in an upper view of the columns, though apparent in a side view of the bank.

The columns are from one to four feet in diameter, and from four to six sided. Many of them are thirty feet long. The terminal plane is flat, as with the columns to the north of Kiama, and it follows the same principle in approximating to horizontality whatever the obliquity of the prism. The variation from horizontality is greatest with the most oblique columns, being, in some cases, twenty degrees: there appears to be a fixed ratio between the amount of variation and the obliquity.

Effects of heat are apparent at the junction of the basalt and conglomerate, though more decided in the basalt. The facts show that the fused basalt flowed over a bank of *cold* conglomerate. The bluish basalt passes gradually to brownish-black, brownish-red and brownish-yellow colours, with the last of which it joins the conglomerate; and the bank is mottled with purple, green, reddish, and yellowish-gray tints, and contains in its clayey base, masses and fragments of basalt. Along the line of junction, the conglomerate is much entangled in the basalt; yet is scarcely harder here than in other portions, probably because the bank was so small as to be heated alike throughout.

We cannot therefore doubt that the basalt, in fusion, flowed over a small ridge of conglomerate, in a stream at least fifty feet thick, and derived the position and forms of its columns from the varying inclination of the surface. We perceive a tendency to verticality between *two* cooling surfaces, the bank below, and the water above (for the eruption was probably submarine); and from the influence of the two the curved forms resulted.

Numerous instances in this region illustrate the fact that columns are formed only within certain rates of cooling. If too rapid, there are only irregular cracks, with imperfect traces, if any, of a columnar structure. This was the condition of the upper part of the basalt at the blowhole (figure, p. 497); out of the sixty feet, the upper twenty are not at all columnar, though very much fissured. The absence of structure in the basalt immediately adjoining the bank of conglomerate above described, may be owing to the same cause.

A columnar structure is distinct at Prospect and Pennant Hills, near Paramatta, and also in the hills adjoining Puenbuen. In the latter region perfect columns were observed at one place, but without any peculiarities requiring remark.

A *concentric* structure, subordinate to the columnar, is observed in some of the cliffs, though not common. Towards the north end of the second cliff, north of Kiama, there is a fine place for examining

it, though it is scarcely distinguishable before incipient decomposition. As the process of change advances, the structure becomes very apparent, and the columns are resolved into a pile of spheres made up of concentric coats which are peeling off. This subject will be farther remarked upon when treating of the decomposition of these rocks.

In the *dikes* of basalt, a transverse columnar structure is very common; but it is mostly restricted to the central portion. Some of the dikes are naturally divided into three parts, of which the outer or two lateral are similarly non-columnar. This is the fact with the dike



represented in figure 1, page 506. The annexed figure of another dike shows the structure referred to; in this case the central portion is nearly twice the width of either lateral portion. The latter instead of having transverse fissures,

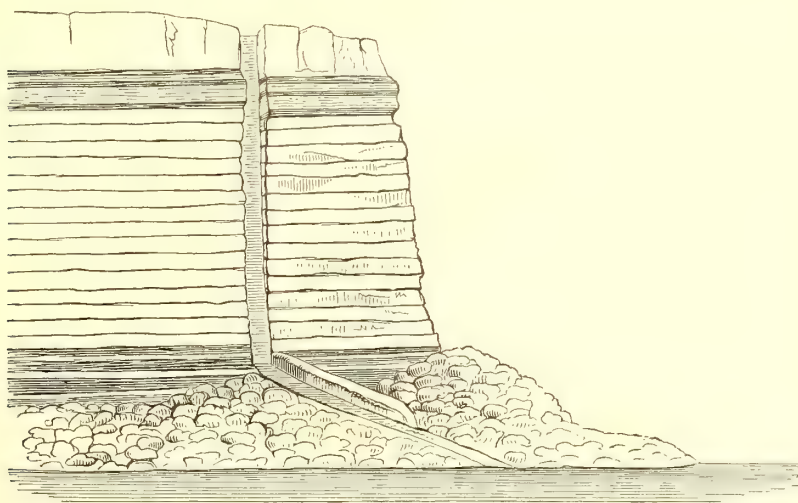
are at times divided longitudinally; in some cases by fissures filled with calc spar or quartz, but more commonly the longitudinal structure is produced by harder seams of basalt, which, when the surface is worn, stand out in small ridges. This is exhibited in the above figure. In some instances the longitudinal structure prevails through the whole width of a dike, either in the form of fissures or ridgelets, or both. This is the fact with a dike a foot wide intersecting imperfectly columnar basalt on the second point north of Kiama. The calcareous seams are from an eighth to half an inch wide, as in a dike at Rocky Cove.

The *colour* of a dike is seldom uniform throughout. Though dark or nearly black at centre, they are on either side generally grayish-white, greenish or yellowish, from mixture with the powder of the rock it intersects. The dike sketched in the last figure has a light grayish-green colour for a depth of three inches; the aspect of this portion is dull clayey, the texture rather soft and quite decomposable. A thin and soft ochre-yellow seam lies exterior to all. The dike on Nobby is argillaceous for eight inches on each side. The dike, three feet wide, just south of Newcastle Point, is similarly impure for two and a half inches either side. The breadth of the impure basalt varies with the size of the dike. More or less of it characterizes all the dikes that intersect the sandstone formation, while it is very seldom met with in those that cut through the basalt. It proceeds beyond doubt, as suggested above, from the inclosing rock, which is more or less scraped and worn by the ascending fluid basalt. Impurities are

thus afforded by *sandstone* that are not given by basalt, which is both harder and is of the same nature as the erupted matter. We may comprehend the origin of the harder longitudinal lines in some dikes, (causing the small parallel ridges or the riband structure,) if we consider that such ejections may often take place by successive efforts or pulsations; each alternation of rest and motion would naturally produce a separate and parallel effect on the rising fluid rock.

The action of the heat of dikes on the adjoining walls is scarcely at all apparent when they intersect basalt. When intersecting sandstone, the result is various. At times nothing can be detected; but generally there is a slight hardening and discoloration. The red colour is sometimes rendered a deeper red, or brownish-red, as near a dike in the second cliff south of Kiama; in another place, it is altered to gray. The grayish-blue sandstone adjoining the large dike of Rocky Cove is hardened and altered to a dirt-brown rock. Adjoining a dike at Black Head, the sandstone is much fissured for a foot, and exhibits some approach to a columnar structure at right angles with the lateral surface of the dike.

The most surprising change we met with occurs in the island of Nobby. This island, excluding its low and wide beach, is about two hundred yards long and thirty-four high. Towards the northern end, the dike cuts vertically through the layers of rock and the two coal



beds. Owing to the heat of this dike, the rocks of the whole island, from one end to the other, have been literally baked. The same layers

on Newcastle Point consist of argillaceous sandstones and soft clay, or clayey shales, as shown in the section on page 474. But on Nobby, the clay layers are a fine compact chert, looking like flint, and of flinty hardness and conchoidal fracture. The argillaceous sandstone, excepting a coarse variety, has experienced the same metamorphosis, and has become a chert, scarcely distinguishable from that made from clay. The coarser sandstone, though baked, shows still its granular structure, and the white clayey particles intermingled. Nodules originally of clay in this coarse rock are now as fine a chert as any on the island, breaking with a smooth conchoidal fracture, and affording sharp-edged fragments.

These alterations, although extending through the island, are less distinct towards its southwestern end, which is one hundred and fifty yards from the dike. The finer argillaceous layers are a perfect chert even here; but the sandstones are only a little hardened; they crumble readily on exposure, and undergo more rapid disaggregation than the same rock on the main land, where not operated on by the high heat.

The chert has mostly a uniform grayish-blue colour, like the clay before the baking. Some varieties, however, have a brown, light grayish-green, or light blue tint; and others are striped with these colours so as to resemble riband jasper. The layers still contain vegetable remains, and in general they retain their black colour; but very near the dike many of the specimens have lost this colour through the combustion of the carbon, and only impressions of leaves remain.

The alterations in the coal are equally interesting, and they extend to a distance of six or eight feet each side of the dike. Within this distance the bitumen has been expelled, and the coal where not clayey approaches charcoal. The impure layers, or those more or less argillaceous, have been baked to a black coaly rock almost as compact as the chert. The surf, which has torn away the rocks at the foot of the cliff, and probably at some former period removed many a yard from its face, has spent its force less effectually against this indurated coal layer; a black wall of it, a few feet high, extends across the beach for two hundred yards, although the basalt alongside has been washed away to the level of the beach. The preceding figure shows its position: it averages four feet in height, and is from five to six feet wide. At a distance it looked much like an immense knotted log that had been charred. In texture it is extremely tough, and it contains imbedded masses of compact charcoal. Adjoining the dike, fragments of the

coaly rock are entangled in the basalt, and small hand specimens may be broken off, showing the two combined.

Although the heat has been sufficient to alter the rock for one hundred and fifty yards from the dike, no approximation to granitic rocks was anywhere to be found. The chert had no trace of a crystalline character; neither had the sandstone any peculiar structure beyond what is understood from the expression *baked* sandstone. Its opaque clayey particles were similar to those in the unchanged rock, except that they were whiter and more like particles of pipe-clay.

Owing to the small extent of the island, we cannot trace the effects of heat beyond one hundred and fifty yards from the dike. The main shore to the southward is about three hundred yards distant, and here the clays and coal were unaltered. The transfusion of the heat to such a distance from its source could only take place under water, for we well know how small a thickness of dry firebrick is needed to confine the heat of the hottest furnace. The waters of the ocean would be heated by the erupted rocks, and the moisture of the clayey and sandstone layers, and of included cavities among them, would aid in receiving and transmitting the heat. So that a clay which, if dry, would have not been affected to a distance of a foot, might thus have been baked to a distance of some hundred feet.

Minerals in Basalt.—Besides feldspar, augite, and chrysolite, these rocks contain geodes of quartz and chalcedony, calcareous spar, stilbite, and chabazite.

Large geodes of quartz and chalcedony occur near Kiama, and at Rocky Cove, three miles to the southward; and occasionally the quartz is amethystine. The geodes in these regions lie mostly in an east-and-west or east-southeast and west-northwest direction. They have mostly an ear-drop form, as in the annexed figure, and have the smaller end pointed to the eastward.

The calcareous spar of the Kiama region occurs at times in large crystallized masses, two feet in diameter, occupying cavities in the basaltic conglomerate, and there are also small crystals in some cavities. Stilbite is met with in the same rocks; though the specimens are not of much interest to the mineralogist. Chabazite occurs in the hills near Puenbuen in small unmodified rhombohedrons.

Decomposition of Basaltic Rocks.—The basaltic rocks of Australia



are widely unlike in tendency to decomposition. It is impossible to procure a specimen of unaltered rock from some dikes, without excavating to a depth of several feet. There is a large dike on the first point south of Kiama, which appears externally like a bed of brownish-yellow earth, filling a fissure in the rocks; and upon close examination only faint traces of the original structure could be detected. The dike of Nobby is another illustration of this rapid decomposition.

Along the beach, however, where washed by the sea, it is still unchanged. It is a general and important fact that a rock which alters rapidly when exposed to the united action of air and water, is wholly unchanged when immersed in water or exposed to constant wetting by the surf.

The process of decomposition is finely exhibited on the second cliff north of Kiama, towards the north end. At first sight, a distinct argillaceous deposit was supposed to overlie the columnar basalt; for it was twenty feet thick, and of a whitish colour, resembling a soft crumbling marl, thus wholly unlike the basalt, and the common results of basaltic decomposition. Still it had proceeded from the alteration of a regular columnar variety having a dull grayish-blue colour. The original rock is exceedingly compact, showing no trace of crystallization, excepting an occasional minute crystal of feldspar; and within the reach of the swell, it was still compact and solid.

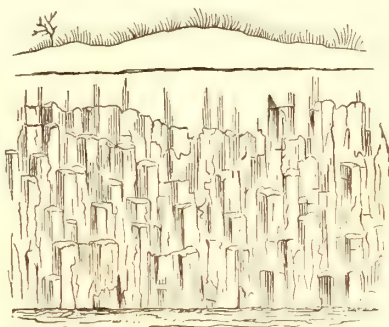
The rock has a concentric structure, and to this it owes in part its rapid decomposition. The alteration commences between the concentric layers, rendering them apparent, although not so before. At first a thin ochreous line appears, arising from iron; either magnetic iron disseminated in the rock, or from that of the constituent mineral augite. This ochreous colour afterwards mostly disappears, and the concentric coats become separated by thin clayey layers of a white colour, more or less striped with ochreous lines. In a more advanced stage of the process large ovoidal masses of basalt, (but little changed in appearance excepting the development of a slaty concentric structure,) lie in the cliff separated by a considerable thickness of the whitish clayey layers, which are stained by irregular ochreous lines. At last the centres of the spheroidal masses yield, and finally the change is so complete that the concentric arrangement is entirely lost, and a soft whitish or yellowish-white argillaceous deposit, with few ochreous spots or lines, takes the place of the compact basalt.

In basalts of more compact structure these changes take place more slowly. The grayish-blue basalt in the Illawarra range, near Broughton's Head, when long exposed, is discoloured exteriorly to a

depth of an inch and a half. The colours, beginning within, are dirt-brown, grayish-yellow, ochre-yellow, brownish-red; and they are evidently dependent mostly on changes in the condition of the iron which the rock or its minerals contain.

When the rock includes much chrysolite, the results of decomposition in some instances give a fissile or micaceous appearance to the rock. At Prospect Hill, five miles west of Paramatta, this change is in progress. The rock is a black ferruginous basalt of homogeneous aspect, breaking with a smooth fracture and no appearance of crystallization. It contains chrysolite; but the grains are small and not apparent except on very close examination. The decomposed basalt overlies the columnar basalt, as represented in the figure here given, which is a section from the quarry.

Were we unable to trace the transitions, and distinguish the columnar structure through the whole, we should scarcely suspect its basaltic origin. Indeed it was pointed out to me as an instance of mica slate overlying basalt. Particles of rusted mica, as they seemed, were distinct, and it much resembled a decomposing variety of that rock. On close inspection and an examination of



the rock in different stages of change, it became evident that the pseudo-mica was nothing but altered chrysolite, which had rusted from partial decomposition, and split into thin cleavage scales.

The crystals of chrysolite have evidently a parallel position in the rock, and hence the plane of easiest cleavage lies in the same direction, or, as the cleavage shows, parallel with the upper surface, that is, at right angles with the vertical axis of the columns. The passage from the compact to the decomposed rock is, in this case, unusually abrupt. Alteration takes place, (through the elimination of oxyd of iron as before suggested,) slowly at the surface, which, therefore, chips off as soon as decomposed, and exposes a new portion. This sudden transition may, in part, proceed from the absence of any natural planes of fracture, (which are brought out when there is a concentric structure,) and perhaps in part also from the presence of chrysolite. The layer of pseudo-mica schist is in some places five feet thick, and has a rusty brownish colour. Above, it passes into three

feet of earth of the same origin, having a brownish-black colour, and this is covered again by four feet of brownish-red soil.

The syenitic basalt of the more distant portions of Prospect Hill is also very decomposable. It forms a brownish-yellow bed, spotted with decomposing crystals of augite.

Siliceous concretions have often been observed to result from the decomposition of basaltic rocks; and I would attribute to this source a deposit of this nature occurring in the soil of the plains at the foot of Prospect Hill, five miles west of Paramatta, where it was pointed out to the writer by the Rev. W. B. Clarke, well known for his geological researches. There are four or five layers in a section of the soil bordering a small brook, alternating with the common earthy material of the soil; the uppermost was within twenty inches of the surface. The concretions are in irregular nodules, varying from the size of a hazelnut to that of the fist, though in the same layer nearly uniform. They consist of clay concreted by silica, and have a white or grayish-white colour. The basalt of Prospect Hill consists largely of feldspar, and as it is undergoing decomposition, silica is liberated, and taken up by the waters, again to be deposited in the soil of the plains below. This deposition would necessarily take place in those layers of the soil which were the most compact or clayey.

VI. CIRCUMSTANCES ATTENDING THE ORIGIN OF THE DEPOSITS.

There are several striking facts in the nature and condition of the rocks we have described which give us some insight into the early history of New Holland. The first particulars that we observe are as follows:—

a. The layers below the coal abound in *animal* fossils, and contain but few traces of vegetable remains.

b. The coal series is profuse in *vegetable* remains, and offers rarely a species of animal. A single fish is all we are acquainted with.

c. The layers above the coal (the Sydney sandstone series) contain but few traces of vegetable remains, and none of animal.

There was therefore a disappearance of marine animal life in the region, after the lower layers were deposited, and a comparative absence of vegetation after the deposition of the coal layers.

The character of the argillaceous sandstones below the coal, and the

positions and unbroken condition of the fossils, indicate that the deposits were marine, and originated in moderately shallow waters, the depth probably not exceeding one or two hundred fathoms; and also that the shells inhabited the spots where they now occur. The nature of the material constituting the rock is such as would have made, before consolidation, a muddy bottom, well fitted for the growth of mollusca; and here we may believe the animals were living and found their nutriment before they were entombed. Can we discover the circumstances attending the process of destruction and burial? We have described the overlying bed of basalt, and showed that it flowed in a broad submarine stream over the existing bottom of the ocean. That there should have been consequently a destruction of life is not remarkable; and we find the effects apparent in the fossils and the containing rock. The bivalves have the valves almost uniformly united. This alone proves that their death was no usual decay, for in such a case the valves commonly become scattered. They are sometimes gaping a little, though seldom widely, being usually open just about as far as the large muscle permits the shell to gape by its relaxation, an effect which would naturally proceed from the action of heat under water. Some specimens are broken in, as by pressure. Individuals of certain species, especially of *Productus* and *Spirifer*, are collected together in great numbers, apparently associated in their own natural bed of mud.

The shells, moreover, are mostly silicified, and often present the structure of agate or chalcedony; and this effect may be a consequence of the eruption, for the heated waters take up silica in solution, and distribute it widely around. Especially would the wet mud over which the fused basalt flowed, be well calculated for silicifying the contained shells. The diffusion of this silica is well attested by the siliceous concretions, which lie like cannon-balls in the rock, and nearly constitute some layers. We cannot resist the conclusion, therefore, that heat occasioned a destruction of life; and the facts already detailed have made manifest the effects of heat also in the discoloration and hardening of the rocks in which the remains of life were buried. Other results of the outburst of basalt are apparent in the scoria and basaltic fragments occurring in the overlying sandstone.

The source of this outflow of igneous rock is an interesting subject of inquiry, and the evidence with reference to it is not ambiguous. The trend of the air-cells (or mineral nodules filling the cells) has often been pointed to as indicating the line in which a stream of

amygdaloidal rock had flowed; for such air-cells would necessarily be lengthened in that line. In the case in question, we have not only oblong cellules, and the evidence they afford, but we have these cellules large at one end, and drawn nearly to a point at the other, with the pointed ends all lying the same way: and as their direction is to the eastward or towards the sea, we conclude that the eruption occurred somewhere to the *westward* or northward and westward. Some of the dikes of the cliffs appear to have had a connexion with the outbreak, but most of them belong to a subsequent era, as they intersect also the sandstone above.

A second eruption of basalt took place after the other accumulations of material had been made, which produced a layer of sandstone over the preceding bed. But this sandstone contains no fossils.

The extent of the destruction experienced cannot be known; for in few places the fossiliferous layers below the coal outcrop above the level of the sea. The Hunter region is an interesting place for their study; but my own time did not allow of sufficient exploration. The same alternation of basalt and sandstone, and apparently of the same age, occurs in Van Diemen's Land; and we may therefore infer with reason that Illawarra was by no means its limit. Yet it appears that the eruptions were to a great extent local, though they may have been numerous; for in Illawarra only the southern half of the district was covered by them. For while the coal series lies upon the basalt to the south, there is to the north nothing intervening between it and the lower sandstones.

The influence of the heat, through the diffusion of hot waters, caused, however, the disappearance of animal life, simultaneously, in both extremities of the district, and there is also evidence, that the northern portion was removed somewhat from the source of heat in the fact that the fossils are less perfectly silicified, or not at all so.

We have thus made out the character, course, and effects of the Illawarra basaltic eruptions. Similar eruptions occurred in various parts of Australia to a much later period, the age of which remains to be determined.

We next pass to the *coal deposits*.

The first incident of the coal era which we notice, is, that the region before under water had become dry land, a fact of which we have decided proof. For there are traces of just such pools made by standing water, as would and do occur in low flats, along the shores of a sea. We have spoken of thin beds of clay-ironstone, often but two or three

inches thick, and some rods in extent, occurring *upon* the layers of argillaceous sandstone, and also enveloped *within* them, and cracked or fissured as shown on page 480. These cracks are confined to the thin beds themselves, instead of extending into the rock above or below, and are precisely similar to what we often see over the bottom of shallow pools, after the water has evaporated. Moreover, the fine clayey material is just what settles in such places, and forms usually their bottom; and besides, the ferruginous character is a common feature of the waters of such pools, and consequently of the clay at bottom, after the evaporation of the water. We therefore ascertain not only the general fact that the land had emerged, but may point out also where there were spots of standing water, and read farther how they evaporated in the sun, and the fine mud of the bottom cracked on exposure. We also learn that the elevation of the emerged land was probably small; for, as stated, the remains of a fish were found in the lower coal deposit at Newcastle. From this last fact, we might think that the place was still beneath the sea; but not necessarily, for these animals are often thrown up dead on sea-shores, and floated over low flats by river floods; and the absence of other marine fossils, as well as the facts above stated, militate against the supposition. The logs and stumps of ancient Coniferæ, which are common in the lower portion of the coal series, call to mind the logs which are frequent in marshy lands, just emerging from the water; and the clay-ironstone constituting these, resembles that of the thin ferruginous beds above described. The waters of marshes often contain in solution the carbonate of iron, and also organic salts of this metal, while in broad streams of running water, such iron depositions do not take place.

We infer, therefore, that the region where the coal strata of Australia were forming was an extended low flat, subject either to floods from fresh waters, or else connected with the sea and exposed to tidal inundations, besides the heavy waves that attend an earthquake or an elevation of the land. The alluvial shores of our own southeastern coast, and that of Texas, are to the point as illustrations, affording examples of both the marine and fresh-water flats. Illawarra Lake in the district of Illawarra is a less perfect example, yet it is peculiarly interesting as showing the process of change from a salt-water to a fresh-water lagoon, owing to the simple action of the sea in accumulating beach sands; other portions of the same district have by this process been changed to dry land.

Although we have attributed a destruction of marine life in Illawarra to basaltic eruptions, this is not necessarily the cause of the absence of animal remains from the deposits above; for the elevation of the land above the sea,—its condition during the coal depositions,—would account for this absence. We cannot affirm that the shores were not again peopled, or in other points were not still alive with the same Mollusca, and we are furnished with no evidence to prove that the same fossiliferous rocks that lie below the coal, may not in other places have been forming during the coal epoch. It may or may not be, as evidence hereafter to be obtained shall declare.

The absence of all marine fossils from the Australian coal beds appears to set aside the idea that the sea could have contributed to these deposits; and this is farther evident from the nature and condition of the vegetation. If then the sea has not been an agent in the results, we must look alone to fresh-water inundations for the various alternations of beds. And on this point Australia affords important facts.

The rivers of the country have their annual freshets, as those of other lands; and every seven, eight, or ten years there is a more extended flood, covering immense tracts in the interior.

While the writer was at Maitland, on the Hunter, there was a rise of thirty feet in this river, and the waters spread widely over the country around. Eight years before, the inundation was still more extensive, and the people were taken in boats from the tops of their houses. In the Kangaroo Grounds, dead grass and brushwood—the leavings of a flood,—hung from the trees thirty feet above the existing level of the river. The plain of Bathurst in the interior has been, within the memory of the settlers, a swamp, owing to the rise of the Macquarie; and the great valleys of the Darling and Lachlan, though the streams were nearly dry when visited by Major Mitchell, were marshy and in part under water at the time of Oxley's expedition. He remarks that a rise of only a few feet in the streams of the west, would deluge areas of a thousand square miles and more; and over the "interminable plains, as level as the sea," he saw evidence in the brush about the trees that the whole had been lately flooded. From the marshy nature of the country he hastily concluded that the interior of New Holland was a marsh and uninhabitable. For the last fifty miles he saw no stones or pebbles of any kind "save two, and these were taken from the maws of emus." The soil was in general sandy, but in some parts a stiff clay; and the sand contained enough clay to become thick and muddy after rains.

These facts establish the point that fresh-water agency, even at the present day, is capable of producing a variety of results over a widely extended surface. The gentlest depositions may take place upon the drying flats, when the waters are quiet during the subsiding flood; or there may be coarser beds, with transported logs imbedded within them, produced from the action of *flowing* waters.

Where and how did the coal plants grow are the most difficult questions connected with this subject. The great number of leaves imbedded together, and all perfect, is certainly proof of no long transportation. Moreover, existing rivers give evidence that such material brought down in the body of the current would be scattered far and wide, and mostly borne away to the sea, instead of being collected in large accumulations. Ordinary river flats do not contain such beds.

Again, the leaves are so neatly compacted in thin even layers with clay, that the deposits have no resemblance to accumulations of leaves in the soil on which they grew. The extreme tenuity of the slaty structure produced by the leaves, and the clean pale colour of the deposited clay, look more like an effect produced beneath water after a quiet transportation to some moderate distance. This would seem to have been the mode of origin of the clay layers containing leaves, if not of the beds of coal themselves: and as the latter are often made up of alternations of more and less clayey layers, and show a thin striping, as if from a gradual deposition of the material, it may be true also of the coal beds. It will be remembered that there is no uniformity in the character of the layers above and below the coal beds, although commonly those immediately adjoining the coal are more soft clayey than elsewhere. The tables on page 471 and beyond, give the facts on this point.

The plants, therefore, either grew on lands near where the leaves were deposited, from which they were perhaps borne off by the gentle rise of waters attending a flood;—the rise and movement of the waters being gentle, because the inundation in these parts covered low lands at a distance from the main current: or, they constituted a floating vegetation, as some geologists have suggested. The remarkable abundance of floating plants at the Lake de Bay, on Luzon,—which float out in great quantities by the canal to Manilla harbour, there to be deposited (see beyond),—seemed to the writer a direct illustration (though on a small scale) of a common condition in the coal era. In favour of this view, we may remark that the productions of nature have had reference in all time to the condition of the globe. In

this distant epoch, when dry land was just emerging, and vast areas of shallow fresh and marine waters must have existed as the continents rose slowly from the sea, we might infer that the vegetation would have corresponded to the period, and that quantities of floating plants would have existed, far exceeding those of any subsequent era. This hypothesis is far less incredible than the opposite. For these immense areas capable of growing plants, as existing facts show,* would otherwise have been a waste. The Author of Nature teaches us in his works not only that the resources of his power are boundless, but also that a wise system of economy has ever been involved in his plan of creation.

The annual and decennial floods may have aided in producing the variety of effects before us in New Holland. In addition, the country was undergoing a gradual subsidence. By this means, regions that at one time would have been reached only by the quiet waters during

* Since the above views were written out, I have observed the following interesting facts observed by Prof. Royle, (Rep. Brit. Assoc. for 1846, p. 75.)

“Among the various subjects, Dr. Royle stated, to which he might draw attention, was the thick vegetation which clothes the surface of the lakes of India. Dr. Royle stated that he himself having been chiefly in the north of India, had not seen this vegetation to the extent in which it existed in the more southern parts of India; but even there it was sufficiently to support numbers of the small Grallæ, and among them the Chinese Jacana. But having on one occasion been detained on the banks of some of these lakes on the northwest of Bengal, he had been much struck with the thick and varied vegetation of the floating masses with which their surfaces were covered. These consist of numerous stems, leaf and flower-stalks of a variety of plants closely interlaced and matted together, the younger parts, requiring both light and air for the performance of their functions, finding their way to the surface; while the older are pushed downward, when the more herbaceous parts decay. Among these plants are most of the genera and some of the species even which are found in similar situations in Europe, but with them such plants as *Æschynomene aspera*, with its thick cellular stem, *Convolvulus edulis*, *Herpestes Monniera*, and *Utricularia stellaris*, *Marsilea quadrifolia*, *Trapa bispinosa* and *bicornis*, with species of *Polygonum*, and *Dysophilla verticillata*. The last is peculiarly interesting from its long jointed and striated stem with its whorls of leaves. Of most of them it may be observed that they have little or no root; the floating stems are long and slender, very cellular, with the vascular bundles arranged around the circumference with little or nothing like bark. By Dr. Buchanan Hamilton these lakes have been seen of much greater extent and covered with a much more dense vegetation, so much so, that he described the floating masses to be sufficiently substantial for cattle to graze upon the grasses with which they became covered, but that occasionally some fall through and are lost. He describes, moreover, some bushes and trees as growing in the midst of the water, and among them a Rose, a Barringtonia, and a *Cephalanthus*.”

Dr. Royle continues by applying these facts to explaining the formation of coal.

the highest inundations, may have been so low at another time as to have felt the rapid movement, and these changes of level were hence concerned in producing the alternations of material detailed on a former page. The large logs of Coniferæ in some of the layers, are evidence of a change like that here explained. If a region, which before was one of quiet depositions, were afterwards to come within the rapid part of the flood, in consequence of a subsidence, there would probably be other regions of quiet depositions produced at a distance elsewhere; and it is possible that evidence of this may yet be ascertained.

There may be some reason for the very abundant vegetation during the coal era in Australia—a region which is now comparatively unproductive—in the probable fact, that a large amount of land was then becoming dry from the ocean, and thus favoured the production of clouds and rains; and also in the warmer state of the earth than at any later period. It is not impossible, moreover, that the composition of the atmosphere as, commonly supposed, favoured rapid growth.

The subsidence in progress during the coal formation, ended finally in submerging the land beneath the sea, the condition of the region where the Sydney sandstone was forming, as is evident from the constitution and structure of the sandstone layers.

Sand is to a great extent a seashore product, as we have remarked in another place. It is formed where the tritulating waters have considerable motion, and where, therefore, the finer material derived from the constant wearing of the sands, is washed away. In still seas or quiet waters, the gentler action produces a fine mud. The material of the Sydney sandstone bears evidence, therefore, of ocean origin, either on seashores like the sands of beaches, or in shallow waters off coasts. To this conclusion, the structure of the rock affords other support.

The *inclined layers of deposition*, dipping so uniformly to the north-east in the neighbourhood of Port Jackson, point to a sea whose waves acted from that direction. At the same time, the thinness and delicacy of the structure, the changes in character, as if depositions once formed were afterwards partially removed, and were then again enlarged by new additions, show that the action of the waves was nearly constant and of varying force. In the changes presented by the rock, we may point out the very period in its progress when the action was for a while quiet, for we find there the structure becoming argillaceous, owing to the finer trituration.

Were the inclined lamination less general and less regular in amount and direction, we might attribute it to local causes. But in fact it pre-

vails over large areas, and is nearly constant in dip; in the cliff of the South Head of Port Jackson, very many of the layers show more or less of it. The frequent changes in a single layer to a horizontal structure, indicate the variations in the force of the waves, and possibly variations in the state of the tides. When a part of a layer consists of oblique laminæ of deposition, and the other part of horizontal, it is generally the lower part which is characterized by the oblique depositions; as if these were produced by a heavier sea, and the horizontal when the sea subsided; and we may almost fancy that the results are in some instances the effect of a single tide, or perhaps more probably of a single storm in the ocean of the period. We had occasion to observe this variation in a striking manner at the mouth of the Columbia River. During the rise or fall of the tide, the sea on the bar was so heavy that the boats were unable to pass from the ship Peacock, then aground; breakers six or eight feet in height rolled in successively with great violence, though the weather was calm. But at ebb tide, the surface was nearly smooth and the boats pulled back and forth, landing the crew from the wreck. In a few hours the tide had set in strongly again, and so heavy were the seas, that the boats attempted in vain to reach the vessel for the remainder of those aboard, and one with its crew was near being lost. They were compelled to wait for another ebb tide. In periods of gales the waves are still more violent.

It is obvious that the action here explained will account for the variations in the stratification in New Holland. Of similar character is the action of the swell of the sea upon the bottom in the shallow waters of a coast, especially when there are extensive flats washed over by the sea. It has been shown by M. Siau that the agitations of the sea even at great depths produce parallel ridges or ripples on the bottom.*

It is important to observe that off the east coast of New Holland there is now a current analogous to the Gulf Stream, flowing from the northeast, and thus corresponding actually with the direction here demanded to account for the dip of the inclined layers of deposition. This current would have washed over New Holland in the *same* direction were the country at any time submerged, and from that direction would the waves travel onward across the accumulating sands. The granite summits or ridges, many greenstones or basaltic peaks, and the limestones and older slates in or beyond the Dividing range, may have been in part the land of the period. The twelve or fifteen hundred feet of sandstone in New South Wales must have

* See farther, page 105.

required, therefore, a continued gradual subsiding of the land. The sands are mostly granitic; even the several ingredients of the granite may be distinguished, and we must therefore look to granite ridges for its origin, and probably to those of the south and west. In this respect, these rocks differ from those below the coal, which are to a large extent, where exposed in Illawarra and at Harper's Hill on the Hunter, made from basaltic material.

It is justly a matter of astonishment that through the whole of these deposits we find no remains of marine life. But it is a general case that in seas with a sandy bottom, mollusca are of rare occurrence; and when they are met with, the dead shells are generally worn out by the trituration. Many instances of this kind are mentioned in the Report on Coral Islands, instances where the sands were within a few hundred feet of reefs of growing corals and shells, and yet no fragment of shell or coral larger than a grain of sand could be detected.* Such facts are common about all the islands bordered by coral reefs, and at first they naturally excited much surprise. At Hanalei on Kauai, are deposits very closely resembling those of the Sydney sandstone, even to the inclined layers of deposition and absence of fossils. In this case, however, the rock is of beach origin.

The formation of this sandstone in steep banks beneath a sea, as supposed by Darwin to account for the configurations of the valleys, may well be doubted.† Such a result may take place when the sands are chemically agglutinated, as in the case of calcareous sands by lime. But accumulations of siliceous sand, except when eddied by currents on a small scale, are not thus formed in isolated deposits, with intervening channels or valleys a thousand feet or more in depth: a broad current, gulf-stream like, sweeping over the region, could hardly have occasioned the eddyings required by the hypothesis of Mr. Darwin.

The eruptions of basalt during the progress of these depositions, and also subsequently, were not numerous. The island of Nobby, at the mouth of the Hunter River, has been described as a fine example of the influence of heated dikes on clays and sandstone when under water.

Many fissures, shakings of the earth, and probably many earthquake waves, accompanied these effects. The *regular structure* of the sandstone, as shown in its *transverse fissures, may be connected in some degree with the course or direction of the tension, causing elevation, one of the lines being formed in the line of the movement, and the other trans-*

* Page 149, and elsewhere.

† Volcanic Islands, p. 136.

verse to it. Such cracks might take place without corresponding fractures in deposits below, since the Sydney sandstone, besides being more brittle, is farther removed from the centre of oscillation. The trend of the fissures corresponds with the two great systems of island ranges in the Pacific, and of mountain ranges in the world; and they afford additional illustration of the great principle in dynamical geology, explained on pages 425-436.

In the preceding pages we have traced out the principal points in the geological history of New South Wales, through the system of deposits described in the foregoing chapters. We have seen evidence that along by the eastern shores, before the coal era, there was a muddy bottom abounding in animal life; that ejections of basalt in Illawarra, and probably also in some other parts, buried the mud, destroying all life, silicifying the shells, and hardening the rock as well as forming concretions, through the agency of the heated siliceous waters; that the region emerged from the sea, and was near the water's edge when the coal series began; that the layers of the coal series were probably deposited by fresh waters during the different states of annual floods, and wider deluges occurring at more distant periods; that a subsidence, which may have been gradual during the coal depositions, finally submerged the whole, or brought it to the sea level, and then the Sydney sandstone, with its occasional argillaceous layers, began to accumulate, either along beaches, or more probably in water sufficiently shallow for the bottom to be covered by the waves. Before the lowest of these deposits, basaltic or greenstone rocks were abundant in New South Wales, and during their progress similar eruptions occasionally took place, and earthquakes caused fissurings of the rocks. From this point we may continue the geological history of New South Wales, by speaking of the degradation which has taken place over its surface, and the evidences of recent changes of level.

VII. DEGRADATION OF THE ROCKS OF NEW SOUTH WALES AND FORMATION OF VALLEYS.

The great depth, extent, and number of the valleys of New South Wales are calculated to excite wonder, and perplex us much in the study of their origin. In some of these sandstone regions, the gorges intersect the country in endless succession, and are alike in their inaccessible precipices of one, two, or three thousand feet. They are deep

gulfs, with walled sides, composed of horizontal layers of sandstone. These layers seem once to have been continuous; and what is the force which has thus channelled the mountain structure? Are they "stupendous rents in the bosom of the earth?"* Are they regions of subsidence? Can it be that they were never filled, but were depressions left between the heaps of accumulating sediment that constitute the sandstone, which depressions were afterwards enlarged by the sea during the elevations of the land?† Or may we adopt the "preposterous" idea, that simple running water has been the agent; and if so, was it fresh water, or the ocean?

The forms of these valleys are as remarkable as their extent. Major Mitchell states that Cox's River rises in the Vale of Clywd, 2150 feet above the sea, and leaves this expanded basin through a gorge 2200 yards wide, flanked on each side by rocks of horizontally stratified sandstone eight hundred feet high: here it joins the Warragamba. Some of its tributaries rise at a height of 3500 feet above the sea, and the ravines they occupy cover an area of 1212 square miles. From this he calculates that *one hundred and thirty-four cubic miles* of stone have been removed from the valley of the Cox.‡ The facts observed by us are sufficient to substantiate the general result, although we cannot add definite estimates of our own. The Kangaroo Valley is another example of a valley, two to three miles in width, and a thousand feet to eighteen hundred deep, opening outward through a comparatively narrow gap: and by a rough calculation from our own examinations, and the map of Major Mitchell, the amount of rock necessary to fill the valley is equivalent to a rectangular ridge, twelve miles long, two miles wide, and two thousand feet high. On the map of the Illawarra District, the form of this valley, (from the colonial surveys,) may be seen; and it is interesting as an illustration of the general character of these sandstone gorges, though wider than many of them in proportion to its length. This is but a small example, however, compared with those of the interior. Mr. Darwin remarks upon this peculiarity of form,—their extent and width and many branches, yet narrow openings at their lower extremity; and he observes that the same is the character of the bays along the coast.

In studying the origin of these valleys, we have then to consider the following particulars:—

* Strzelecki's New South Wales and Van Diemen's Land, p. 57.

† Darwin's Volcanic Islands, p. 137.

‡ Expedition into Australia, ii. 352.

1. Their high, precipitous, or vertical walls of stratified sandstone, and their flat areas at bottom—excepting where the descent of the stream is rapid.

2. Their frequent great breadth towards their head, while below, they are often very narrow, like a large bay with a small entrance.

3. The absence of all traces of the fragmentary material which could have filled these valleys.

The idea that running water was the agent in these operations appears not so “preposterous” to us, as it is deemed by Mr. Darwin; and we think it may be shown that Major Mitchell was right in attributing the effects to this cause. The extent of the results is certainly no difficulty with one who admits time to be an element which a geologist has indefinitely at command. But the subject admits of full explanation, as we believe, without making any improbable supposition on this point. We need but refer to a former page, in which we have discussed the subject of valley-making by denudation among the Pacific islands, to show that New Holland, after all, is not the most remarkable land in the world for valleys of denudation.

We should consider that the rock material is far more yielding than that of basaltic Tahiti. Indeed the whole rock, from the uppermost layer to the deposits below the coal, is remarkably fragile, considering the age of the deposits,—crumbling readily, and often breaking without difficulty in the fingers; and besides, it is much fissured. Even the harder fossiliferous Wollongong rock has been described as falling to pieces of itself when exposed to the air. Moreover there are occasional clayey or argillaceous layers which are still softer; and many of those of the coal formation are not firmer than the material of a common clay bank. The denudation of such material requires no preparatory decomposition, as with many igneous rocks, but takes place from wear alone, and with but slight force in the agent.

It is obvious for the same reason that the material carried off by denudation ought not to appear in fragments through the lower country. A short journey along a rapid stream would reduce even large masses to powder. The plains of the Kangaroo Valley are covered in places with basaltic pebbles or boulders; but the sandstone, which is the prevailing rock along the bed of the stream and in the enclosing hills, has scarcely a representative fragment among the debris. The sandstone blocks are worn to sand or earth by the torrent, while the harder basalt is slowly rounded. On the plains of Puenbuen, similar facts were apparent. The hills contain sandstone

and basalt, but only the latter appears as boulders or pebbles over the plains, or along the streams below.

This Sydney sandstone does not even require running water to promote degradation. In many caverns along cliffs, the rock gradually falls to powder by a species of efflorescence. There are numerous instances of this along the coves of Port Jackson, where the crystallization of the saline spray reduces the rock to its original sand; and in the interior of the country there are large caves, formed apparently by this same process, though probably from the crystallization of nitrates. Near Puenbuen, these caves are from six to twenty feet deep, and from four to forty long. The roof is arched, and appears to be constantly crumbling, while the bottom is covered with a fine dry ash-like sand, into which the feet sink several inches. The same operation is going on along the summits of the Illawarra range; and one huge block was found so hollowed out in this way as to be a mere shell, which sounded under the hammer like a metallic vessel.

These various facts bring before us some idea of the yielding nature of the rock which the waters have to contend with in the denudation of this country, and they also illustrate the various processes at work. We allude to a single other mode of degradation before passing: it is the action of growing trees and their roots, both in opening fissures and tumbling blocks down the precipices. It is a cause influencing very decidedly the characters of cliffs, and at the same time preparing the rock for decomposition and wear.

The credibility of the view we favour is farther sustained by the character of the streams. We have alluded to the great extent of the floods, and the rapid rise of the rivers attending them. The stream of the Kangaroo Grounds, when visited by the writer, was a mere brook, fordable in any part, and it flowed along with quiet murmurings. How different when the brook becomes a river thirty feet deep, driving on in a broad torrent, and flooding the valley; and this had been its condition but a few weeks before. If, as has been shown, the transporting power of running water *increases as the sixth power of the velocity*, and a stream of fifteen miles an hour has more than ten times the transporting power of one moving ten miles an hour, and more than a million times that of a stream of two miles an hour,* we can comprehend how inadequate must be the conceptions of this force which we derive from viewing the streams at low water.

* WM. HOPKINS, *On the Transport of Erratic Blocks*, Trans. Camb. Phil. Soc. viii. 1844, p. 221.

This rise in the Kangaroo Grounds is an index of what takes place every few years over the whole country. Our surprise at the amount of degradation subsides before such facts; and we rather wonder that sandstones so soft and fragile, which have been exposed probably from the Oolitic period, still cover the surface to so great an extent as they do at the present time.*

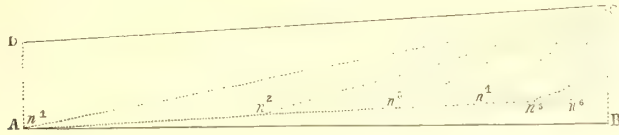
Mr. Darwin derives his principal argument against the hypothesis of denudation from the forms of the valleys,—their width, extent and ramifications, and yet *narrow* embouchures. But we find on consideration that this form is a necessary result of the mode of denudation under the circumstances supposed.

In our account of the valleys of the Pacific islands (page 379), it has been shown that the gorges change their character where the slopes become quite gradual, from a narrow defile with convergent sides, to a broad channel with vertical walls and flat bottom: the cause of this change has been explained on page 386. The same cause should produce a like effect in Australia. Though it be a repetition, we add in this place a brief explanation of the process. A stream, in making a descent of two or three thousand feet from the higher summits to the level of the sea, gradually deepens its bed by wear. Since the waters are increasing in quantity from various sources as they flow onward, this deepening of the gorge should be most rapid at its lower extremity; and it would continue in progress until the bed in that part became so low or gradual in slope, that the waters had lost to a large degree their rending force, and any excavation at bottom was made up by the material deposited along its course. This fact determines a permanent height for the bottom of the lower valley. As the stream continues its wearing action in the same manner, the lower valley is gradually prolonged upward, retaining nearly the same slope at bottom (one or two feet to the mile); consequently the steeper portion of the gorge is at the same rate becoming shorter and still steeper. Thus the head of the stream may finally become a series of cascades,

* If the annual amount of sediment borne along by the Mississippi were assumed as the amount for Cox's River, the one hundred and thirty-four cubic miles of excavation, estimated by Major Mitchell, would have been made in less than six thousand years, as we learn from a simple calculation. The assumption may be much too large for so small a stream, even where there is so much to favour it in a rapid descent, and abundant and convenient material for wear and transportation; yet not more so, than the assumed six thousand years is less than the actual period during which the region has been exposed to degradation.

or, as happens at times in the Pacific, it may be reduced mostly to a single cascade of a thousand feet or more.

The progress of this change may be better understood from the following cut.



A B C D is the rock to be cut through by the stream. Suppose denudation to produce first the course C n^1 . The stream is filled, as is commonly the case, by lateral channels and rills down the sides of the gorge, as well as by the main source; and the amount or depth of water is thus in constant increase, as it flows onward. Denudation is consequently most rapid the farthest from the head, or towards n^1 ; the valley, therefore, increases in depth in this part till the slope has become so gentle here as to counterbalance the greater amount of water, at which point the bottom of the valley ceases to increase in depth; in this condition $n^1 n^2$ becomes the bottom of the lower valley, and C n^2 the steeper portion above it. In the same manner the valley bottom continues to prolong at nearly the same slope, and C n^3 , C n^4 , C n^5 become successively the course of the stream descending into it. And even C n^6 , is not an exaggeration of possibilities, for many examples of it are met with.

But the results explained are but a part of the actual course of things in these regions of horizontally stratified rock. As on Oahu and elsewhere, when the denudation at bottom has reached its limit, the waters exert but little degrading power except during floods, and this takes place by the sides of the overflowing stream; at the same time, depositions of detritus take place along its banks. The result is that the rocks bounding the valley are worn away below, and are often undermined, as explained on page 387; the valley widens at bottom to a flat plain, while the enclosing wall by the process becomes nearly vertical. A narrow ribband of land between high precipices of rock is therefore a necessary result of the action.

Degradation still continues along the upper or steep part of the main stream, and also along the many streamlets and rills pouring down the valley's sides; and in each of these streamlets there is a tendency to produce below a flat-bottomed valley. The consequence is, that they increase the width and extent of the main valley-plain; for

whenever they become thus flat-bottomed, they contribute to its lateral enlargement. At the same time, the bluffs at the lower extremity or embouchure of the main valley remain without much change, as the denudation is mostly confined to the vicinity of the streamlets alluded to, and these streamlets are most abundant above, since they are produced and fed mostly by the rains in the higher part of the mountains. It is natural enough, therefore, that the valleys should not only become flat below and precipitous in their sides, but also that they should widen least at their lower extremity. We see, therefore, no necessity of appealing to any other cause than simply running water, to account for the most stupendous results in Australia.

It has been supposed that the sea has been largely concerned in the denudation which has produced the Australian valleys. On this point enough, perhaps, has already been said on a former page. We find no reason for attributing any of the valleys to this source, although it is possible that some modifications may thus have resulted. The facts at Port Jackson are a sufficient reply on this point. The cliffs of the estuary actually undergo very little change from the action of its waters, and are far more altered by the mode of efflorescence described, and by rills of running water; and such action as is exerted, tends to remove the headlands instead of deepening the coves. There is, therefore, good reason for believing that such estuaries as Port Jackson and Macquarie were dug out by fresh waters, and have since been submerged. The fact that there is a correspondence in trend with the fissures of the sandstone, shows that their direction was determined by these fissures, or by faults which have the same origin. We have remarked that the rock has not the same dip in the two Heads of Port Jackson, a fact indicating the existence of one or more intermediate faults.

Action of the Sea.—The proper action of the sea is seen in the character of the sandstone shores of East Australia, and especially in the wide platform of rock, below high tide level, lying at the foot of lofty cliffs. The manner in which the shore rocks are worn so as to leave this wide platform, has been explained on page 109. It is a simple projection of the lower layer of the cliff; from above it, the waves have carried away the rock to a distance inward of fifty to one hundred and fifty yards. A view of this platform is given in the sketch of the South Head of Port Jackson. It occurs, with few interruptions, along the whole range of sandstone shores. At Newcastle, also, and Wollongong Point, are fine exhibitions of it. The rock is so fragile

that there are seldom accumulations of debris at the base of the cliffs. In some places, this action has separated islets from the coast. At Wollongong Point, a rude column and hills of rock stand upon the platform, the wear having removed the rock within, so that at high tide they are cut off from the main land. Such examples are not uncommon.

Other effects of the sea in removing dikes of basalt are of frequent occurrence in Illawarra. One of the most remarkable instances occurs in a cliff eighty feet high, where a trench eight feet wide, narrowing to four, extends into the cliff one hundred to one hundred and fifty yards. The waters rush in below, and are still engaged in removing the dike. This, though appearing to be an example of valley-making by the sea, in fact shows how little is done through this agency: for we have here a removal of one hundred yards or more, in a single narrow line, scarcely wider than the original dike, and therefore with hardly any action on the sides of the narrow channel. The force of the waves is expended wholly against the farther extremity of the channel, and very little laterally. The action is in the same direction as on the open shores. As a line of coast receives the force of the waves with less obstruction than a narrow channel or bay, the former will always experience a greater amount of wear, except when, as in the case before us, there is a channel of different and more yielding material to be removed. The basalt is easily removed by the sea, because of its many fractures and its non-adherence to the walls of the dike.

VIII. EVIDENCES OF CHANGE OF LEVEL.

It is probable, from the absence of more recent deposits between the Sydney sandstone and the tertiary, that these beds appeared above the waters in Eastern Australia soon after their formation; and the great abundance of salt lakes and briny impregnations over the country were probably derived from the previous oceans. Since that period the denudation spoken of in the preceding chapter has been in progress. Subsequent changes of level have taken place, as is apparent in the coral reefs of the shores north of the parallel of twenty-eight degrees, in the tertiary of the southern and western shores, and certain terraces and shell deposits along the coast.

The coral reefs indicate an extensive subsidence along the east and northeast coasts of New Holland, (page 399,) the amount of which we have had no means of definitely ascertaining. That it must have been

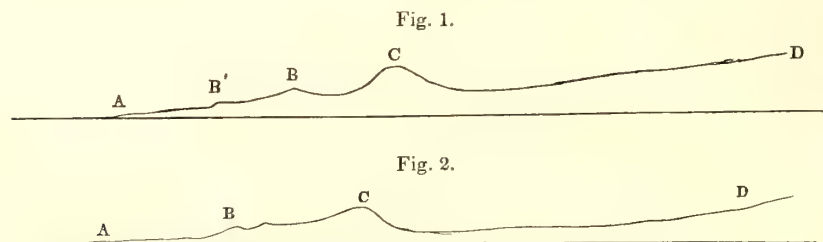
great, is evident from the wide channel and deep waters between the outer reef or barrier and the shore, the distance, as we have stated, being, in some parts, fifty or sixty miles, and the depth sixty to eighty fathoms. We cannot believe the subsidence to have been less than the depth of the inner channel, or five hundred feet. The forms and extent of Ports Jackson, Broken Bay, Macquarie and Stephens have been alluded to as proofs of subsidence, probably the same that is indicated by the coral reefs.

Calcareous deposits on the southern and western shores, first noticed by Flinders, appear to indicate, in some parts, a considerable rise of the land. For facts with reference to this coast, we must refer to other authors, and especially Fitton's Appendix to Captain King's Voyage, Mr. Darwin's Volcanic Islands, and Strzelecki's New South Wales. The formations appear to be of comparatively recent origin.

On the eastern coast there are occasional elevated beaches or deposits of shells, and some appearance of terraces.

The evidence of elevation from shell deposits should be received with hesitation, for it is well known that along shores they are often heaped up in great quantities by the natives of the country, who subsist generally to a great extent on the species of the coast. Along some of the coves of Port Jackson I observed beds of recent shells, as in the deep cove just east of Sydney; but I should sooner admit them as evidence of the temporary residence on the spot of migratory Australians, than of any shifting of place in the land.

In the Illawarra district, there is a low ridge, fifteen to twenty feet above the sea, extending along the coast for much of the way between Bulli and Wollongong. It consists largely of shells, and more resembles an elevated beach than anything of the kind seen elsewhere by us in New South Wales. The annexed figures represent sections of



the shore between Point Towrudgi and Ballambai. From A to B is the present beach, and B is the highest point the sea reaches. Back of B the sands sometimes decline a little and then rise to a higher

level at C, which is the summit of the low ridge referred to. It is about ten feet higher than the first. From C there is a rapid slope to a lower level, which is occupied mostly by forests; and three to six miles back the land gradually rises into the Illawarra range. The shells of this beach-ridge are much broken, like seashore specimens; but many are nearly entire, and generally the nacre is little injured. The form of these shores leaves little occasion for doubting that the upper ridge is actually the summit of an ancient beach, formed like the lower one (B).

A large portion of Illawarra has been but lately reclaimed from the sea. The former condition of the district, especially of the part north of Wollongong, appears to be well illustrated in the existing "Illawarra Lake" and "Tom Thumb Lagoon." Both of these lakes were once connected with the ocean by wide mouths; but for the four years past, the former, which is about six miles long by three broad, has been closed by sands thrown up by the sea, and now a sand-beach one hundred yards wide separates it from the ocean. The water is gradually becoming fresh, and has already so far lost in saltness that the oysters, cockles, &c., formerly living there, are all destroyed. The fresh-water streams running into it may again break down the barrier, as they have already raised the water two or three feet, and this has often taken place in former periods previous to its last closing. Thus salt-water and fresh-water formations might go on in many alternations without any change whatever in the level of the land. Tom Thumb is about one-third of the lineal dimensions of the Illawarra Lake. It has been closed, but is now open, though by so shallow a channel that we may pass along the beach by its mouth on horseback at low water during calm weather. Several of the existing marshes in Illawarra are known to have been lakes. The change to their present condition may have been hastened by a small elevation of the land. The Illawarra mountain range was probably once the line of coast. The advance of the shores by the gradual accumulation of sand from the sea is seen at Shoalhaven, where, for three-fourths of a mile back, the land is a low seashore accumulation of loose sand, in which shells are scattered. The water for a long distance off the beach between Black Head and Shoalhaven is very shallow. A deposit of shells occurs half a mile from the Illawarra Mountain, west of Tom Thumb Lagoon; but we cannot confidently say that they were not carried there by the natives.

On the borders of the Hunter and on its islands there are large

deposits of shells, which are dug and burnt for lime. As the region is liable to high inundations, we cannot affirm without farther examination that the shells bear any evidence of a rise of land; yet such appears to be the fact.

On the sandstone shores of Port Jackson and at the South Head, there are three or four terraces of rock, which apparently indicate so many successive efforts of elevation in a height of two hundred feet. But we look upon the evidence with much doubt.

Other geological changes are indicated by the vast caverns in the limestone region of the Wellington Valley. Many wonderful facts have been brought to light, through the bones they contain, with reference to the ancient Fauna of this strange continent. But as they came not within the range of our observations, we refer to other works for an account of them. The caves have been well described by Major Mitchell, and the bones and animals by Professor Owen.

We close our account of New South Wales by a list of the more important works and memoirs illustrating its geology.

Journal of Two Expeditions into the Interior of New South Wales, in 1817 and 1818, by JOHN OXLEY, Surveyor-General; 4to., 1820.

Sketch of the Geology of the Coast of Australia, by WILLIAM HENRY FITTON; forming an appendix to the "Survey of the Intertropical and Western Coasts of Australia," by Captain P. P. King.

Three Expeditions into the Interior of Eastern Australia, by Major T. L. MITCHELL, F.G.S., Surveyor-General, 2 vols. 8vo. London, 1838. Contains descriptions of fossil bones from the Wellington Valley, by Professor OWEN, with drawings; and also several species of fossil shells from Harper's Hill.

Physical Description of New South Wales and Van Diemen's Land, accompanied by a geological map, sections and diagrams, and figures of organic remains, by P. E. DE STRZELECKI, 8vo. London, 1845.

Volcanic Islands, by C. DARWIN. 8vo. London, 1844; pp. 130—137, on New South Wales.

On a Fossil Pine Forest at Kurrur-kurrân, by the Rev. W. B. CLARKE, in the Geological Proceedings for 1843, iv. p. 161.

On Marble and Quartz, in connexion with Plutonic Rock in New South Wales, by Rev. W. B. CLARKE; Quarterly Journ. Geol. Soc. No. 3, Aug. 1845, p. 342.

On the Plants of the Carboniferous System of New South Wales, by the Rev. W. B. CLARKE; and also on the Trilobites of N. S. W., Quart. Journ. Geol. Soc., No. 13, pp. 60, 61.

On the Fossil Botany and Zoology of the Rocks associated with the Coal of Australia, by F. M'COY. Ann. and Mag. Nat. Hist., vol. xx. 1847.

On the Geological Structure of Australia, by J. B. JUKES, Rep. Brit. Assoc. for 1846, p. 68. Also, Voyage of H. M. Ship Fly.

A Voyage to Terra Australis, &c., in the years 1801, 1802, 1803, by Matthew Flinders, Commander of the Investigator, 2 vols. 4to., with an atlas in folio; London, 1814.

Voyage de Découverte aux Terres Australes, &c. Tome i. rédigé par M. F. Péron, Naturaliste de l'Expedition, Paris, 1807; tome ii. rédigé par Péron et L. Freycinet, 1826; tome iii. by Captain Freycinet.

Also the voyages of DUPERREY, D'ENTRECASTEAUX, and VANCOUVER.

Discoveries in Australia, with an account of the Coasts and Rivers explored and surveyed during the Voyage of H. M. S. Beagle, by Captain J. LORT STOKES. 2 vols. London, 1846.

Also:—various memoirs in recent volumes of the Journal of the Royal Geographical Society, including observations by E. J. EYRE, Esq., Governor G. GREY, Captain C. E. FROME, Dr. L. LEICHARDT, G. W. EARL, and Captain CHARLES STURT.

CHAPTER X.

GEOLOGICAL OBSERVATIONS ON THE PHILIPPINE AND SOOLOO ISLANDS.

THE Philippine Islands constitute a large archipelago of triangular shape to the east of the China Sea, and the Sooloo Group is properly the southern limit of this archipelago, between Mindanao and the north of Borneo. The region has been long known to abound in volcanoes; but it is less well-understood that far the larger part of the land consists of ancient Plutonic and stratified rocks. The Sooloos appear to be wholly volcanic. The southern extremity of Luzon is also volcanic, and there are cones on Mindoro, Mindanao, and other islands. But the greater part of Luzon north of Manilla is said to be covered with granites, gneiss, talcose rocks, sandstones and shales containing coal deposits, and yielding also ores of lead and copper. Specimens of the coal and ores were received by us through the kindness of Don Inigo Azaola and El Señor Roxas, of Manilla. Luban contains copper pyrites in talcose and chlorite slate; and the same formation is continued in Mindoro, where it passes into serpentine, specimens of which were contained in the cabinet of Señor Roxas. Gold occurs here in quartz, and probably in the talcose rock. We sailed by Panay, one of the large islands of the archipelago, and observed nothing volcanic in the appearance of its mountains, which had similar features to the main range of Mindoro. Some of the peaks were estimated at eight thousand feet in height. One of our boats touched at San José, a village on the western shores, and brought off a number of pebbles from the beach, which were varieties of the talcose rock, with quartz and jasper; and the jasper, as in California, may appertain to the talcose formation. On Mindanao, at Caldera, besides rolled fragments of basalt, porphyry, and chalcedony,

there were numerous pebbles of talcose rock and slate, syenite, hornblende slate, and quartz, either compact or slaty.

From these facts we learn that the volcanoes are but a subordinate part of the group.

The trends of the islands and the rectangular intersections of two systems are worthy of our attention. Thus, the body of Luzon is at right angles with the south extremity; Palawan is at right angles nearly with Mindoro; Panay and Negros with the south extremity of Luzon; the eastern part of Mindanao, with the western part. The seeming exceptions to the rule are nearly all found to harmonize with it when we observe the curving eastern outline of the group, and consider the changes of direction in the transverse trend requisite to preserve this rectangularity. At the same time we should remember that there is a tendency to curves in the latter trend also, as shown in the Sooloo Islands tailing off from Western Mindanao.

LUZON.

The island of Luzon has nearly the shape of a boot, lying north and south, with the foot turned eastward. The body is about three hundred and fifty miles long, and the southern extremity or foot two hundred and fifty miles. In our approach to it, we first made the western cape, where we observed in the distance a range of high mountains, with rather even slopes and undulating outline, and low flat shores bounding apparently extensive plains. As we neared Manilla, several isolated heights came in view, which had the appearance of volcanic cones, and just north of the bay, one of these high elevations, with long slopes and broken summit, still retained small craters upon its sides, although the declivities were deeply worn by denudation. Another peak farther to the north presented similar features. The even declivities slope at an angle of about twelve degrees, gradually diminishing downward, and becoming nearly a level plain at foot. The large harbour of Manilla is bounded by a low level country, which in the distance to the westward rises into mountains, mostly two or three thousand feet high; and one flat-topped cone of full six thousand feet shows itself in clear weather. On the north, the only point seen from our anchorage, rising above the flat shores, was the cone called *Mount de Arayat*, which is thirty miles distant, and over five thousand feet in altitude.

In the interior, twelve miles south of east from Manilla, there is a fresh-water lake called Laguna de Bay, covering an area of nearly four hundred square miles. A large stream flows from it, and passing in several wide channels through the city of Manilla, empties into the harbour.

One of the interesting points about this lake is the fact that vast quantities of floating plants live on its surface, and pass down the river into the bay, carrying along great numbers of fresh-water snails of different species. Here we have, therefore, fresh-water shells and vegetation which is not marine, accumulating under salt water, for they sink after a while, and must become buried in the mud of the bottom along with the remains of marine life. This floating vegetation illustrates a theory with regard to the vegetation of the coal beds; and it certainly gives the view strong support, as we have remarked when speaking of the coal of Australia.

From this digression, we return, mentioning a few facts relating to other parts of the island before describing more particularly the vicinity of the Laguna de Bay. The *Laguna de Taal* is a similar lake, twenty miles farther south, averaging twelve miles in diameter, and covering an area of one hundred miles. It contains a volcano still smoking, the Volcano de Taal. The cone, as I was informed by residents on the island, is about nine hundred feet high. The crater has about the same depth, with perpendicular sides, and is near two miles in diameter. At the bottom of the crater there are two small cones and many smoking fissures. The crater is reputed to afford pure native sulphuric acid, in addition to sulphur and some volcanic salts. There are also several other cones about the lake.

Southeast of this lake the island is said to be wholly volcanic, and in this part, towards the southeast corner, stands the high cone of Albay, called by the natives Mount Isaroc, whose eruptions in 1814 covered with ashes a large extent of country and several villages. It is a steep but regular cone about three thousand feet high; it still smokes and occasionally discharges cinders.

Volcano de Taal and Mount Isaroc are the only active volcanoes in the southern part of Luzon. To the north there is a crater in the northern province of Xocolos, which has been in eruption since the Spaniards first arrived on the island, but is now quiet.

The broad plains of Manilla are, for the most part, underlaid by an ash-coloured tufa, and even over its lower parts, where no sections exhibit this tufa to view, the soil appears to have been derived from the

same material. Ascending the river, four or five miles towards the Laguna de Bay, the banks, which below are but five or six feet high, rise to forty and fifty feet, and in some places to sixty feet, and they expose a vertical front of tufa. It is a soft rock easily worked, and constitutes the common building material in the city. It consists of fine volcanic earth or cinders, with fragments of scoria, pitchstone or pumice, which occasionally are of considerable size. Impressions of leaves and silicified wood are of common occurrence, and some of the wood is beautifully opalized, though the greater part has the pitchy lustre of *resinite*. Many fine specimens of these vegetable remains were received by the Expedition from Don Inigo Azaola. They are mostly palms, and appear to be recent species.

A similar tufa occurs also around the Laguna de Bay, and constitutes the plain on the south side. Sections may be seen near Baños, and between Bay and Baños along the bed of a small stream. The layers in view were generally several feet thick, in some places fifteen feet.

There are several volcanic summits about the Laguna de Bay, varying in altitude from fifteen hundred to six thousand or seven thousand feet. The highest is called *Maihaihai*.* Near Bay and Calawan are other summits of undoubted volcanic origin, though now much broken in outline, and densely enveloped in forests. Near San Pablo, there are said to be nine craters, which are now occupied by small lakes. Towards Calamba, to the northeast of Los Baños, there are three small volcanic hills, one of which contains a pool of water that nearly communicates with the lake.

Near Baños, about a mile back from the lake, commence the declivities of Mount Magueling, the only one of these ancient cones which I had an opportunity to ascend, and that to a height of only two thousand feet. Its height by estimate is three thousand or three thousand two hundred feet. The rocks were seldom in sight on the ascent, on account of the deep soil and abundant growth of vegetation: where visible they were either trachyte or tufa. The tufa of the gently sloping plains around the base of this mountain had probably here originated; yet the summit was so broken, and the declivities were so much worn that no distinct crater was seen. There are several small subordinate cones on these plains, one of which was observed at the foot of the mountain, about two miles back of Los Baños, and another on a jutting point along the lake, between Los Baños and Bay. The latter was about one hundred and fifty feet high, and as

* Pronounced Myhyhy.

many yards in diameter. There is a broad plain at top lying between two prominent points. The hill consists of tufa, and appears to resemble "Punchbowl" Hill on Oahu; the layers dip at an angle of thirty or thirty-five degrees, and are from a few inches to five feet in thickness. The tufa is a soft friable rock, scarcely at all indurated, consisting of coarse and fine fragments of scoria and pumice imbedded in finer volcanic ashes.

The *Hot Springs at Baños* have been frequently mentioned by travelers. There are about a dozen springs, three of which pour out copious streams of water. A stone aqueduct has been built up around the main one; the water rushes out with considerable force, and spreading itself over the shores, flows into the lake. The temperature of the water where it leaves the aqueduct is 178° F. Over two steaming pools, domes had been built, about six feet in diameter, for use as steam bathing houses; the temperature of one was 160° F., and that of the other 140° F.: the latter, I was told, had of late diminished in temperature. About another place near the aqueduct there was a stone wall, enclosing stone reservoirs for baths. The place was once a fashionable resort for the gentry of Manilla; but everything is now in decay. The only attendants upon the baths at the time of our visit were the washerwomen and cooks. The shores were strewed with feathers from the fowls that had been scalded for cooking.

The water has no perceptible taste, and only a faint smell of sulphur was observed. There was no escape of gas. The stones were covered with a white incrustation which appeared to be siliceous; and a species of feathery vegetation occurs also upon them, bordering the streamlets where the temperature is 160° F., and presenting various shades of green and white. The rock of the vicinity is the tufa already described.

The volcanic appearances about the Laguna de Bay evince that the region was once a scene of extensive eruptions. Talim, an island near the centre of the lake, was probably one of the volcanic summits, and another small island off Bay consists of the lavas of another vent. Yet in our short ramble we discovered no evidence that the lake corresponds to a single crater. The hot springs are the only existing indications of fire. The whole region had probably experienced subsidence, in consequence of the volcanic operations that were formerly in progress. On this ground, the existence of such a lake in the interior of the island is easily understood.

The region around the Bay of Manilla has much resemblance to

that about the Laguna de Bay, and it is probable that they were alike in origin. Some islands near the entrance appear to be remains of the smaller subordinate craters, while the high summits of the adjoining country were evidently its great volcanoes. Their lofty conical form leaves no doubt of their volcanic origin.

The latest volcanic eruptions of these regions appear to have been attended with extensive ejections of ashes and scoria. This is the usual operation of subsiding fires.

This volcanic portion of Luzon is remarkable for the richness of its soil and its luxuriant vegetation. It affords abundantly most of the fruits and agricultural products of the tropics. Rice, coffee, sugarcane, cotton, and Manilla hemp, are the most important crops.

The secondary deposits of Luzon are not found in the region over which our two days' ramble extended. The specimens of coal examined at Manilla were associated with a greenish gritty sandstone, which is said to contain fossil shells. The coal looks much like our own bituminous coal. Some of the masses were eight inches thick, and possessed all the lustre and compactness of the ordinary Liverpool coal. Many of the specimens had a rough brown exterior, one-eighth of an inch deep, which had resulted from weathering.

Calcareous rocks are found at Beningona north of the Laguna de Bay: and on the shores of this lake there are said to be limestones forming from recent shells.

I was told by Señor Roxas that a bed of coral occurs on the shores of Luzon, six hundred feet above the level of the sea, at Point St. Diego, south of Manilla.

SOOLOO ISLANDS.

The Sooloo Group contains about a hundred small islands. They are sprinkled through the sea in a line between Mindanao and the north of Borneo, and among them are numberless submerged coral reefs. Traversing these regions, we were much of the time on soundings, and anchored in the open sea at night. Several islands were in sight at once. The largest of the group, Jolo (or Sooloo,) is about thirty-six miles long and sixteen broad. From this size, they dwindle to mere points of rock.

All the islands are volcanic, excepting some patches of coral reef. When off the shores of Mindanao, I counted ten or twelve distinct

cones, and several of these were perfectly regular and even in their steep slopes. The sides of two inclined at an angle of forty degrees. Some of the cones run up almost to a pointed summit, while others were broken off and had the common oblique truncation of volcanic peaks; others were still more broken, and gullied by denudation. We passed by two small islands, called from their forms *Asses' Ears*, which appeared to be the remains of cones.

The island of Jolo has the same volcanic constitution. The outline of the principal range rises into several conical peaks, and the declivities slope gradually away at a small angle like the larger volcanic mountains. They belong to the several craters which united together form the main range. The most elevated points are about two thousand feet above the sea. Some of the cones stand a little isolated, and their smooth declivities remind us of the Hawaiian Islands. The angle of inclination is ten to twelve degrees or less.

The jealousy of the authorities prevented our taking an excursion into the interior of Jolo. The loose blocks that lay about the village of Soung were cellular lavas, and an ash-coloured tufa resembling that of Manilla. A small uninhabited island off the harbour, where a few hours were spent, consisted of a coarse volcanic breccia, containing large angular masses of lava, compact and cellular. There were two hills in the small island, about three hundred feet high, which were probably parts of a former cone; between them lay a salt water lagoon communicating with the sea on the north. Other islands in the vicinity had similar features, and probably a similar origin; but we had no opportunity to examine them.

No evidences of change of level were observed in the group. The coral reefs seen were all submerged, and in no case formed platforms at the water level: as far as this goes, it tends to prove a subsidence rather than an elevation. It seemed surprising that so extensive coral shoals should not have reached the surface. This is partially attributable to the volcanic character of the group, whose fires must have been in operation to a very late period, and were to a great extent submarine in their action. Yet it is possible that extensive subsidences may have taken place; and if there are any changes in progress they are probably of this character.

Notwithstanding the abundance of rocks that meet one on every side, the island of Jolo, like others of volcanic character in a climate sufficiently moist, is abundantly fertile, and has an air of luxuriance which belongs peculiarly to the tropics.

CHAPTER XI.

DECEPTION ISLAND.

THE following remarks on Deception Island are from the Journal of Dr. J. S. Whittle, of the Expedition, who visited the place in the schooner *Seagull*, in March, 1839.*

The harbour of Deception Island has the shape of a horseshoe, and is from fifteen to twenty miles in circumference. The entrance is but three hundred yards wide. It is inclosed by a ridge of hills varying from eight hundred to one thousand eight hundred feet high; on the north, as seen from the bay, they are black and gloomy, while those on the south side are streaked with red. Not a trace of vegetation is anywhere to be seen. Pendulum Cove, in which we finally anchored, is a small basin, about four hundred yards in diameter, surrounded by some of the highest hills on the island; their slopes are deeply furrowed by the rains, and present a singularly bleak and desolate appearance.

There is great difficulty in ascending the hills on account of the looseness of the soil, as it gives way under every step. When dry, it has a dark gray colour, but is perfectly black when wet. The banks are formed of volcanic rocks, nearly of the same colour as the soil, though sometimes lighter, and of masses of ice, mixed layer for layer with earth.

On the southern side of the harbour, about two miles from the anchorage, several streams of salt water were observed running from the lower part of the hills and emptying into the bay, which were hot enough to have boiled an egg. Three miles farther towards the mouth of the harbour we saw vapour rising in immense quantity;

* Many specimens were collected by Dr. Whittle and Mr. J. W. E. Reed, U. S. N., but they were unfortunately lost in the upsetting of a boat.

and on approaching the place, found that it was the crater of an extinct volcano. It was situated about six hundred yards from the beach, from which it was separated by a strip of low land; on the other sides it was bounded by high hills. The crater had fallen in, and was filled with salt water. It was probably three-fourths of a mile in circumference, and the banks of the pond or crater were from fifteen to forty feet high. Around this crater there were many smaller ones, varying from a foot to a yard square; and on the side farthest from the bay there were numerous hot springs, some in ebullition, and every crack in the earth emitted steam.

About the mouth of one of the small craters there was a lining of lichen, which appeared to be the only kind of vegetation on the island. Crystallized salt was found attached to stones, where it had been deposited by the evaporation of sea-water. Other steaming hills were observed in the distance, but were not visited for want of time.

Proceeding in a boat from the volcano just mentioned, we sailed along that side of the harbour. We found a beautiful gravel beach, and passed many singular peaks, cones, arches, and columns of rock, and one which was an inverted pyramid sixty feet high. Some scoria was here collected that was light enough to float.

The appearances of volcanic action were as conspicuous in all parts of the island as in that above described, the only difference being that the eruptions there may have been the most recent.

The shape of the island is like that of a large volcanic mountain, half submerged, in which the crater communicates with the sea, and thus has become a harbour; and the small craters of the surface are probably subordinate points of eruption around this former centre.

According to an account of this island, received from Captain Smiley by Captain Wilkes, subsequent to the return of the Expedition, the whole south side, in February, 1842, appeared as if on fire; and thirteen volcanoes were observed in action.

CHAPTER XII.

GEOLOGICAL OBSERVATIONS ON THE ISLAND OF MADEIRA.

THE most striking peculiarity of the mountain scenery of Madeira consists in the jagged outlines of the ridges, the rude towers and needles of rock that characterize the higher peaks as well as lower elevations, and the deep precipitous gorges which intersect the mountains almost to their bases. The shores in most parts are lofty cliffs, occasionally showing an erect front one or two thousand feet in height. These cliffs are interrupted by a few small bays, where a richly cultivated valley approaches the water between abrupt rocky precipices, or green fields lie surrounded by an amphitheatre of rugged hills. These narrow bays are the sites of the villages of Madeira. Near the eastern cape of the island, we observed many isolated rocks standing off the land, with bold sides and broken outline. One of these islets had a slender pyramidal form, though extremely jagged surface, with an arched way through its base, affording a passage for the breakers.

The surface of Madeira rises on all sides to a high central ridge, and deep valleys radiate towards the shores. The roads are an endless succession of steep ascents and descents; yet they open to so many views of unusual beauty and grandeur that the traveller finds little tediousness in the route. The Corral is one of the most wonderful of its gorges, and though often a theme for the traveller's pen, its grandeur remains yet untold. The enclosing walls of two thousand feet,—the narrow strip of green at bottom, with its winding rivulet, its chapel and its vineyards, reduced to a miniature size by the distance,—the bold turrets of rock that tower up from the depths of the gorge,—and above the highest western walls, the summit of Pico Ruivo, lost in clouds,—are some of the features of the scene as it appeared to the writer.

Pico Ruivo is the highest point on the island, being 6237 feet above half tide, according to the barometrical observations of the Expedition.* Over the western half of the island, the central ridge (Paul de Sierra) is less broken than to the east; it has been ascertained to be 5194 feet high. There are extensive *forests* of heath and broom scattered over the heights; for the heath grows to the stature of trees, or a height of thirty feet, and the broom attains nearly half this size. The eastern extremity of the island is a narrow ridge of rock, partaking of the general character of the island, though much less elevated.

The valleys usually enclose a strip of cultivated land between their high, precipitous sides, watered by a streamlet, which becomes a mountain torrent in the wet season, though it may be nearly dry in summer. The latter was the condition about the middle of September of 1838, when we spent *five days* on the island.

Rocks.—Madeira consists throughout of volcanic rocks, excepting small deposits of tertiary and recent limestone.

The igneous rocks are mostly a compact grayish basaltic† lava, a scoriaceous rock of similar composition, and different varieties of tufa and coarse conglomerate. The basalt is generally tough, with few cellules and a bluish-gray colour: but a brownish-red shade is also common, and characterizes whole cliffs. The texture is rarely at all crystalline, and the rock, therefore, breaks with a smooth surface, and usually a conchoidal fracture. It contains, however, grains of olivine, and occasionally distinct crystals of feldspar or augite. The olivine is sometimes very profusely disseminated. The augite occurs in large black crystals, which are quite brilliant on the surface of perfect cleavage.

From the compact basalt there are insensible gradations to a perfect scoria of a brownish-red colour.

In some specimens obtained from the bed of the Socorridos, the rock was a vesicular trachytic rock, containing thickly disseminated tabular crystals of feldspar. Another vesicular variety contained the three minerals, feldspar, augite and olivine. The olivine had often a submetallic lustre when broken, arising from incipient decomposition. Obsidian and pumice were met with only in beds of tufa. Some of the vesicular varieties contained stilbite in its cavities.

* The altitude, as determined by Captain Ross, in 1839, is 6097·08—6102·90 feet. (Voyage to the Southern Seas, 1839—43. London, 1847; vol. i. 6.)

† We still use the word *basaltic* in a general way, in preference to more specific terms, for a rock containing augite and feldspar, and often olivine.

A columnar structure is of frequent occurrence over the island, though seldom perfect. One of the first places that strike the eye on entering the bay of Funchal, is a mass of oblique and curved columns, a short distance from the city, near Ilheo Rock.

The tufas vary from a friable earthy rock to coarse conglomerates of scoria or pumice. Dark brown, brownish-black, yellowish-gray, ochreous and red, are the colours they present. Some varieties look like brick, both in colour, lustre and structure. Others are like loosely compacted earth. The coarser kinds often contain imbedded grains of the several minerals above mentioned; and at a locality near Ilheo Rock, (harbour of Funchal,) a friable yellow tufa afforded numerous small but perfect crystals of chrysolite, which were highly modified, and had a grayish-green colour. The pumiceous bed examined was mostly made up of small fragments of pumice as large as a hazel-nut. Other conglomerates consisted of angular and rounded masses of the several varieties of basaltic rock and scoria. The largest mass observed was about one hundred cubic feet in size.

The varieties of rock described occur in alternating layers, and most of the cliffs and sides of the valleys present a regularly stratified structure. In a distant view, there is a striking resemblance to a cliff of secondary limestone; the stratification was very uniform and distinct, and nearly horizontal. This fact was exhibited with great perfection along the walls of the deep gorge called the Corral, where sections one to two thousand feet in height are exposed to view. Even isolated peaks, standing in this gorge, and rising to a great height, were stratified in the same manner, and the layers were equally regular, and as nearly horizontal. Pico Grande was of this kind; it is one of the loftiest peaks of the island, and owing to its singular castellated outline and isolated position, it is a peculiarly majestic sight on the descent to the Corral. The stratified structure is distinct from top to bottom. In our rapid jaunt we had an opportunity to learn only that the alternations are numerous from compact and scoriaceous basaltic layers to tufaceous or conglomerate beds, of various colours, and coarse or fine in different degrees. Even the steepest precipices are faced with ferns and shrubs, which cling among the rocks; and on account of the luxuriant vegetation, much labour would be required to take down a correct account of the alternations of rock which constitute them.

Although nearly horizontal, a slight dip to the southward was apparent, yet not exceeding three degrees. At one place an inclination of

fourteen degrees was observed ; but it was local, and varied much in a short distance.

At Brazen Head, the eastern cape of the harbour of Funchal, the following were the alternations of beds observed, beginning above :—

- 24 feet.—Hard grayish and bluish-gray compact basaltic rock, scoriaceous above and below.
 6 feet.—Tufa ; red and *columnar*, immediately under the overlying basalt, but yellow below.
 32 feet.—Tufa ; fine-grained, soft and friable, with $1\frac{1}{2}$ feet of pumiceous conglomerate near the middle of the bed.
 2 feet.—Pumiceous tufa.
 $4\frac{1}{2}$ feet.—Tufa ; fine, friable, ash-coloured.
 7 feet.—Ibid.
 $\frac{1}{2}$ foot.—Pumiceous tufa.
 6 feet.—Tufa, fine ash-coloured.
 5 feet.—Pumiceous tufa, coarser above.
 7 feet.—Tufa ; fine ash-coloured.
 35 feet.—Compact basalt similar to the uppermost bed.

The whole height is one hundred and twenty-nine feet ; of this, seventy feet are tufaceous, and lie between two layers of basaltic rock. The seventy feet of tufa are divided into four layers of well-defined limits. The prismatic structure of the upper part of the first layer of tufa was quite regular. The prisms were two to three inches thick, and about three feet long ; above, they had a deep brownish-red colour and some lustre ; below they gradually changed to a yellowish-red shade, and were less hard. The structure is the result of the heat communicated by the superincumbent layer when first ejected. The change of colour to red, owing to the heat depriving the oxyd of iron of its water, had taken place in many parts of the island where examined by us.

The upper basaltic layer has a rough, scoriaceous look above and below, while the interior is very compact, and it resembles thus many of the subaerial ejections of recent volcanoes.

To the east of the place where this section was observed, the layers overlap the hill, saddle-like. From the gradual change in the dip along the coast, and the character of this hill, it seemed probable that there had been a point of eruption in the vicinity.

Dikes.—Dikes are frequently met with over the island, wherever the rocks are uncovered. Several were observed along the path leading in and out of the Corral, some of which appeared to cut through

the lofty walls to their summit. They were similar in form, consisting of a compact gray or bluish-gray basaltic rock, and scarcely alter at all the adjoining rock, except where it is a tufa.

The following sketches exhibit a number of dikes intersecting the cliffs between Machico and Caniçal. The cliffs consist mostly of a

Fig. 1.

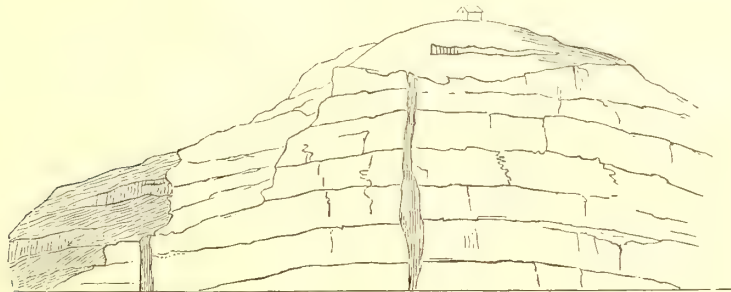


Fig. 2.



hard brownish-red rock, alternating with narrow red layers, and a few broad tufaceous deposits of a brown colour. The dikes are from six inches to six feet in width : in one place there were *nine* in a distance

Fig. 3.



of two hundred feet. The dikes were generally transversely fractured, showing a tendency to a columnar structure ; but in the broad dike, represented in figure 3, there were lines of fracture parallel to the walls.

It is a remarkable fact, that notwithstanding the number of dikes here seen, the layers intersected by them were not dislocated.

Degradation—Decomposition.—The valleys of Madeira are nearly free from debris at the base of the lofty cliffs. This is so different from what is seen in our own country, that at first it struck us as a very singular fact, especially as the alternation of tufaceous and compact layers of rock expose the precipices to rapid wear; but it is fully explained by the absence of frosts, and was afterwards found to be a common characteristic of the igneous islands of the Pacific. Another cause may consist in the rapid formation of soil over the declivities, the growth of vegetation forming a protection against degradation. There is soil and verdure even on the fronts of the most precipitous bluffs, wherever there is a cleft or a projecting shelf for their lodgment; and many a large tree may be seen clinging with its roots to the side of some perpendicular height, far beyond the reach of man. The warm climate, and the abundant mists that envelope the summits of the island, are both favourable to the rapid growth of vegetation.

LIMESTONE OF CANIÇAL AND ST. VINCENT.

Incrustations and spherical concretions of carbonate of lime are found at various places along the coast, above high water mark, where they are apparently formed by depositions from the sea-water thrown up as spray. Along Brazen Head the scoriaceous rock, in some places, was covered with globules of carbonate of lime, one-sixteenth of an inch in diameter. Just east of Camera de Lobos, the incrustations were, in some places, half an inch thick, and they presented the usual banded colours of stalagmite, arising from the gradual deposition of successive layers.

The Caniçal limestone is situated just beyond the village of Caniçal, near a small chapel dedicated to "Nostra Senhora da Piedade," which stands on a cliff facing the sea, (see figure 3, preceding page.) We landed from our boat just beyond this elevation, and after a few minutes' walk up a sandy hill, reached the deposit. It borders both sides of a low valley, which cuts obliquely across the point of land forming this extremity of Madeira. The uppermost limit is an even horizontal line on both sides; on the southern side this line is about one hundred feet above the sea, while, on the northern, it is consider-

ably higher. Over the surface below this line, there are small patches of limestone layers, consisting of calcareous sand, and great numbers of cylindrical stems of lime are lying around, or standing upright. These stems are often branching, and vary from a fraction of an inch to ten inches or more in diameter; yet the "petrified forest," as it is called by Mr. Bowditch, is hardly knee high in any part. The exterior of the concretions is arenaceous, and within, they have generally a sandy look, with no trace of any regular structure. Some of the larger specimens are tubular, from the removal of the centre, which is less firmly compacted than the exterior. They appear to be concretions around the root-fibres of some plants, or about the perforations of some seashore animal. It cannot be doubted that the whole region was once at a lower level, and, at the time, calcareous sands, from triturated shells, and perhaps, also, crabs, may have been washed in by the sea, as beach deposits, to a certain limit above high water mark. It is possible that the upper ledge, on each side, was the water limit; but from the character of the sands and the layers of calcareous sandstone, and their resemblance to the beach sand-rock on coral islands, the former supposition is, perhaps, more probable. There are numerous land-shells in the calcareous sand-rock, besides some of marine origin. Several of these shells are described and figured, in the work on Madeira, by Bowditch. Other collections were made by James Smith, Esq. ;* and from the examinations of Mr. Lowe, all but a sixth are recent species.

The St. Vincent limestone was discovered by Bowditch, and set down by him as of transition age. In our brief time on the island we did not reach it. It occurs, according to Mr. Smith, twenty-five hundred feet above the sea, and contains corals and marine shells, which indicate a tertiary or post-tertiary origin.

Large quantities of a coral limestone were seen at Funchal, which had been brought from small islets near Porto Santo. It so resembles, in its white colour, compactness and homogeneous texture, much of the coral rock of the Pacific, that the two could not be distinguished. Some of the blocks abounded in fossilized corals, besides casts of shells resembling, as nearly as can be determined, recent species. It also contains occasional pebbles of the basaltic rocks of the region.

* Proc. Geol. Soc. of London, No. 73, Dec. 6, 1840.

Concluding Remarks.—The igneous origin of Madeira, through the ejection of its rocks as separate streams of lava or fluid basalt, with intervening cinder or fragmentary eruptions, hardly admits of doubt. It is also obvious that at least its later eruptions, were, to a great extent, subaerial, and continued to a comparatively recent period. Its origin has been considered as dating no farther back than the tertiary epoch. But of this we have no evidence, and probably none will ever be detected. The age of rocks is usually determined either by the contained fossils or relative order of superposition: neither kind of evidence exists in Madeira. Though we know that the surface rocks are comparatively recent, we must also admit that the recent lavas of the surface may rest on a continued series of other igneous rocks that may count back to an early geological epoch.

The centre or centres of eruption have not been satisfactorily ascertained. The Corral is considered by some writers one of the craters, and it has a very strong resemblance to Kilauea in the Sandwich Islands; for there are, at Kilauea, the same abrupt walls, regularly stratified from top to bottom, and as free from scoria, and it would be necessary only to open a gorge from the south extremity to the sea to complete the resemblance. But other examinations may be required to determine with certainty whether this is its real origin, or whether it has resulted from a subsidence attending an eruption from some other centre.

The recent elevation of the island indicated by the San Vincente limestone appears to have amounted to two thousand five hundred feet. From the limestone of Caniçal, we should infer that the rise in that part since its formation was eighty or one hundred feet, and that it was unequal in amount on the two sides of the valley.

The islands of Porto Santo and the Desertas belong to the Madeira Group, but were not examined by us.

It is interesting to observe that the trend of the island of Madeira, is the same with that of a line from the Desertas through Madeira, it varying little from N. 66° W.; while the trend of Porto Santo is N. 42° E., or within eighteen degrees of being at right angles with the Madeira line.

CHAPTER XIII.

GEOLOGICAL OBSERVATIONS ON CHILI.

THE Andes are the prominent feature in the Chilian landscape. From the harbour of Valparaiso, the eye passes rapidly from ridge to ridge over the foreground of the scene, but is detained in lengthened gaze by the sublimity of the snowy summits which bound the field of vision. Many of the nearer heights, rising from one to ten thousand feet, would give grandeur to most other regions, though here they are but undulations of the surface at the base of the great chain. In the view of the Cordilleras, the attention becomes finally concentrated upon a single conical summit, the Bell of Aconcagua, standing behind the main range; it towers above the lesser heights to an altitude of twenty-three thousand feet, and even in summer is covered with snows half-way to its base.

The little attention which we were able to give this region of ancient and modern fires was confined to a study of the granitic rocks of the coast, and a rapid examination of the geological structure of the country in two trips to the mountains, one by Santiago and the other by Aconcagua.*

General Features of the Country on the Routes Examined.

The coast along the Bay of Valparaiso, and far to the north and south, is generally formed of a cliff from seventy-five to three hundred

* The writer visited none of the mines of Chili, excepting a single one in the Jaguel Valley, where a few hours only were spent. On the subject of the rise of the Chilian coast, as he saw the coast only at Valparaiso, no new observations were made. The mountains were ascended near Santiago by a single route to a height of twelve thousand feet, and near San Felipe de Aconcagua, to a height of four thousand feet.

feet high, above which the land rises to a much greater elevation. These cliffs are composed of granite, gneiss, or syenite, and form a rugged, broken shore. Where the valleys terminate on the sea, the cliffs are interrupted by sand or shingle beaches, some of which are three to five miles long, and are intersected by the mouths of streams. It is not unusual, however, for these streams to become dry by absorption into the sand several rods from the sea.

Leaving Valparaiso,—which is situated on a narrow strip of land edging the sea and forming the shores of a small, shallow bay,—the land rises rapidly from the top of the first elevation or cliff, and reaches soon an altitude of a thousand feet. The slopes thus enclose an extensive amphitheatre, the bottom of which is occupied by the city and bay. Numerous valleys extend down from the summit, which alternate with flattened ridges.

After gaining the ascent back of Valparaiso, (called the *cuesta* or ridge of Valparaiso,) and passing over a few miles of undulating country, we reach an open plain, which continues eastward, or a little south of east, for thirty miles, over which the road to Santiago passes, scarcely deviating from a straight line. Some ten or fifteen miles to the southward and eastward, the country is much intersected by rounded hills and ridges; and to the north, the region appeared to have a similar broken character. Thirty miles to the north, stands the Campana or Bell of Quillota, a nautical landmark, estimated at nine thousand feet in height.

A high mountain ridge, the *Cuesta de Zapata*, situated forty miles from Valparaiso, interrupts the straight and level road, and separates the region passed over, from a second level, which is of similar character, though confined within narrower limits by the mountains on either side. Sixty miles from Valparaiso, a still loftier ridge intersects the country, called the *Cuesta de Prado*. Beyond it, after passing over a few miles of irregular hills, we reach the great plain of Santiago, thirty miles wide, lying at the base of the Andes. This plain, as has been ascertained by a series of barometrical observations, is situated one thousand seven hundred and fifty feet above the sea, which gives an average rise of twenty feet to the mile; or, if we take off the first rise of one thousand feet, directly back of Valparaiso, and consequently near the coast, the average will be but nine feet to the mile. This inner valley or plain upon which Santiago is situated, extends both north and south, varying its breadth at intervals;

it is said to be over six hundred miles long. The elevations between it and the coast are sometimes called the coast or lower Cordillera, (Cordillera de la costa, Cordillera baja,*) while on the east, stand the higher Cordillera, or the Andes proper, (los Andes, Cordillera alta.)

Leaving Valparaiso for Quillota, the road for the first twenty-five miles extends northward, not far from the seashore, and through this distance it is very uneven, on account of the numerous valleys which intersect the route. The largest of these valleys, three leagues from Valparaiso, has a breadth of two miles, and is the site of the small village of Viña del Mar. It is a sandy plain for nearly three miles from the sea, and through it a wide shallow stream flows along to the ocean. Twenty-five miles from Valparaiso, we reached the broad valley of the Concon, a fine stream which rises in the Andes. At this place the road turned east, and followed the south side of this valley to Quillota, about seven leagues from the sea. Quillota occupies the centre of the valley to the south of the river, and is situated at the foot of a low, smoothly rounded, granitic hill (Mellaca Hill), about three hundred feet high, and a mile and a half in circumference. The elevations which bound the valley on the south are low until near Quillota, where, to the southward, stands a lofty abrupt ridge, which may be seen at sea. The Campana, or Bell of Quillota, lies farther to the south, and is shut out of view by this ridge.

The valley or plains of the Concon, below Quillota, have a varying width of three to six miles. Above Quillota, the width is generally less than two miles, and it is occasionally narrowed to a few hundred feet by the approximation of the ridges either side. Towards San Felipe de Aconcagua, twenty miles from the foot of the mountains, the valley again widens and expands into a broad plain lying at the foot of the Andes, continuous with that of Santiago, though forty miles farther north.

The road from Quillota to San Felipe takes a more direct route, and passes over three ridges. The *first*, about four miles northeast of Quillota, is the ridge just noticed; when at its summit, we look down, on either side, into the valley of the Concon. On descending, we again followed the south side of the valley. Low, rounded elevations characterize this side, while, on the north, the heights are lofty and precipitous, and at the season of the year visited by us, (in May, the last of autumn,) they had a bleak appearance from the snow which

* Domeyko, *Ann. des Mines*, iv. Ser. ix. 18.

was lodged about the rocky, angular summits. They may be ten thousand feet high. Twenty-eight miles to the east-northeast of Quillota, the road ascended a *second* *cuesta*, of less elevation than the first; and descending again, continued along the Concon to San Felipe, leaving but once the level of the plain, about six leagues before reaching that city. This ridge, or *third* *cuesta*, as it may be called in future reference, curves around to the eastward, and assumes bold features, with a regular columnar structure above. On the opposite side of the valley, the lofty frosted ridges retreat to the northward: and thus, from between these heights, we opened on the plains of Aconcagua. Beyond, to the east, rose the Cordilleras, at this late season clad in winter's snows almost to their foot. San Felipe is but fifteen miles from the mountains. The Bell of Aconcagua disappeared behind the nearer snowy heights as we approached the city. It is not in Chili, but belongs to the eastern Cordilleras in La Plata.

The above descriptions are somewhat detailed, because, as they were the only routes traversed by the writer, there will be frequent occasion to refer to the places and *cuestas* mentioned.

The general height of the Andes in this part of South America varies from twelve to fifteen thousand feet. The main ridge is a solid mountain mass, with little that is striking in outline; here and there a peak lifts itself above the summit with a rude conical or turreted shape and jagged outline, consisting usually of columnar rocks. Near San Felipe, a little to the north, there are two of these elevated peaks, not far apart. One of them, the northern, has a slender conical form and pointed summit, and leans sensibly to the southward. The other rises from a broader base, and has the outline of a truncated cone, though consisting, like the former, of columns. Behind Santiago is another of the prominent peaks in this part of Chili. It is a crested ridge standing high above the adjoining portions of the Cordilleras. Only these elevated points are covered with perpetual snows.

The eminences between the Andes and the coast vary in features according to their constitution. Those of a granitic or gneissoid-granitic character, have a tame outline, and prevail along the coast. The greenstone or porphyritic heights have usually a bold front, and a precipitous columnar brow overlooks the plains at their base.

The surface of the country among the many hills, ridges and mountains of Chili, west of the great range, is, in most instances, nearly a perfect plain, and this level character is one of the most striking fea-

tures of the landscape. This is the case with the bottom of the narrower valleys, excepting those among the Cordilleras; and the wide plains are but the bottoms of wider valleys. The hills about the plains of Santiago appear like islands in a quiet sea; for the slopes do not decline into the plain by a gradual blending, but terminate abruptly below, as if the country had been levelled off around the standing eminences. The same is true of the plains of Aconcagua, and of the valley of the Concon through all its extent. The rivers, in consequence of the level character of the valleys, usually run in three or four shallow pebbly channels, which are united by cross courses, forming together a network of water over the valley-plain. In the thawing season, these shallow fordable streams become deep and dangerous torrents. They often rise rapidly; and as the melting in the mountains ceases at night, there is a periodical rise and fall of water in the course of the day.

There appears to be no want of fertility in any part of Chili, except such as results from a lack of water. This is the principal obstacle to cultivation, and it is extensively overcome by artificial irrigation. Over the dreariest waste, a line of rich green is observed wherever there is a trickling streamlet to afford the needed moisture.

GRANITIC SERIES OF ROCKS.

Granitic rocks, with which we include gneiss, syenite, and mica and hornblende schist, constitute the coast of Chili in the vicinity of Valparaiso, as well as to the north and south, and occur here and there over the country to the Andes. Extensive exploration would be required to make a map showing accurately their distribution, since they occur among the trachytic, porphyritic, and greenstone ridges, instead of being separated in a range of country by themselves. Between Quillota and San Felipe, the *first* cuesta, four miles from the former city, and about nine leagues from the sea, consists of trachyte; the *second*, twenty miles beyond, is composed of porphyritic greenstone; the *third*, twelve miles farther to the northeast, is granitic, with numerous greenstone dikes; at Quillota, Mel-laca Hill is granite. It is hence impossible to draw a direct line between the coast and the Andes, dividing all the granitic from other igneous rocks.

The granite of the coast near Valparaiso is, to a great extent, gneis-

soid, and in some places passes to a perfect gneiss, or even a mica slate. Dark gray is the prevailing colour. The rock consists of white or grayish-white feldspar, white or colourless quartz, and black mica in small scales. The mica has occasionally a greenish tinge, and sometimes (as half a mile southeast of Valparaiso, where the rock is remarkably micaceous,) it has a bright gold-yellow colour. These changes are frequent and without regularity. The passage of the granite to gneiss often takes place in spots subordinate to the general mass of granite. The rock is often a true gneiss at an exposed point, having a distinct dip and direction; but the same rock, a few feet distant, defies all attempts to distinguish the angle of inclination; and as far in another direction it may have all the characters of a true granite.* This is the common fact about Valparaiso.

A mile to the southwest of Valparaiso, towards the lighthouse, the granite becomes syenitic; at first, there is a sparing dissemination of hornblende; and then the proportion increases till the rock is gneissoid syenite and hornblende schist. The syenitic granite has a greenish tinge, and the schist a black or greenish-black colour. A similar passage of granite to syenite occurs a mile to the north of Valparaiso beyond Essex Beach; also of still greater interest, in the cliff just north of the beach of Viña del Mar, three leagues from Valparaiso. The granite at the latter place is rather feldspathic, and the mica it contains, is in coarse black scales. In a neighbouring cliff there are planes of fracture which dip to the southwest-by-south forty-five degrees; while in that just referred to, there are narrow interpolations of a dark gray rock, resembling dikes, and dipping to the southwest

Fig. 1.

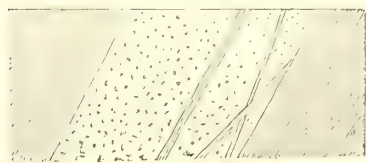
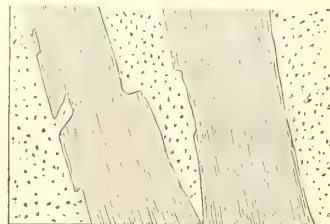


Fig. 2.



seventy degrees. Figure 1 represents a breadth of eighty feet, and figure 2 of thirty. This dark rock is between gneiss and mica slate

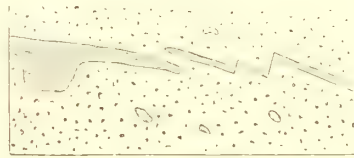
* Mr. Darwin alludes to this irregularity, but concluded that the strike of foliation was about north-by-west and south-by-east.—*Geological Observations on South America*, p. 162.

in structure, and approaches an argillaceous shale, though less slaty; it appears to contain a little hornblende. A few rods north, there are similar intercalations of a gneissoid rock having the same dip, which are black with hornblende, though presenting a fine texture like the micaceous rock just referred to. The lines in the figures show the direction of lamination.

The hornblende, in some places, forms small disseminated concretions half an inch in diameter, scattered through the granite, and there are also a few isolated ovoidal masses, as in figure 3, representing twelve feet.

The granite still contains mica; but a short distance farther to the north, it begins to be hornblendic, through a gradual replacement of the mica by this mineral. The hornblende at first

Fig. 3.



is rather soft, and of a green colour, and could scarcely be distinguished from chlorite except by the more decided hornblendic character exhibited a little farther to the north, where the rock is a true syenite. The pseudo-dikes of compact hornblendic schist, now become more extensive and appear like thick layers: they constitute a considerable portion of the coast.

Both the granite and the hornblende schist are frequently intersected by the same feldspathic veins, and they often contain magnetic iron ore. In some instances, however, a feldspathic vein is faulted by the syenitic schist, as shown in figure 1.

The dark globular spots which have been referred to as occurring in these rocks, include generally a larger proportion of mica or hornblende than occurs in the parts around. They rarely exhibit a concentric structure. In one instance, the inclosing rock was concentric, though the ovoid mass itself was tough and compact.

Just north of Valparaiso, on the shores, there are small concretions in the granite, two or three inches in diameter, which consist of a feldspar exterior about half an inch thick, with a dark micaceous centre containing small deep-red garnets. No garnets occur in the adjoining rock. The nodules are scattered quite thickly through the rock, and look somewhat like imbedded fossils. Over the water-worn surface of the rocks many of these concretions are partly worn off, and only half the feldspathic shell remains, emptied by abrasion of its micaceous material and garnets.

On the way beyond Viña del Mar towards the Concon the rock is generally a granite; but at several places there are transitions similar

to those just described. A few miles to the north of Viña del Mar, near the road, the hornblendic schist outcrops and presents a thin schistose structure with a dip to the west-by-south of seventy-five degrees. Three miles south of the Concon, on the same road, this hornblendic schist intersects the granite like a narrow dike. The granite just south of the Concon is almost purely feldspar.

On the road up the valley of the Concon towards Quillota, there are a few schistose beds subordinate to the granite, which in hand specimens have a very ambiguous character. The rock somewhat resembles an argillite; it has a very fine texture and a grayish-blue colour.

The resemblance to dikes in many of these beds of schist is extremely close. Often the syenitic rock when rubbed, presents all the appearance of an earthy greenstone; yet the schistose structure parallel with the walls is peculiar, and distinguishes it from the greenstone of ordinary dikes.

The small rounded eminence adjoining Quillota, called Mellaca Hill, is composed mostly of a coarse granular granite consisting of white feldspar and quartz with black mica. This is distinctly seen on its southwestern side, though the decomposition of the surface is so deep that a fresh fracture is obtained with some difficulty. On the northeast side, a syenitic rock crops out, composed of albite and hornblende, with little quartz. The albite has a pure white colour. The hornblende is in black prismatic crystals, often half an inch long and perfect in their faces; many are cruciform. The rock is compact and would make a handsome as well as durable building stone. Near the same place I obtained from boulders, apparently derived from this hill, a light-green rock, consisting of compact epidote with some disseminated flesh-coloured feldspar. Near by, I collected a crystalline limestone of a light-greenish colour; the tint was derived from minute oblong leaflets of talc sparingly disseminated through it. Some of the veins in this Mellaca Hill consist of protogine, or a grayish-white granular compound of feldspar and compact talc; others were a variety of granulite; others a compound of feldspar, quartz, and albite, containing some particles of magnetic iron, and a few slender crystallizations of talc.

In the ridge designated the *third* cuesta on the road from Quillota to San Felipe, there is the same passage of granite to syenite.

A few miles east of San Felipe de Aconcagua, towards the foot of the Andes on the route to the Jaguel Valley, there is an isolated granitic ridge, the rock of which consists of white albite and hornblende of a greenish-black colour, resembling the variety of syenite

found near Quillota, though it is less perfectly crystallized, and the albite is not of so clear a white colour. Like many granites and syenites, it contains many ovoidal spots of a darker colour than the rock, which appear at a distance like imbedded stones; they have, however, the same constitution as the rock, except that they include more hornblende, and both the hornblende and albite are in finer grains. Boulders of the same rock were abundant in the Jaguel Valley, one of the gorges of the Andes, and they were often of large size; yet no similar rock was observed in place in the hills adjoining the valley for the short distance—fifteen miles—which we ascended it. This albitic rock appears to be allied to the *Andesite* described by Mr. Darwin as intersecting the sedimentary rocks of the western chain of the Cordilleras, and therefore of comparatively modern origin. No facts were observed in connexion with the particular ridge here described, which indicated its age.

From the facts which have been detailed, it appears that the transitions in the granite to syenite, and to micaceous and hornblendic schist, are numerous and interesting. We have found pseudo-dikes of argillaceous schist in granite, and not far off, where the granite changes to a syenite, there were similar pseudo-dikes of hornblendic schist, conformable in position to the argillaceous, and these were conformable to lines of fracture near by in a granite cliff free from the pseudo-dikes: and we have found these pseudo-dikes increasing in extent, and becoming layers of schist.

A coarse concentric structure often characterizes the granite. On the road to the north of Valparaiso, along the coast, there are sections in which globular concretions are exhibited to view that are two to three feet in diameter. They readily peel off in concentric layers.

Veins and Dikes in the Granitic Rocks.

The granite and syenite of this region are remarkable for the number and complication of the granitic and epidotic veins. Epidote is occasionally disseminated through the rock, but usually occurs in narrow seams composing independent veins, or forming the walls of the granitic veins.

Epidotic Veins.—The veins of epidote are usually very narrow, seldom exceeding a fourth of an inch, and in general not over an

eighth of an inch. The rock each side of the vein is in most instances discoloured for three-fourths of an inch or more.

a. This discoloured portion sometimes partakes of the green colour of this mineral from impregnation with it, and occasionally when so, the walls of the vein have a compact structure, a dark polished surface, and a dull green colour.

b. In other cases, the adjoining rock has a rusty or half-decomposed aspect, and the mica, which is elsewhere black, is here altered to a dull brownish colour.

c. In the majority of instances, however, especially when the rock traversed is feldspathic, the gray or white of the feldspar is changed to a deep flesh-red, or brick-red. The feldspar has evidently received this tint from its proximity to the epidotic vein, and it is due beyond doubt to oxyd of iron, one of the constituents of epidote. In many places where the seam of epidote can scarcely be distinguished on account of its minuteness, its position is marked by this flesh-red band.

These epidotic veins occur both in the granite, gneiss, and syenite, and they have the same characters in all these rocks. They also intersect the veins of granite, and it is especially through these veins, that the flesh-red bands are most distinct. In many places, epidote forms the walls of these veins; again, it is found running irregularly through them in various directions, and crystallizing where in favourable positions; again, it enters apparently into the constitution of the vein, so as to form a compound rock of epidote and feldspar, the feldspar having throughout a deep flesh-red colour. There are instances of feldspar which is flesh-coloured, though not containing epidote; yet, in such cases, veins of epidote are always abundant in the vicinity, and frequently intersect the granitic vein.

Neat crystallizations of epidote were not observed, though imperfect and minute crystals were not rare. The epidotic veins contain no foreign mineral excepting feldspar, and in these instances we have considered them feldspathic veins with walls of epidote. In one instance the feldspar constituted less than half the width of the vein.

There is no uniformity of direction in these veins; they cross very irregularly, and many disappear after continuing for a few feet. Figure 4 is a map of the veins on the surface of a block of syenite but ten feet square, observed on the coast near the Valparaiso lighthouse. The rock has a dark colour, and contains a large proportion of black hornblende. These veins, so various in direction, have the

same colour and other characters; they are mere lines themselves, but the green colour extends an inch either side gradually losing itself in the dark colour of the syenite. Figure 5 is another instance of a large number of epidotic veins variously branching and occasionally intersecting; it is a diminished sketch of a surface six feet square.

Fig. 4.



Fig. 5.



The rock is granite, and is part of a granite vein. For half to three-quarters of an inch either side of the epidotic seam, the colour is red, as above explained. Instead of a single seam of epidote along the centre of one of the broadest of these bands, there are three or four very narrow lines running along together, and in one of them the epidote is partially crystallized.

Additional remarks on the epidotic veins, will be offered after describing the granitic veins.

Granitic Veins.—The various cliffs and artificial excavations for roads, about Valparaiso, afford numerous sections for the display of granitic veins. In many places they traverse the rock apparently in all directions, reticulating the face of the cliffs, so that the size of the intervals between them seldom exceeds ten feet square. We might describe some of the cliffs as consisting of a network of granite veins filled in with gneissoid granite.

The only minerals noticed in these veins besides epidote, are tourmaline, garnet, chlorite, and magnetic iron. The tourmaline is in blue-black crystals, but they are seldom well defined. The garnets are small and occur in a few only of the veins. Chlorite covers portions of the walls in some places south of Valparaiso, not as a continuous coating, but scattered here and there in pieces as thick as the hand, and a few inches broad. The mineral has the usual imperfectly crystalline texture and dark olive-green colour. Magnetic iron occupies the centre of narrow veins, intersecting the hornblendic schist and granite north of Viña del Mar, and at other localities it is sometimes disseminated in small quantities through the granite. Iron

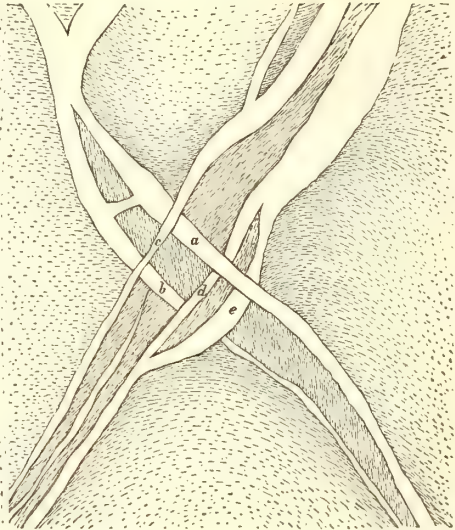
sand is found along the beach just north of Valparaiso, and also to the north of the beach of Viña del Mar.

The veins are of every size, from the merest line to several yards. The same vein (figs. 6, 7) is often very irregular in its dimensions, occasionally enlarging to an extensive bed, and again diminishing to

Fig. 6.



Fig. 7.



a narrow thread. The broadest vein observed was ten feet wide at one place and a foot in others. They are also variously curved, and sometimes abruptly bent and faulted.

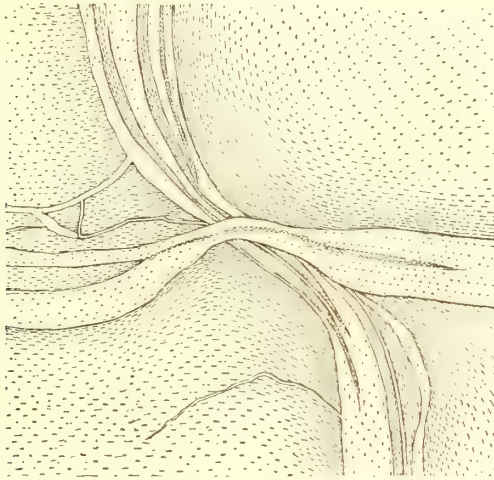
The material of these veins is generally a feldspathic granite, coarsely crystallized, containing but little quartz, and the mica in rather large crystals. The feldspar is white or flesh-red, becoming sometimes brick-red near epidote veins. Quartz veins are not common, though occasionally seen on the hill back of Valparaiso and elsewhere. Others of granular feldspar and compact talc, white or slightly greenish in colour, have been described as occurring in Mellaca Hill.

The hornblendic schist to the southwest of Valparaiso, below the lighthouse, intersects the granite like veins or dikes, as has been described on a preceding page. The same is true of the schist north of Viña del Mar. Some of the veins are narrow and tortuous, and their black colour causes them to stand out in strong contrast with the light tint of the inclosing granite.

Structure.—There are many points of an interesting character in the structure of the larger granitic veins, and the including rock.

The gneissoid granite adjoining a vein, sometimes changes to a well-characterized mica schist, or becomes a micaceous gneiss. And occasionally the direction of the layers conforms in part to the direction of the vein. This fact is exhibited in figures 6, 7, 8, which represent sections of a vein along the shore nearly a fourth of a mile southwest of Valparaiso. Below or above the intersection, (sometimes both,) the laminae of the schist adjoining are curved to correspond with the angle of intersection; and in other parts of the figures, only a tendency to the same structure is apparent. But when the vein is

Fig. 8.



straight there is usually no conformity; yet a schistose structure is more distinctly developed alongside than is elsewhere apparent in the rock. The character of the lamination is apparent in the figures.

The veins when large, although entire in certain parts, become subdivided in others into several narrow portions, which continue on for a while, variously changing their size and course, and then reunite. The spaces between the strands often consist of mica schist or gneiss, like that adjoining the vein, and the schist is in general longitudinally laminated. In some places the mica schist is included in isolated masses, and from these there is a gradual transition to long parallel lines, which are sometimes broad, and either unbroken or interrupted at short intervals. These facts are shown in the figures referred to, in which the character of the rock is indicated. The limits of the two rocks, the feldspathic granite of the vein and the schist, are tolerably well defined, though sometimes united by insensible gradations.

The small interior veins, in the cases here explained, often appear like distinct veins running through gneiss or mica slate, as is seen in the figures.

One remarkable vein in the same region, has a longitudinal structure, and consists of eleven stripes of alternating quartz and gneissoid granite, although but a foot wide. (Figure 9.) It occurs in a dark-coloured granite approaching gneiss; and as the coating either side is rather soft and epidotic, its removal has caused the vein to stand out quite distinct from the inclosing rock. The alternations are as follows:—1, quartz, forming the centre;—2, a stripe of gneissoid granite on either side of the quartz;—3, another layer of quartz on each side;—4, a repetition of the gneissoid granite;—5, narrow stripes of gneiss;—6, external stripes of quartz, containing some epidote disseminated or in seams. The third of these stripes is less distinct on one side of the centre than on the other. Although the several component portions of this riband vein are distinct in their characters, yet there are no traces of a line of fissure separating the stripes; on the contrary they form a single solid crystalline mass, which would break as soon across the quartz as along the line separating it from the gneiss on either side. There are other examples of this structure in the same region, but none was observed with so numerous alternations.



Direction and Dip.—Allowing equal importance to all the veins, small as well as large, we could deduce from their direction only the fact that there is no prevailing course. But from the larger veins alone we arrive at results of some interest.

One of the largest veins observed runs along the coast for half a mile or more, commencing a short distance beyond St. Anthony's Castle to the southwest of the city; it is the same that has afforded the sections exhibited in figures 6, 7, 8. Its direction is southeast by south and northwest by north. Another vein in the same region follows a southeast and northwest direction. Over the hills south and southwest of the city, the feldspathic granite veins stand out in broken walls, the inclosing rock having been removed by decomposition and wear. Large veins not far distant run in a southeast by south and northwest by north course, and dip to the northward and eastward fifty degrees. Two veins in the same vicinity have a southeast by east and northwest by west course, and dip nearly with the preceding. Another vein, four feet broad, within a fourth of a mile of

the last, follows the same direction. Another, one foot wide, runs from south-southeast to north-northwest.

From these observations, it appears that the veins in this neighbourhood vary in direction from south-southeast to southeast by east, or north-northwest to northwest by west.

On the ridge back of Valparaiso, two miles west of the first Post House, there are numerous veins, and the general course is southeast by south and northwest by north, with a dip to the northwestward. Two other veins in the same region run in a northeast by east and southwest by west direction. Another has a south-southeast and north-northwest course.

The dip is very irregular; it is sometimes to the northeastward, and at others to the southwestward. The large vein along the coast, so often referred to, consists properly of two veins, crossing nearly at sixty degrees, and dipping in the two directions just stated. The line of intersection is a few feet above high-water mark.

Intersections.—The granite veins present some striking peculiarities at their intersections, and are also variously faulted. Figures 6, 7, 8, illustrate the crossing of the two large veins on the coast. In figure 6 the two veins are so united and commingled at their intersection, that it is impossible to say which one cuts the other. Indeed there is no actual intersection: the veins seem to combine in one, and then again to disjoin, and continue on their respective courses. Where united, the included *islets* of gneiss are very numerous and extremely irregular in form: and the small veins which are subordinate to the larger run around in the most eccentric manner, sometimes following a *zigzag* course, as the figure shows. A separate small vein may be seen coming up from the left and passing some distance into the veins at their junction, and then extending apparently into the upper right branch.

In figure 7, a few rods distant from where figure 6 was sketched, the veins are each divided into two portions or strands, and they intersect. One of these strands, *a*, distinctly intersects one in the other vein, but is itself intersected by the other strand of the latter; while the second strand of the former is intersected by both of the latter. These large veins occur on the surface of a cliff one hundred feet high, and the view includes about fifteen feet of the lower part.

In the third figure, (figure 8,) both veins, as they approach the intersection, become gradually narrower, with a curving outline; and where they cross, they have less than one fourth their ordinary width.

After intersecting, they again enlarge, and at nearly the same rate as they before diminished. At this place one of the veins appears to intersect the other.

These cases are examples from among many which the region presents.

Faults.—Faults at the intersection of granite veins by granite veins are of rarer occurrence than those in the line of veins of epidote; there are also a few faults along cracks which are not distinctly epidotic.

Faults may be found throughout the granite region wherever there are veins to be faulted. Along the shores under St. Anthony's Hill, beyond the Castle of the same name, is a good place for observing them. The same cliff below the lighthouse affords interesting examples of them. Sections along the road to Quillota, as it passes out of Valparaiso, are also good localities, and there are others on the elevation back of Valparaiso. At one place, in a vein two feet wide, there are four faults within a length of eighteen inches, as represented in figure 10. In another similar vein there were five faults in the same distance (figure 11). Figure 12 represents six faults in a distance of six feet, in a small vein, an inch wide, all of which are in the line of

Fig. 10.



Fig. 11.

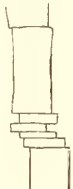


Fig. 12.

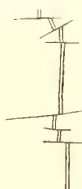


Fig. 13.



minute epidotic seams. Figure 13 is another example of similar faults. Along the line of the faults there are some epidotic stains, with distinct veins in many places. The walls of the rock in these seams (or apparent lines of fracture,) are smooth, and the rock of the faulted granitic vein consists of white feldspar and quartz.

In some cases the vein, besides being faulted, has its original direction changed. Such has been the fact with the left part of figure 14, the singularity of which can scarcely be described. On the right of the same figure another remarkable fault is represented, which has taken place at the intersection of two granitic veins: the separation by fault is about a foot; and the parts are still connected uninterruptedly by a narrow feldspathic vein (*m n*) passing obliquely from one part to the other in the direction of one of the intersecting veins, and in such

a manner as to appear continuous with the separated parts of one of the veins.

Fig. 14.

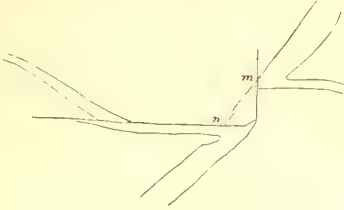
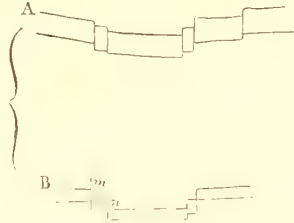


Fig. 15.



These faults, as exhibited in the sections, sometimes affect one of two contiguous veins, without affecting the other; or they affect the two differently. In figures 10 and 11, the two veins are but a few feet apart: yet in one, there are *four* faults, and in the other *five*; moreover, in the latter, one of the principal faults has a direction contrary to any in the former. Figure 15 is another example of the same fact: the vein A is about six feet above the vein B; and although so near one another, there is an additional fault in the upper vein. The lower vein is also remarkable for its oblique direction (*m n*) between the first two faults.

Besides the faults described, there are also interruptions in veins, where the parts of a vein are distant though parallel. Figure 16 represents one of the very many instances of this species of fault. The parts were never united, being separated by the intervening granite or gneiss. This example lies a few feet above figure 13, in which are faults of the ordinary kind. In figure 3, both faults and interruptions of the kind here described occur in the same vein.

Fig. 16.



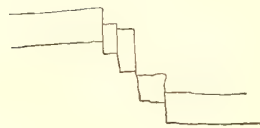
Origin of the Granitic and Epidotic Veins.

The two theories for granitic veins find many arguments for their support in the facts which have just been considered.

In favour of the theory of segregation, we observe—(a) that the ribband vein in figure 9, exemplifies a veined structure produced where there could not have been a separate injection of the seve-

ral bands. (b) The complication of veins and islets of micaceous gneiss in figure 6; the long line of the same micaceous gneiss in the material of the veins which graduate into the feldspathic granite either side; the irregular sizes of the intersecting veins, and especially the fact that the one below on the right is very narrow compared with its continuation above to the left;—all these points are unlike any described veins in volcanic regions. (c) The singular mode of intersection in figure 7, and the character of the included micaceous gneiss, its width much exceeding that of the granite strands either side, are peculiarities differing from known injected dikes. (d) The intersection in figure 8 presents the same difficulties, which are farther heightened by the singular subdivisions of the intersecting veins. (e) Again, there are seeming objections to the theory of injection in the singular faultings represented in figure 14, for there is no way of joining the separated parts so as to make them continuous; so also in figure 17, the parts are of unequal size, and do not fit one another;

Fig. 17.



in figures 10 and 11, which are but six feet apart and parallel, the faults are different in number and direction; and the same is true of A and B, figure 15. (f) Besides, the micaceous structure about the vein, in figures 6, 7, 8, must have been induced by the heat, if they are veins of injection, which is contrary to the deductions

of many geologists, who attribute the structure to a previous lamination arising from a sedimentary origin.

Several of the above-mentioned difficulties in the way of the theory of injection are only apparent. If in the faulting of a rock, there is a *lateral* as well as an *up and down* slide, that is, if the displacement from fractures is oblique, the several parts of a faulted vein, as presented on a surface section, should not necessarily have the same breadth; and besides, the faultings of adjacent veins, as seen on an exposed surface, might differ in number and direction. Even the peculiarities in figure 14 may be fully explained on this ground. The interruptions in figure 16 are understood if we consider that they may all connect with a single vein beneath the surface, just as wood which is widely cleft on one side may have the cleft show itself on the opposite side, in a few rents following parallel lines. The objections *e* are therefore of no weight.

The last objection (*f*) is merely imaginary, since it is now established that the schistose structure may be a result of the crystalliza-

tion of some schistose mineral: and although it may conform to the lamination of deposition in a metamorphic rock, this is not a necessary nor actual result under all circumstances.

The objections derived from the large vein represented in figures 6, 7, 8, will be found to lose part of their weight, when we consider the nature of the rock in which they occur, and the extent of the fractures and faults elsewhere indicated;—that the veins of granite at Valparaiso form a network throughout the rock, and are everywhere faulted and shifted in various oblique ways; and that the rock, a gneissoid granite, having but imperfect cleavage directions, would fracture in any way, though with some uniformity for the larger fissures, a uniformity which has been pointed out. In volcanic regions, the rocks are generally in layers, and the fissures are made a few at a time, or singly; and in granites intersected by trap dikes, the fractures are few and distant, showing by their comparative simplicity, even when most complex, that the rending the rock had undergone was simple in its character. But in the cliffs of Valparaiso, if there have been any fractures, the whole mass was broken in all directions, and the parts were made to slide upon one another very variously, some falling together again, and others opening irregularly. The diminution of the vein at the intersection represented in figure 8, might be a result of gravity in the various parts around; the fissures would be diminished, enlarged, or entirely obliterated in this way, in different places, as the veins exemplify in their many irregularities. If, then, the *smaller* veins indicate fractures, their great number and various characters are such that the *larger* veins should be of the very kind, as regards irregularity of size, that here exists. Their various subdivisions, separated by lines of micaceous gneiss, indicating several parallel fractures following one course, may have resulted from the rending action, (probably a lateral pressure and upturning,) which broke the rock so extensively, and smoothed, by rubbing together the surfaces of many fissures. Their direction was determined, like the direction of the larger veins, either by the structure of the rock, or the direction in which the force causing the fractures operated. The thinness of some of the seams, and the fact that they often appear as if they were only a variety of the granite which some cause had rendered more micaceous in lines, are the only objections to this explanation; and these, it seems, must give way before the other evidence.

We here assume that the greater part of the granitic veins, as well as the faults, belong to one period. Of this we have probable evi-

dence in their similar lithological character; this, however, is of little value. Better than this, we see direct proof in some of the facts illustrated by the preceding figures. Thus, in figure 15, A and B are parallel veins, as already mentioned, and are nearly parallel in their faultings, a fact which proves them to have been cotemporaneous in their faults. Yet in figure B, the interval between two faults (*m n*) is filled by an oblique seam, consisting of the same granite as the faulted vein, and evidently of simultaneous origin. We are compelled by this fact to admit that the fault took place before the injection, or at least before the fused material of the vein had cooled, and we are also required to conclude that the faults in figure A were of the same period. In figure 14, there is an instance of an oblique seam (*m n*) connecting two separated parts of a faulted vein, and the granite of the seam, as in the above case, cannot be distinguished from that of the vein; showing again that the faulting and the fracturing of the rock by which the vein was produced, were cotemporaneous results.

The complete coalescence of the two large veins in figure 6, at their intersection, appears to prove that they were filled at the same time. In figure 8, one intersects the other; but such a result may proceed from only a small difference in the time of filling. Figure 7 is wholly inexplicable on the supposition that the veins were not simultaneous in origin.

These facts, in connexion with the great similarity in the texture of the veins themselves, are reasons for believing that when the rock was fractured, there were displacements also; and soon afterwards the filling with granite took place. Such an amount of fracturing could not have taken place without much faulting.

The cotemporaneity of the veins and their faultings presents an argument against the segregation theory as regards these veins. For this theory would require us to suppose that faults of the different kinds explained may be a result of segregation. Crystallization when going on exerts an inductive influence around; but no facts authorize us in assuming that these faultings can be thus explained.

It is probable, also, that the epidotic seams either belong to the same epoch with the granitic veins, or are of subsequent formation. The walls of some of the granite veins are epidotic, and in these cases we must believe that the epidote could not have been subsequently ejected.

The lines of faults are the courses of epidotic seams; and if the faults are cotemporaneous with the opening of the veins, as many

must have been, the epidote could not be the result of a subsequent ejection from below. The question, therefore, comes up, were they formed by ejections, liquid or gaseous, accompanying the ejection of the granite, or were they the result of a subsequent heating of the rock, and some change by segregation along the lines of previous fracture or the walls of some of the granite veins? The inquiry also arises, how could a gneissoid granite become more micaceous and schistose adjoining an ejected vein, especially when this vein is more purely feldspathic than the rock either side? Epidote is not uncommon in the vicinity of trap dikes, where it has been formed by the action of the heat of the dike on iron, lime, silica and alumina, which ingredients are either all contained in the enclosing rock, or are derived in part from the heated trap. Towards forming the mica and epidote, there is some magnetic iron disseminated in the gneissoid granite. But we forbear offering any farther conjectures with regard to the steps in the process.

The objection to the view of ejection derived from the structure of the riband vein, is the only one yet unnoticed. It may be a result of segregation, similar in origin in some respects to concretionary nodules concentric in structure, but varied by the position of the material. Yet, possibly, this character has arisen like that of the dikes noticed on page 510; and the difference may be mainly due to that slow cooling which allowed, in the case before us, of the distinct crystallization of the material.

Direction of lamination in the micaceous gneiss near or within veins.

—The gneissoid granite has a schistose structure of its own, and this modifies, as figures 6, 7, 8, show, the direction of the laminated structure in the micaceous gneiss. This direction is farther modified by its relation to the positions of the two crossing veins of granite. The following deductions in view of these points are derived from the facts:

1. The micaceous gneiss enclosed within the veins, is laminated parallel with the direction of the vein. In this case the heat exerted its influence alike or nearly so on the two sides; and the vertical axis of the crystals of mica is perpendicular to the source of heat. At the intersection of the veins, the larger vein gave the character to the lamination (figure 6). Also, where the veins are nearly equal, the direction of the lamination at the intersection in the included micaceous gneiss was determined by that vein (other things being equal) whose heat exerted the greatest influence. In figure 7, the lamination at the intersection is nearly in the line of *a* or *b*, because *a*, *b*, are nearer

together than c , d ; but between d and e , for a like reason, the lamination is parallel with d . Thus, in each of the cases stated, the lamination is parallel with the source of heat, or in other words, the crystals of mica have the vertical axis at right angles to the source of greatest heat.

In the upper and under divergences of the intersection, the lamination is curved so as to approximate to parallelism with the walls of the converging veins—the source of heat. This is shown in figures 7, 8, and upper part of figure 6. In the lower part of figure 6, the veins are very unequal, and the consequence is that the lamination is parallel to the larger vein, and curves upward, and becomes nearly horizontal where it meets the small vein.

To the left of the intersection, the lamination is nearly at right angles with the lower vein, or is but little oblique. This appears to be determined, in part at least, by the original direction of the lamination in the gneissoid granite. To the right of the intersection, the lamination for a short distance is, in some cases, nearly parallel with the walls, and in others oblique, approaching to parallelism.

The facts lead us to conclude that while the original direction of the lamination in the gneissoid granite has influenced the position of the mica formed near and within the veins, the heat of the veins was the more efficient cause determining its position; and it tended to give the crystals or scales of mica a position parallel with the heated vein, (or such that the vertical axis of the crystal should be at right angles to it,) in consequence of which, the lamination has the same direction. The heat above and below the intersection would necessarily extend farther than on either side, and this may have been one cause of the greater influence in these parts.

Veins of Hornblende Schist.—(Figs. 1, 2, 3, pages 562, 563.) These veins, when small, resemble, in many points, the granitic veins. When large, they appear to form extensive beds. Whether injected or not in such a case, we have no facts to determine. The lamination parallel with the walls is seldom exemplified in trap dikes.

Decomposition of the Granite.

The hills of the sea-coast are much rounded, owing to the ready decomposition of the gneissoid granite constituting them. The rock is generally so deeply altered that it is difficult in any part to obtain

fresh specimens. In this decomposition, it may be observed that the feldspar first yields, becoming white and opaque, with a friable earthy appearance. The mica also, if black, is soon changed in colour to a rusty brown, owing to the development of the iron it contains, and it loses at the same time its elasticity and cohesion. The syenitic and hornblendic rocks of the region are more durable than the gneissoid granite. Mellaca Hill consists on one side of a decomposable granite, and on the opposite of a durable syenite. The rock on the ridge above Valparaiso is a granite containing very little mica. It is hastened in its alteration, or disintegrated, by the oxydation of magnetic iron, which is sparingly disseminated in grains or small veins. The feldspar shows little tendency to decomposition until minutely divided by the iron. The rock crumbles into a fine gravel, which has a red tinge from the oxyd of iron.

GREENSTONE, BASALTIC AND PORPHYRITIC ROCKS OF CHILI.

In the following account of these rocks, their modes of occurrence, characters and transitions are mentioned as they appeared along different routes pursued by us: we had no time for much exploration.

A league to the north of Valparaiso, on the road which follows the coast, two dikes of greenstone intersect the gneissoid granite. The greenstone in one of these dikes presents scarcely any traces of crystallization, and consequently no signs of its constituent minerals. It is soft and has a glistening lustre. The rock of the other dike, a few rods beyond, is similar to the first, but is more granular in texture, and contains light-green particles of some decomposed mineral, which appeared to be feldspar. It breaks with an earthy fracture. Numerous dikes in the Cuesta de Zapata, on the road to Santiago, afford the same variety of rock, and it is also abundant in the Cuesta de Prado.

This earthy greenstone often passes into a more compact rock, having the hardness of feldspar and an impalpable structure, as is observed in the Cuesta de Prado, where much of the greenstone is tough and compact. In the mountain back of Santiago we found a similar compact greenstone; and also a porphyritic variety containing small crystals of feldspar.

Mellaca Hill, at Quillota, in the valley of the Concon, is intersected

by a large number of greenstone dikes. Much of the rock is compact, without any traces of crystallization; and this variety in some of the dikes contains minute crystals of calc spar. The compact greenstone passes into a crystalline rock (diorite) of an olive-green colour, containing distinct acicular crystals of hornblende.

In the "*third cuesta*" on the road from Quillota to San Felipe, the following varieties were observed in dikes along the road.

1. A compact dark olive-green rock, breaking with a rough fracture. It is easily cut with a knife, and is translucent on the edges, in which respect, as well as in general appearance, it resembles serpentine.

2. A similar greenstone, a few rods distant, porphyritic with indistinct crystals of feldspar, which give it a dull spotted appearance. The disseminated crystals are about an eighth of an inch thick.

3. Near the last, a grayish-green rock with a smooth fracture and a few acicular crystals of hornblende half an inch or less in length.

In the "*second cuesta*," between Quillota and San Felipe, the rock constituting it undergoes remarkable variations of character. It is mainly composed of feldspar. Ascending from the southwestward, we met with:

1. A compact graystone, having a grayish colour, in some places becoming slightly reddish. It contains a little epidote, of a dull-green colour, disseminated through the feldspar base. It breaks with a smooth conchoidal fracture, and is rather tough.

2. A few rods beyond;—a similar rock, but having a coarser texture, and containing distinct crystals of feldspar and a few nodules of chlorite.

3. A few rods beyond;—the rock is more epidotic and contains a larger proportion of chlorite nodules: it is also more porphyritic than No. 2. The colour varies, as we proceed, to a brownish-purple.

4. Farther up the ascent;—the same rock as the last takes a brownish-red, or even a brick-red colour, and is delicately porphyritic; the epidote occurs crystallized in small geodes, an inch or so in diameter; and other geodes contain minute quartz crystals: these geodes are very numerous. The epidote crystals are about a fifth of an inch long, and have the usual pistachio-green colour.

This variety continues along for several rods, with little variation except in the shade of red colour, which in some places is very deep and brownish.

5. At the summit, the rock is brownish-black and very compact and

tough: it is sparingly porphyritic with small crystals of feldspar, and contains a little epidote.

On the descent to the northeastward, over the lower part, the rock becomes a gray porphyry; it is a compact rock, nearly impalpable in structure, having a grayish-blue colour and containing large crystals of feldspar. These crystals are half an inch or more in length and are very thickly disseminated; they are generally compound. The rock still contains a little epidote.

These transitions, here indicated, are a caution with reference to inferring a difference of age in the dikes of a region from their lithological differences; for here we have a number of striking varieties in a single ejected mass.

It appears that more or less epidote is disseminated throughout the whole; and where the epidote is most abundant the red colour of the rock was deepest. This corresponds with the fact that the epidotic seams intersecting granite veins occasioned a red colour in the feldspar adjoining them. The effect is undoubtedly due to iron. It is probable that where the rock of the cuesta, when it was in fusion, contained too much iron to be all taken up by the epidote, a portion remained free as an oxyd, and gave the red tint. Oxyd of iron and some lime are all that are needed, in addition to the elements of feldspar, for producing epidote.

The "*first cuesta*" between Quillota and San Felipe consists of trachyte, a white feldspathic rock having little lustre and a rough fracture. It has usually a slight tinge of red, and is traversed by numerous reddish lines. The rock is fragile, and in some places fragments cover the surface of the ridge.

Towards the top of the ridge, the colour becomes a dirty gray. At the top it passes to a dark green colour, and becomes porphyritic, and the rock then *resembles some of the porphyritic greenstones of other localities*.

The predominant igneous rock near the outlet of the Jaguel Valley in the Andes, east of San Felipe, is a gray clinkstone (or graystone), consisting apparently almost solely of feldspar. The more compact varieties have a fine texture without any disseminated crystals, and break with a smooth surface and a conchoidal fracture. It passes by gradual transitions to a gray porphyry, containing numerous small crystals of feldspar or albite; which of the two, was not satisfactorily determined. The colour varies little, except in becoming darker in some places. The texture of the rock is at times imperfectly granular.

One variety (properly amygdaloidal) contained small globules (or globular nodules) of quartz, thickly disseminated; and the globules were covered with a dark-green coating of chlorite or green earth. In this valley, loose boulders, apparently from the same rock, had a brownish-red tint, and were porphyritic with tables of feldspar about half an inch long and half a line thick.

The non-porphyrific graystone, above alluded to, when in worn pebbles, might be taken for an argillaceous rock; but by its transitions to a variety having a porphyritic character, its true nature was apparent.

On the ascent of the Andes near Santiago, the ejected rocks resembled many of the varieties described. Above, they became coarsely cellular in some places, and resembled a true lava, and red and purple shades of colour were common. The examinations were too hasty for minute descriptions.

The high ridge back of Santiago, which appears to have been one of the centres of eruption along the line of the Andes, is a sublime object in the Chilian Cordilleras, and especially when seen from neighbouring heights among the mountains. When about eleven thousand feet above the level of the sea, a deep valley lay between us and its declivities. For six thousand feet, there was one long ashy slope; so unvaried that even the sight of it seemed to produce the weariness of an ascent. Above, black rocks broke through a mantle of snow, in rude columns, some forming divergent groups, and others rising into turrets and crests.

Direction of the Dikes.—The dikes vary much in direction, even in the same ridge, and without a thorough study of the whole country, it is difficult to deduce any conclusions of interest.

One of the dikes, a league north of Valparaiso, trends southeast or south-southeast, and dips 50° to the northeastward. The other has the same course, with a dip of sixty degrees. These dikes are bounded on each side by a layer, a fourth to a third of an inch thick, consisting of a whitish argillaceous earth, which peels off readily. It is soft and crumbling, and resembles kaolin, and is probably the result of the friction against the granite walls produced by the injected greenstone as it ascended.

In the Mellaca Hill, the dikes run generally to the northwestward.

In the "third cuesta," near San Felipe, where the dikes are numerous, the course is almost uniformly southeast, varying occasionally to east-by-south. At one place there were six dikes, from eight inches to six feet wide, in a distance of twenty feet. The intervening

walls of granite were narrower than the dikes, varying in width from six inches to three feet. These dikes did not appear to have produced any alteration in the adjoining rock.

In the Jaguel Valley, a dike of graystone cuts through a red porphyroid sedimentary rock, and is changed nearly to a black colour adjoining the walls, while the red rock itself is deepened in tint.

STRATIFIED OR SEDIMENTARY ROCKS.

On the ascent of twelve thousand feet near Santiago, it appeared that the vast mass of the Andes consisted mainly of a conglomerate or earthy rock, having in many places the aspect of a porphyry, yet showing its composite character on a worn surface. The shades of colour were various, as red, yellow, gray, green, brown, purple, and several were sometimes in combination. The colour often varies at short distances, and occasionally a red colour or some other shade pervades a large part of a bluff vertically through several layers, without much lateral extent, or any appearance of its being connected with the stratification. The rock also appears to pass through very dark shades nearly to black.

The structure of the rock varies from a coarse conglomerate, composed of rounded pebbles, twelve to fifteen inches in diameter, to a fine argillaceous deposit, more or less schistose; and between these extremes, there is every possible variety. The pebbles of the conglomerate are imbedded in a base which appeared to be argillaceous; in some kinds the pebbles are closely compacted together, and in others they are scattered through this base. In the latter case, it is often difficult to distinguish the rock from a true porphyry, especially as the base often contains disseminated crystals of feldspar, and the pebbles may not be apparent on a surface of fresh fracture. A rock of this kind is used at times for a flagging-stone in Santiago, and unless carefully inspected, it would be set down at once as a red porphyry.

The pebbles are as various in composition as the rocks of the mountains, consisting of different kinds of porphyry, porphyritic greenstone, graystone, trachyte; besides, there are others which have an argillaceous appearance: these may be portions of the above-mentioned rocks half decomposed.

The rock sometimes assumes a hard compact structure and fine granular texture; and again it is soft and tufaceous in aspect. Some

varieties on the mountains contained a kind of jasper in broad imperfect veins, resulting apparently from the action of heat.

The stratification of the rock is often distinct, but observations on this point should be extensive to be of much value.

No fossils were observed excepting lignite. This occurs in the Jaguel Valley in a fine conglomerate, consisting of argillaceous and porphyritic pebbles of different colours, half an inch in diameter and smaller. The locality is situated high up on a steep acclivity, bounding the valley on the south, and according to our estimate, is four thousand five hundred feet above the sea. The place was too much buried in soil to be uncovered in the few hours of our visit to it; but specimens lay around, some of which were imperfectly bituminous coal, and others were very argillaceous. Some coarser varieties contained thin chalcedonic seams. A few specimens of the conglomerate were found with the lignite imbedded. The purer lignite burnt freely with an empyreumatic odour.

The silicified wood of the Andes is said to occur in a similar conglomerate; but whether it belongs to a single epoch, or, as is more probable, to different periods, has not been satisfactorily determined. It occurs in the form of agate, jasper and hornstone, and generally retains well the texture of the original wood. The external surface is often bleached by exposure, and sometimes in this way is made to resemble bark. One specimen obtained had been bored by some insect or worm before it was petrified. About two miles from the Post House, eight miles east of Valparaiso, there are numerous fragments of silicified wood, and among them part of a trunk of a tree, two feet in diameter and fifteen inches long. From their position, it was evident that they had been transported to their present place since they were silicified. A single specimen of similar fossil wood was met with on the hills just south of the Concon, twenty-five miles north of Valparaiso.

The copper mines of Chili are connected with the dikes and sedimentary rocks of the Andes. In our hasty glance at the copper mine of the Jaguel Valley, we observed that the vein occurred in the claystone or sedimentary rocks, near an intersection of it with a compact clinkstone, and passed also into the clinkstone. The dike is about six feet wide, and runs nearly northeast and southwest. The claystone has a dark greenish-brown colour, and resembles a wacke.

It is much fissured, and the surface and seams for a hundred feet from the vein are green with chrysocolla, or siliceous carbonate of copper, which mineral occasionally occurs also in botryoidal concretions.

The lode was apparently a string of nests or interrupted seams. The immediate gangue consisted of calc spar and quartz. The ore which occurs at the place is mostly the sulphuret of copper or vitreous copper ore; besides which there are the variegated and gray copper ores, and some carbonate of copper in addition to the chrysocolla. The occurrence of native copper is always considered a bad sign among the Chilian miners, as it is supposed to indicate that the mine will soon run out; and they say that it is generally associated with much red oxyd of copper.

This mine is situated on the steep slope of a ridge, nearly two thousand feet above its base, and eight hundred from the top. The excavations have been carried on nearly four hundred feet into the side of the mountain; formerly the mine was productive, though yielding little at the time of our visit.

The limited time in Chili was too short for any farther examination of its mines.

The coal mines of the country were also out of our limits. They are described as extensive and valuable. The principal that have been opened are situated near Talcuhanu, in Arauca, on Chiloe, and at Penco near Valparaiso. The coal is good for ordinary purposes, and is used by the steamers of the coast; but it contains too much pyrites to be employed in smelting ores. A specimen examined by Prof. Walter R. Johnson, contained 67.62 per cent. of fixed carbon.

The beds are believed to be of the tertiary epoch, and therefore promise to be less productive than if of the older carboniferous formation.

CHAPTER XIV.

GEOLOGICAL OBSERVATIONS ON THE VICINITY OF LIMA, PERU.

FAR to the north and south of Callao, the sea-port near Lima, there stretches a broad plain, which extends to the foot of the mountains, six to ten miles from the coast. Thence it continues winding among the ridges, till the valleys begin to take their mountain character. The city of Lima, situated about seven miles from Callao, lies just under a ridge, which is the first outlier of the mountains. This plain, though in appearance nearly level, has a gentle inclination towards the sea, and the city of Lima has been determined barometrically to be at least five hundred feet above the ocean's level. North of Callao the sea-coast is low, and the land rises slowly from the water; while to the south, the sea-beach is backed by a cliff fifty feet in height, consisting of alternating beds of clays and sand. This cliff, as appears in a view from the harbour of Callao, extends to Rocky Point, twelve miles to the southward.

Beyond the plain, to the eastward, the ascent of the Andes commences by a very gradual rise. These lofty mountains, about eighteen thousand feet in height, have a heavy massy character in the view from Callao; the outline is slightly undulating, without a peak to add boldness and effect to its sublimity. One single summit was seen rising a little above the general range, and this alone was covered with snow. The mountains elsewhere were wholly bare. Though loftier than the Chilian Andes, the view from the coast certainly falls short of the latter in effect; and I am informed by Dr. C. Pickering, who ascended from Lima to the summit, that he met with no scene which equalled in grandeur that of the Santiago heights.

The plain which borders the sea, where not wholly a waste, is covered with only a scanty growth of vegetation. Yet it is abundantly productive where supplied with moisture. It is well known that it never

rains at Lima, though dense dripping mists are not unfrequent; and this aridity of climate is still more remarkable to the south over the province of Atacama, which is a perfect desert. We have already alluded to the cause of this dryness;* and we perceive from it, that the Andes have, to a great extent, protected the lands to the eastward from the fate that has befallen Africa, besides supplying from their snows a great number of streams. This chain, therefore, though many a city may have been laid waste by the earthquakes and eruptions it has engendered, is a blessing and not a curse to the continent.

RECENT DEPOSITS OF THE COAST.

In the cliff south of Callao, the geological constitution of the plain above is finely exposed to view. This cliff varies in height from forty-five to sixty feet. On measurement with a line at one place, it was found by the writer to be forty-eight feet high, which is hardly below the average elevation.

The material of the cliff consists of layers of sand, more or less argillaceous, alternating with others of an impure clay, and others of coarse pebbles. None of it is indurated into a coherent rock. The lowest layer is a bed of coarse gravel, with rounded stones often eight or ten inches in diameter. The pebbles are identical in character with those now forming the beach, being rolled fragments of the various rocks of the mountain. Above this, the layers are mostly of sand or clay, though sometimes pebbly.

The first above the lowest is argillaceous; and generally yellow or ochreous in colour, varying to a reddish or purplish tint. It contains, especially in its lower part, large stumps and branches of an exogenous tree, the wood of which is soft and mostly blackened, though not carbonized. The largest mass of wood observed was two feet in diameter, and several were six feet long. Others were mere twigs. The branches were commonly flattened, from pressure, to a thickness but a third or a fourth of the breadth. They lay scattered through the clay without any regularity; and neither roots nor leaves were observed with them. The fragments are so small, in some places, that they give the clay a mottled appearance when broken.

The same layer is penetrated with irregular cylindrical stems, resembling twigs of different sizes, from an eighth of an inch to an inch in diameter, though generally ranging between a fourth and half

* Page 455.

an inch. They are extremely numerous, often but an inch apart, and are almost always vertical, or nearly so, in position. Occasionally they branch so as to resemble a small twig. They appear to be concretions that were formed about the fibres of the roots of some grass. A grass is now growing above the cliff whose numerous rootlets might give rise, under the same circumstances, to a similar appearance. In some instances a vegetable structure or half decomposed wood is found at the centre of the concretion: yet, in the greater part, the structure is arenaceous throughout, and imperfectly concentric. Oxyd of iron is the cementing material in some, and may be in all. The yellow and brownish rings of colour, derived from the oxyd of iron, often resemble in appearance decomposing wood. A solution of iron appears to have trickled down the roots in the soil, and cemented the sand around them.

The wood in this layer often contains gypsum disseminated through it in slender transparent crystals. These crystals are occasionally an inch long; they are perfect in their faces and extremities, and have a brilliant lustre. Some specimens, in which the colourless transparency of the gypsum contrasts with the black wood, are quite beautiful. They usually lie in the direction of the woody fibre, though sometimes otherwise when the crystals are clustered. The form of these delicate crystals is the simplest presented by the mineral. They are often cruciform, as in the annexed figures, but none of the

Fig. 1.

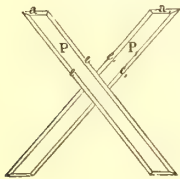
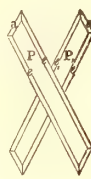


Fig. 2.



arrow-head twins were observed. Similar crystals occur occasionally in the clay adjoining the wood. This gypsum is evidently derived from sea-water, which always contains a small proportion. The wood is frequently wet by the spray of the present seas; and when the water dries it deposits its sulphate of lime and common salt. The latter is liable to be dissolved out by fresh waters, while at the next wetting with salt, the gypsum crystals thus begun would enlarge. This process continued for a time would produce an abundant deposit of crystals of gypsum.

The nature of the wood here buried has not been determined. Dr. C. Pickering suggested to me that it might be the recent willow (*Salix Humboldtiana*) so common in wet places in Western Peru: but this is a mere conjecture.

The upper layer of this cliff, which is from four to five feet thick, contains large numbers of the recent shells of the coast, and the same are strewn abundantly over the plain above. The species are the common shells of the present beach, as already described by Darwin. They are but little altered in appearance, and some are still covered with the epidermis; yet they are generally brittle and many of them may be crumbled in the fingers. Numbers of them have the appearance of having been much worn by the action of the sea on a beach.

This layer also contains brick and tiles or pottery-ware, in small fragments, and in great abundance. With them I found also the jaw of a dog.

On the island of San Lorenzo, there appear to be no remains of the recent formation which has been described, except we include as such, beds of shells near the shores, eighty or eighty-five feet above the sea. These shell beds, described with characteristic accuracy and detail by Darwin, lie in the sandy soil instead of forming a distinct layer, and contain the same shells as observed in the Callao cliff. I collected twenty-two species, several of which differ from those procured by Darwin. A *Crepidula* was by far the most abundant shell, as well here as in the cliffs alluded to.

A few shells were found scattered over the hills of San Lorenzo nearly to their summits, which might have been driven there by the winds, or carried by birds.

Towards the northeast point of the island, along the shores, there is a stratified bank of sand and pebbles with fragments of the slate rock of the island; it is situated at the head of the present beach, about fifteen inches above high water mark. The height of the bed is seven feet. The lower layer consists of rounded stones, two to four inches in diameter, with numerous shells similar to those of the shores; the next above is a layer of sand with pebbles and small fragments of slate, about four feet thick; then follows a layer of coarse gravel, thickly abounding in shells of the species *Purpura chocolata*, with a few other species, the *Purpura* being the principal shell: they have the worn character of beach specimens. The upper layer of this bank is composed of fine earth, from the decomposition of the

rocks of the island. This stratified bank differs much from the irregular bed before described.

The collections of shells with tiles and pottery over the plain south of Callao, as well as the beds eighty or eighty-five feet above the sea, on San Lorenzo, have been adduced as proofs of an elevation of this part of the South American coast. This argument is urged with force and discrimination by Mr. Darwin in his Geological work on South America. My own observations have been confined to so small a part of the coast, that any opinion here expressed is entitled to but little weight, especially as I am unable to draw comparisons with the beds in other portions of the western coast alleged as similar in character. I may, however, frankly confess that the evidence does not seem to me to place the question beyond doubt.

The following are the sources of doubt which have occurred to me from the examinations I have made.

1. The occurrence of the San Lorenzo shells in an irregular bed, spread out just beneath the soil or in it, and not at all stratified.

The action of the ebbing and flowing sea upon a sandy shore, arranges the material to some extent in layers, often of extreme delicacy when the material is fine. A section of any sea-beach proves this to be a general fact. And when the material is coarse, a tendency at least to regularity is apparent. But on San Lorenzo, we find none of this kind of evidence to prove that the land at the present height of eighty or eighty-five feet was for a time a sea-beach within the recent period supposed. The arrangement of the shells affords no proof in favour of such an hypothesis, neither does the position of any sands, pebbles, or stones in the vicinity. The hypothesis that the land was undergoing a slow elevation, would not alter the case. Moreover, the view of Mr. Darwin implies (perhaps, however, it may not necessarily require) that the shell-bed level was the sea-shore *for a period of time previous* to the elevation, and not merely during a rise of the land.

2. The absence of an inner cliff on San Lorenzo.

Some traces of two or three terraces have been said to exist around San Lorenzo. I observed nothing that I could confidently refer to as of this kind. There is an appearance of terraces; but it is slight, and may be attributable with more reason to an occasional harder layer in the sandstone rocks, which causes it to stand out and give protection to others below for some distance, while those above were

worn away. If the sea had acted upon the land at a higher level than at present, even for a short period, we should suppose that with so yielding a rock, cliffs would have been formed. Eighty feet is above the height of the present cliffs on the side facing Callao. These cliffs, moreover, would have continued in a good state of preservation, at least as long as shells could have preserved their freshness in so exposed a situation; and especially in this dry and warm climate, where there is no debris formed by frosts and little by water, and where also the progress of decomposition or disintegration is for the same reason very slow. There is not a gully for a streamlet over the whole of San Lorenzo, because there is no water to wear one out; the surface is singularly smooth from the summit to the shore cliffs, the only interruption arising, as stated, from occasional harder layers, which project and mark the declivities with a few horizontal lines. It is argued that during an elevating movement such cliffs would not form. But we have observed that we cannot rightly infer from the facts that the land did not stand for a period at eighty-five feet below its present level. If this is not admitted, the shells are evidence of a greater elevation than eighty-five feet. And again, if the rise was a very slow and gradual one, we cannot be assured that in a rock so yielding, (as will be soon described,) cliffs would not form to an extent that would not have been obliterated in a few centuries.

The occurrence of relics of Peruvian ware, thread, &c., with the shells, is easily accounted for on the supposition that the shells were accumulated by the Peruvians themselves; and this is rendered by no means improbable when we remember that shellfish are an article of food among all natives living upon a sea-coast. I am confident that the question ought to be oftener asked, whether human means might not have made heaps and beds of shells over land in the neighbourhood of the sea. The natives of Patagonia pile up the refuse shells at the entrance of their huts until they close the entrance, and are compelled to change their residence. The New Zealanders formerly carried basket-loads of shells to the interior whenever they made a journey to and from the sea-shore; and the only reason this is not now continued to the same extent, arises from their living at the present time upon potatoes and Indian corn, which are of comparatively recent introduction.

A rush of waters over the land, such as is occasioned at times by an earthquake, is another cause which might be, and has been, appealed to, to explain the facts before us. The ruins, consisting of

brick and tile and pottery-ware, south of Callao, might lead us to infer that some native settlement had there been devastated. The occurrence of the shells on San Lorenzo in an irregular bed might thus be better accounted for than by the slow action of a beach. Yet we do not feel ready, without farther examination, to attribute the effects to this cause. Mr. Darwin infers that the shells and tile south of Callao were mingled together by this means, but that the land was probably at a lower level (eighty-five feet), to allow of the effect being produced.

The stratified beds, forming the cliff of the shores, south of Callao and the plains back, leave us no room for doubting that an elevation has at some time taken place, of at least fifty or sixty feet, since these beds were deposited probably over a low region which was either permanently or occasionally submerged. But to fix the time when the change of level took place, may require some farther attention than the facts have yet received.

SECONDARY ROCKS OF SAN LORENZO.

The island of San Lorenzo, about seven miles off the shore of Callao, is a narrow, elevated ridge, five miles long in a northwest and southeast direction, and averaging one mile in breadth. On the side fronting the ocean, the cliffs are abrupt, and a hundred and fifty feet or more in height. On the opposite side, they are from fifty to ninety feet in altitude, and alternate with low beaches; and above these cliffs, as already stated, there is a narrow and more or less uneven plain at the foot of the southeastern declivities of the ridge. The northern summit of the island was found, by the barometrical measurements of the officers of the Expedition, to be twelve hundred and eighty-four feet in elevation, the middle nine hundred and twenty feet, and the southern eight hundred and ninety-six feet.

The rocks are either sandstone or argillaceous shale, and they are various in shades of colour, and frequent and abrupt in their alternations. Their decomposition has produced the thin coating of arid soil which covers the declivities.

The stratification is neatly distinct in the cliffs, and may be detected over the sandy slope above, in an occasional horizontal dark line of rock. The colours of the shales vary from a deep red, through grayish, greenish, purplish and bluish shades, to a dark blue-black: and these several colours often succeed one another in the course of a

few feet. Indeed, the rapid transitions from one colour to another, and also from sandstone to shale, are a prominent characteristic of the rocks of the island. The sandstone layers are also various in tint, being of gray, whitish, and light reddish shades. In texture, they are mostly fine, though occasionally pebbly, and they often pass insensibly into the argillaceous shale. Lines of deposition are usually very distinct, occurring every ten or twelve inches, and generally at shorter intervals. The sandstone is mostly rather fragile, and has a sandy surface; the shale falls into small chips on exposure, or upon being struck with a hammer.

The following details of sections exposed, will give an idea of the frequent and abrupt transitions in the rock, and the riband colours which the cliffs exhibit. The first (fig. 1) was taken down on the

Fig. 1.

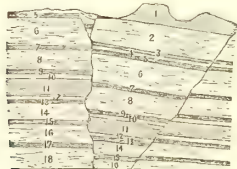
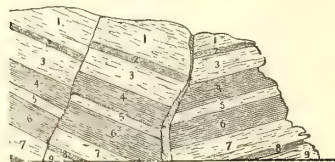


Fig. 2.



north shores, and the whole height is about one hundred and eighty feet. The view represents also the faults which intersect the cliff. Beginning at the top :—

1. { 24 feet.—Shale ; purplish and bluish.
3 feet.—Shale ; yellow.
15 feet.—Shale ; bluish, nearly black below.
2. 40 feet.—Sandstone ; light grayish-red.
3. 3 feet.—Shale ; light shades of blue and purplish.
4. 6 feet.—Sandstone ; light grayish-red.
5. 5 feet.—Shale ; light purplish.
6. 25 feet.—Sandstone ; light grayish-red.
7. 3 feet.—Shale ; light bluish.
8. 24 feet.—Sandstone ; light grayish-red.
9. 2 feet.—Shale ; light shade of colour.
10. 2 feet.—Sandstone ; light grayish-red.
11. 12 feet.—Shale ; mostly dark blue ; upper four feet and lower foot very light coloured.
12. 1½ feet.—Sandstone ; light grayish-red.
13. 1 foot.—Shale ; light bluish.
14. 7 feet.—Sandstone ; light grayish-red.
15. ¾ feet.—Shale ; light bluish.
16. Sandstone ; grayish-red.

In this short space of one hundred and eighty feet, there are eight layers of sandstone alternating with shales of different colours.

Figure 2 represents another cliff, the height of which is but forty-five feet. It is situated a short distance to the north of the harbour, on the east-northeast side of the island. The following alternations were there observed, commencing above:—

1. 15 feet.—Sandstone ; grayish.
2. 2 feet.—Shale ; light bluish.
3. 10 feet.—Sandstone ; grayish.
4. 4 feet.—Shale ; bluish above, in other parts red.
5. 1 foot.—Sandstone ; grayish.
6. 5 feet.—Shale ; mostly red, dirty yellowish above.
7. 7 feet.—Sandstone ; grayish.
8. 1 foot.—Shale ; light bluish.
9. Sandstone.

Such alternations occur everywhere through the island.

In some places, however, there is a cliff of eighty feet, consisting wholly of shale, as may be observed a short distance north of the cliff just described, where the following varieties of shale were noted down.

Eleven feet, dirty yellowish and brownish ; nine feet, alternations of whitish with brownish and yellowish ; twenty feet, dark bluish ; fifteen feet, dull greenish ; twenty-five, dark bluish shale.

The cliff at the northern point of the island consists of a dark, compact blue-black shale, passing into a fine schistose sandstone.

The colours of the sandstone are sometimes arranged in parallel stripes, and frequently in concentric curves. The red bands thus formed are very distinct on the worn stones of the beach. They indicate a concentric structure in the arrangement of the colouring ingredient—the oxyd of iron.

Structure.—One of the most striking characters of this rock is the regularity of its fissures, producing, in some cliffs, vertical planes of fracture, of uniform character, through a height of a hundred feet. In a distant view, the rocks intersected by these vertical fractures have much resemblance to basaltic rocks. They were most distinctly of this character at the northern point of the island, though observable also elsewhere.

There are generally two systems of fissures, dividing the rock into rhombic fragments ; and sometimes another cross fissure occurs,

giving rise to hexagonal prisms. The following directions were noted down.

1. Southwest, and south.
2. Southwest one quarter west.
3. Southwest-by-west and east-southeast.
4. West-by-south one quarter south and south-by-west.
5. West-southwest one quarter west, and south one quarter west.
6. West-by-south and south-by-west.
7. Southwest and south-by-east.

There appear to be two prevailing directions, one about west-southwest and the other south; while a third is sometimes apparent running east-southeast. Some of the fragments are quite regularly six-sided; in other specimens the rhombic prisms afforded angles of sixty to seventy degrees, while at one locality the angle was about eighty degrees.

Dip—Faults.—The rocks of the island dip variously, yet the directions are in general subordinate to an inclination, not exceeding twenty degrees, to the southwestward; the layers consequently have the greatest elevation on the side towards the main land.

The variations in the dip from this general course, have arisen from numerous fractures of the island, which have produced faults in the stratification. Four of these faults have been represented in the two figures just given; and they sufficiently illustrate their general character. The fault to the left (or south) in the second of these figures, amounts to five feet, and the rocks on the north side are the most elevated. The dip on the two sides remains the same, and amounts to about twenty degrees to the west-by-south. In the other fault, the rocks to the north have been uplifted ten feet, and received a dip of eleven degrees to the southwest. A fissure between the two separated parts is filled with fragments of sandstone and shale, which in some places are cemented by carbonate of lime.

Along the same coast, farther to the northward, where the eighty feet of shale occur, there is a fault of much greater extent. This shale is horizontal in position; just south, there is a line of fault, beyond which the dip is that mentioned at the close of the preceding paragraph. The amount of displacement is at least fifty feet, and it may be more, as there is some uncertainty whether any of the shale to the north of the fault is represented by that to the south. This fault appears to be traceable above to the very summit of the island, where

its course is indicated by an imperfect ravine or ditch. This cliff of shale extends north for a few hundred feet, with an even altitude, and then there is another fault, beyond which the beds dip eighteen degrees to the southwest-by-west.

Passing farther northward, just to the southeast of the north peak, the rocks dip sixteen degrees to the southwest-by-south; and the layers of the peak itself dip ten to eighteen degrees to the southwestward.

Of the faults represented in figure 1, the most northern exhibits a dislocation of twenty feet, the rocks on the south side having subsided: the fissure formed has been filled by the comminuted material of the adjoining layers. In the other fault, the layers on the south side have been raised one foot.

If we may infer the total number of faults in San Lorenzo, from those observed in the northern third of the island, it cannot be less than *thirty*; and if this be no exaggeration, we have evidence that this small ridge of rock has been rent into thirty pieces or more. All the parts still remain together, only a little displaced. Yet on the south, there is an islet called the Fronton, with a few intervening rocks, which appear to be disjoined fragments from the main ridge. As a general rule, the rocks on the north side of the faults have been most elevated by the displacement. The period of this fracturing remains undetermined. The only facts bearing upon the subject are, *first*, the smooth surface of the island, showing that sufficient time has since elapsed to smooth over its broken features; and *second*, the calcareous cement which unites the broken fragments in the fissures, are additional evidence that the rocks were under water for some time after the faults were made.

Fossils.—Fossils have been observed in the San Lorenzo rock by different travellers.* In the few rambles by the writer, three species were detected. Two of them, a Turbo and a Trigonina, occur in a single layer of the gray sandstone, one to two feet thick, at different places on the coast fronting northeast, just above high water. The third species, a large compressed Nautilus, was found under the northern peak of the island among the loose stones on the shore. From the species, it is quite probable that the deposits should be referred to the Oolitic era. The unbroken condition of the bivalves renders it altogether probable that the rock containing them, an argillaceous sandstone, was originally the bed in which they lived.

* See American Journal of Science, xxxviii. 201, 202.

Minerals.—Gypsum, common salt, calc spar, quartz, pyrites, and oxyds of iron, occur in the San Lorenzo rocks; and besides these, coal is reputed to form thin layers on the south side. The salt forms thin seams in the shale and sandstone, and the gypsum occurs both in seams and crystallized in fissures. At the shale cliff of eighty feet, already alluded to, the gypsum intersects the rock in every direction, and so numerous are the intersections and flexures, that the shale is cut up by the seams into small angular pieces. The shale often drops out on exposure, leaving the plates of gypsum projecting, and the surface of the cliff in this case appears honeycombed.

These seams or plates are usually less than an eighth of an inch thick, though occasionally half an inch, and sometimes an inch. The thinner are fibrous, while the wider often contain handsome geodes of crystals. These crystals are from a third of an inch to an inch in length, and are brilliant in lustre and perfect in form. Some of these geodes contain several square inches of surface covered with fine crystals, and would be an ornament to any cabinet. The rock is, however, so brittle that great care is required to preserve them from injury.

The calc spar and quartz form occasional veins in the rock. Iron is abundant as a colouring ingredient, and occasionally the magnetic and red oxyds occur in narrow irregular seams. The observatory established on the island for the Expedition, was afterwards removed to the main land, because the needles were affected by the iron of the rocks.

The facts relating to the occurrence of gypsum in the buried wood and clay of the recent shore-deposits south of Callao, afford us an explanation of the circumstances on San Lorenzo. The gypsum has been formed in cracks which previously intersected the rock, and probably by the evaporation of sea-water.

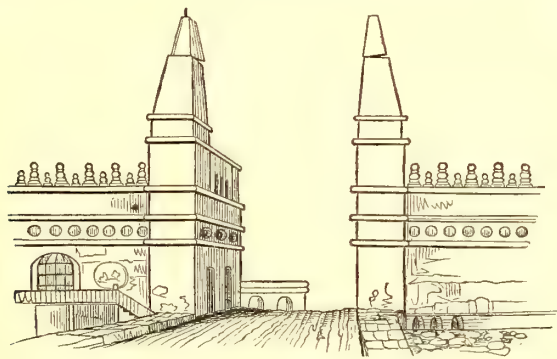
Extent of the Formation.—The extent of the San Lorenzo formation, or its relation to the rocks of the Andes, has not been made out. Immediately beyond Lima, the ridges consist of granite and syenite; and according to Dr. Pickering, the same rocks prevail to a great extent over the forty miles to the eastward. The San Lorenzo sandstone constitutes a point twelve miles south of Callao; and the island of Pachicamac, twenty-four miles south, has the same constitution. Specimens from the latter place, consisting of red and gray sandstones, and red, gray, whitish, and dark-blue argillaceous shales, were procured by Lieutenant Knox of the Expedition.

CONCLUDING REMARKS ON THE GEOLOGY OF PERU.

The occurrence of gypsum in connexion with sandstones upon the Andes has long been known; and Dr. Pickering observed large quantities of it at Baños in the Chancay Valley, fifteen thousand feet in elevation, which he was informed had been brought from Casa Cancha, fifteen miles to the southward, along the summit of the mountain. Sandstone and shale resembling that of San Lorenzo were also met with; but the sandstone was in part a conglomerate, or contained small pebbles. About two leagues southwest of Casa Cancha, an Ammonite was found by Dr. Pickering, imbedded in an argillaceous rock, which is described in the Appendix.

From the pebbles of the Callao beach, it appears that the same porphyritic sand-rocks and conglomerates occur here as in the Chilian Andes. Many of them so resemble porphyry in colour and disseminated feldspar crystals, that it is with the greatest difficulty they can be distinguished. Usually some imbedded pebble may be detected, though often faintly, and this is the only evidence of a conglomerate or composite character. They afford an example of a rock made of porphyry earth and pebbles, altered by heat so as to imitate very exactly a true porphyry.

Effects of an Earthquake.—Many instances of a rotation of the blocks of columns by earthquakes are on record. Yet the subject is one of sufficient interest to authorize this allusion to a fine example of it in Lima, represented in the sketch here given. This is but one



among many examples; for Lima is properly a city of ruins, owing to the earthquakes it has experienced. Walking through the city, we observe scarcely a spire which has not thus lost something of its

height, or been stripped of some of its architectural ornaments. The instance here referred to occurs at the entrance to a large square, called *El Paseo de los Agoas*, constructed long since as an artificial basin within the city, for boat fights and racing. The tips of the various ornaments along the wall are much broken, and the two obelisks adjoining the entrance have the upper stone on each displaced, and turned around on its axis about fifteen degrees in a direction from north to east. To understand some points in the drawing, it should be remarked that the entrance-way is not at right angles with the wall, but a little oblique; and moreover, the obelisks are not equilateral, neither are they similar, though both are three-sided.

These rotations by earthquakes have been attributed by some authors to an actual rotary movement in the earthquake vibration. But it has lately been shown by R. Mallet, that this hypothesis is untenable and unnecessary.* As this author states, a simple vibration back and forth is all that is required to produce a rotary motion in a stone of a column, provided that stone be attached below more strongly on one side of the centre than on the opposite. This may be proved by trial. Another explanation occurred to the writer when viewing the place above described, and it may be deserving of consideration. It is admitted that in an earthquake vibration there is a line in which the action is most intense, and either side of this line the force gradually diminishes as we recede from it. Consequently any object within the range of the earthquake will feel less force on one side than on the opposite, unless it be situated directly in the centre of the track; and hence a rotation might result. If among the rotations of a single earthquake they are indiscriminately right and left, Mr. Mallet's theory must be the true explanation. But if there is a uniformity in direction, over a large area, the latter would find some support.

* Phil. Mag., xxviii. 537, June, 1846; and Am. Journ. of Science, ii. Ser. ii. 270.

CHAPTER XV.

GEOLOGICAL OBSERVATIONS ON THE VICINITY OF NASSAU BAY, TIERRA DEL FUEGO.

NASSAU BAY forms a large indentation in the southern coast of Tierra del Fuego, a few miles to the west of the meridian of Cape Horn. It is about twenty-five miles deep and averages twelve in width. It is partially protected from the influx of heavy seas by several large islands at its mouth, among which Cape Horn is the southernmost, and Hermite Island has the largest extent.

The coast of Nassau Bay presents a succession of deep coves, bounded, with few exceptions, by rugged rocks, which are usually precipitous except at the heads of the coves, where there is generally a convenient landing-place for boats. There are many islands scattered over the bay; and these with the mountain scenery of the coast make the harbour one of the most beautiful in the world. The hills either side of the entrance rise into rude conical peaks of rock, or ridges of broken outline. A few miles to the southwest, the mountains, though scarcely three thousand feet high, have a cold, wintry aspect; and over the expanse of waters at the head of the bay, stands a loftier ridge enveloped in snows.

One of the principal coves of Nassau Bay is styled Orange Harbour. It is situated on the western side of the bay, under the lee of Burnt Island. Here our vessels were anchored, and in its neighbourhood I spent the only day I had ashore.

The surface of the country, as far as examined, is a constant succession of hill and valley. The hills have smooth green slopes below, but usually rise into a ragged rocky crest. The valleys as well as the side-hills are covered with a great depth of rich soil, supporting a dense growth of vegetation. The plants are mostly alpine, and instead

of expanding their stems and branches like the vegetation of warmer climates, they form a matted turf over a great part of the region. This turf is a foot thick, and is often dead below while green and flourishing above, resembling, in this respect, many mosses. It springs underfoot like the mossy surface of swampy grounds, and is actually soaked with water though appearing dry: a cane may almost anywhere be run down to a depth of three or four feet. Over much of the country there is a thick layer of imperfect peat below the vegetation of the surface. Besides the smaller plants, a considerable part of the country is overgrown with stunted trees from six to twenty feet high.

The moisture of the soil is derived mostly from the melting of snows, which cover the country the greater part of the year. There are frequent pools of water standing in the valleys and on the elevated plains, and they are remarkable for having a rectangular or polygonal form as if works of art, and resembling the ponds often made in peat marshes. The vertical sides of these ponds arise from the depth of the turf and peat below. Their straight outline is explained with more difficulty.

Rocks.—Along the coast from Orange Harbour to the head of Nassau Bay, there is a series of stratified deposits, which are here and there intersected by dikes of igneous rocks. The latter generally form the summits of the hills.

Sedimentary Rocks.

The stratified rocks are parts of one formation, and consist of a fine-grained argillaceous shale, alternating with a sandstone more or less argillaceous and a coarse conglomerate. The predominant colour of the shale is a dark bluish slate, which varies to a dull green. It cleaves readily into layers from a fourth of an inch to three or four inches thick, and is easily scratched with a knife. It passes insensibly into an argillaceous sandstone, having generally a dark dirt-brown colour, and consisting of layers seldom less than a foot in thickness.

The conglomerates are composed of pebbles or boulders of soft argillaceous rocks, or of the igneous rocks of the region. In some instances these rocks have a calcareous cement; but in general, the pebbles are united by an argillaceous base. They have an earthy

aspect when broken. Occasionally it is difficult to distinguish the included pebbles on a fractured surface, on account of their earthy appearance and resemblance to the intervening material: the true structure in these instances is apparent on a worn surface. In general, however, the conglomerate character is obvious. The pebbles are of various colours, the most common of which are brownish-black, brownish-red, greenish and red; and in some places they are a foot or more in diameter. On Burnt Island, which forms the southern side of Orange Harbour, the coarse conglomerate contains large masses of porphyritic trap, one of which was three feet in diameter. Although pebbles of trap, porphyry and trachyte are abundant in these beds, I found none of granitic rocks.

These coarse conglomerates pass gradually into sandstones; and some layers of the latter so closely resemble the greenstone of the region, especially when broken, that they could scarcely be recognised except by observing their transitions.

Lines of deposition are not distinguishable in the coarse conglomerate beds: they form layers fifteen to twenty feet thick, alternating with the other varieties of the formation without horizontal or vertical lines of separation.

The beds on Burnt Island present the same characters as on the coast. Coarse conglomerates constitute the lowermost layers; and upon these rests a fine breccia having a calcareous cement. Next follows a similar conglomerate without lime, the fracture of which is remarkably earthy, and the colour dark and nearly uniform. Next above is a fine variety of the same rock, resembling a sandstone in texture, but apparently argillaceous in composition. The succeeding layer approximates more to an argillaceous shale of fine texture.

Dip and Strike of Beds.—The rocks in the region examined are seldom horizontal, but dip generally from twelve to fifteen degrees to the westward. Passing along the coast from the head of the Bay, I found the dip as follows in different places:—

- West-southwest half south, fifteen degrees.
- West by north, eleven degrees.
- West by north, twenty degrees.
- West by north, thirty-five degrees.
- Northwest, nearly vertical.
- Northwest, nearly vertical.

These directions and the amount of dip are dependent, in part, on the intersecting dikes. At one place on Burnt Island, the layers resting

on an inclined dike, dipped at an angle of seventy degrees, while those on the other side dipped thirty degrees.

Fossils.—Only a single species of fossil was observed in this formation. It was found on the shores of Nassau Bay, about half way from Orange Harbour to the head of the bay, and occurred in a compact argillaceous shale, where the rock was passing to an argillaceous sandstone. The fossil is represented on Plate 15, figure 1, and is allied to the Belemnites, constituting the new genus *Helicerus*.*

The specimens were found only in a single layer of the rock; they were quite thickly distributed, fifteen or twenty occurring in a slab a foot square.

Concluding Remarks.—From the character of this formation, it may be inferred that it is of marine origin, and that a large part of the material has been derived from the igneous rocks of the region, or others allied. Even the sand-rocks appear to be made of the same material. The blue shales have less resemblance to rocks from such a source.

The occurrence of a Belemnite in the rock gives us some ground for arranging the beds with the Oolitic series, and probably in the upper part of this series; yet the fossil is so peculiar, that the conclusion cannot receive our full confidence until corroborated by further investigation.

Igneous Rocks.

The summits of the hills in general consist of the outcropping igneous rocks of the region. Over the hills between Orange Harbour and the head of Nassau Bay, the sedimentary rocks rarely come to the surface, owing to the covering of soil and vegetation; and igneous rocks are therefore the only kind which comes in view.

These igneous rocks are various in character. The most abundant variety is a greenish-black greenstone of fine texture, breaking with little lustre, though tough. In some places the colour is grayish-black. Minute crystals of feldspar are often thickly disseminated, and large crystals of hornblende are sparsely distributed through some varieties. Certain dikes abound in veins of chalcedony, with occasional geodes of quartz crystals; and these veins when thin have often a red colour. Much of the greenstone sensibly affects the magnetic needle.

* See Appendix.

The greenstone passes into an amygdaloid. One variety of the latter contains thickly disseminated, small round nodules of calc spar, looking like pebbles, the size being a sixth of an inch or less. At other places, the nodules are larger and more various in size. Besides calc spar, they contain quartz, stilbite and datholite, the last presenting the radiated spheroidal forms of the variety botryolite. Stilbite also formed veins intersecting the greenstone, some of which, on Burnt Island, were two inches thick, and afforded fine crystallizations. The same rock contained green earth in nodules, and a greenish-black mineral in short, hexagonal prisms, which appeared to be another form of the same species.

In addition to the minerals mentioned, epidote is also found in the greenstone, in minute crystals in quartz, or in veins. It is also frequent in massive forms, or occurs impregnating large masses of rock. It has the light pistachio-green colour characteristic of this mineral. Olivine was also observed in small quantities.

Besides the greenstone, a reddish trachyte is abundant about the summits of some of the hills: it has the colour of a well-burnt brick, and is more or less vesicular. The specimens often contain distinct crystals of glassy feldspar and hornblende. A trachyte of a very light greenish-gray colour occurs in other hills, containing the same minerals disseminated in crystals.

Specimens of rocks to the southwest of Orange Harbour were obtained by officers of the Expedition, from which it appears that the greenstone is associated with a green and red jasper, or intersected by it in veins.

Size and Direction of Dikes.—The dikes of greenstone and trachyte were well exposed along the shores of the bay, and on Burnt Island. The following are the characters of some dikes observed on the coast, north of Orange Harbour.

1. Fifteen feet wide, direction, south; slate alongside much distorted.
2. Fifteen feet wide, direction, south.
3. Six feet wide, direction, south.
4. Eight feet wide, direction, southeast.

On Burnt Island, the following were observed :—

1. Four feet wide, direction south-southeast.
2. Direction south-by-east.
3. Direction south-southwest half south.
4. Direction southwest.

Decomposition.—The igneous rocks decompose rapidly on exposure, becoming bleached and losing their crystals of feldspar. The removal of these crystals gives a cellular and somewhat scoriaceous appearance to the external surface of the rock. Some varieties, especially the trachytes, become white externally to a depth of an inch, and resemble a pumice. Owing to this effect, the summit of a hill composed of a dark-coloured rock often presents a white chalky appearance.

The minerals which have been described as constituting nodules and veins in the trap and amygdaloid, bear evidence of having been formed subsequently to the ejection of the rock, and fill cavities left when the bed cooled. Without presenting the various arguments on this point, which have already been published by the writer in the *American Journal of Science*, volume xlix. page 49, a few particulars may be alluded to.

The globules of lime in the amygdaloid described, are covered with a thin incrustation of a greenish-black earth, and appear externally to be black shining globules. This incrustation is the same chloritic material so common in amygdaloids, and which appears to be the first deposit from the infiltrating waters. The stilbite veins occur not only in the greenstone, but also in the conglomerates in the vicinity of the veins.

With regard to the chalcedony, there is some reason to suppose it to have been deposited immediately upon the cooling of the rock, since its veins are very irregular in size, and twist around in every direction.

CHAPTER XVI.

REMARKS ON THE GEOLOGY OF RIO NEGRO.

A WALK of five or six hours about the shores of Rio Negro could accomplish little in the way of geological investigation, and a few brief remarks are, therefore, all we have to present. The works of Mr. Darwin* and D'Orbigny† have already well illustrated the region.

The mouth of the Rio Negro is situated about six hundred miles south of Buenos Ayres, on the confines of Patagonia, in latitude 42° south. The country is a part of the *Pampas* or prairies of La Plata, and lies so low that the land did not become visible till we had approached within twelve miles of the coast. We then barely distinguished an even line, unvaried by a single eminence. As we came to anchor, a range of low bluffs was seen to border the sea to the south. One point of these bluffs, the South Barranca, was afterwards measured by the writer, and ascertained to be ninety-four feet above high water level: they vary from ninety to one hundred feet. Nearer the river, the surface was covered with hillocks of rounded contour, which were found, on examination, to be mostly heaps of sand that had been blown up by the winds, or thrown together by the sea. They were partly protected by tufts of tall grass; but frequently the summits only were covered with these tufts, and as the winds wore away the sides, it left them with a grassy head, presenting a singularly grotesque appearance. These tussucks occur partly in lines of half a dozen or more along the river near its mouth.

The sea-beach to the north and south of the river consists of fine sand and pebbles, and is generally so hard as to receive but little impression from the foot. The pebbles are mostly either quartz, jasper, porphyry, chert, or chalcedony, and the last mentioned has

* Geological Observations on South America.

† Voyage, Partie Géologique, p. 57 to 65.

occasionally the banded colours of agate, or the bright ruby or flesh tints of the carnelian. Small pebbles of granite were rarely seen. The porphyry has a variety of colours, among which purple, red, and green were the most common. The width of the beaches varies from two hundred to five hundred feet, and the inclination is but one to three degrees. There are large shoal flats in the harbour of Rio Negro, which are increasing annually and undergoing frequent changes. We were informed that a northern channel was open five years since, which is now too shallow for navigation.

The sea-shore bluffs and the banks of the river up the stream exhibit sections of the underlying material of the pampas. The layers there exposed to view consist of sandy or clayey material, and are not at all indurated, beyond what might have resulted from pressure and such slight depositions of mineral matters from solution as may happen from ordinary cold waters. The lower layer at the South Barranca is very argillaceous, soft and friable, and has a dirt-brown colour. It extends out as a flat bank, a few hundred feet wide, at the base of the bluff, and is covered with water at high tide. It has been eroded by the action of the water that breaks over it during the rise and fall of the tides, and then runs off in rills, so that it is now a collection of small islets, which may be passed over by stepping or jumping from one to another. The surface of this layer is mere mud to a depth of an inch, owing to the washing of the waters, which are thus restoring it to its original condition. This bed appears to be protected in the same manner as the shore platform of rock in New Zealand and New Holland (pp. 442, 532).

The arenaceous layers, above this lowermost, are of various colours. Some are grayish-yellow, others purplish, and others are nearly white. The bluish-purple colour which characterizes one broad layer, appears to arise from the dissemination of particles of magnetic iron ore, which mingle their bluish-black colour with the colours of the sand. Among the upper layers there is a yellowish or grayish-white compact rock, containing dendrites of manganese, and rolled fragments of the same are scattered over the beach.

The lines of deposition in these layers are generally very distinct. In one of them, many of the laminæ are scarcely an eighth of an inch thick. Moreover they are much curved, and in many places not conformable, precisely as we have described the sand-hills of Oahu, and the Sydney sandstone of New Holland. The figures given in our illustrations of the Oahu rock, (p. 255,) exhibit, with sufficient accu-

racy, the irregularities here referred to. They must have resulted, as in the other cases referred to, from the action of different currents (tidal or others) removing, in places, the sand before deposited, and following the removal by other depositions.

We were informed that near the town of Rio Negro there is a thin layer of the formation, which is an impure limestone and is burnt for lime.

The lowermost layers abound, at some places, in shells of the large *Ostræa patagonica* and *Pecten patagoniensis*, besides other species mentioned by D'Orbigny and Darwin. This *Ostræa* attains a length of eight inches or more, and a thickness of two inches. Many had the valves united, while others were separated and broken; and some had been perforated by *Lithodomi* or *Annelida* before having been inhumed. In the upper layers of the bluff I found the mould of a *Bulla*, a *Marginella*, and a *Turbo*.

These tertiary beds, of which only a coast section was seen by us, are stated by Mr. Darwin to extend continuously eleven or twelve hundred miles, north and south; in some places the formation reaches to the Andes, rising westward to a height of three thousand feet above the level of the sea.*

* "The Patagonian tertiary formation extends continuously, judging from fossils alone, from Santa Cruz to near the Rio Colorado, a distance of about six hundred miles, and reappears over a wide area in Entre Rios and Banda Oriental, making a total distance of eleven hundred miles; but this formation undoubtedly extends (though no fossils were collected) far south of the Santa Cruz, and, according to M. D'Orbigny, one hundred and twenty miles north of Santa Fé. At Santa Cruz we have seen that it extends across the continent; being on the coast about eight hundred feet in thickness (and rather more at Saint Julian), and rising with the cotemporaneous lava streams to a height of about three thousand feet at the base of the Cordillera." Darwin, *South America*, p. 119.

CHAPTER XVII.

GEOLOGICAL OBSERVATIONS ON OREGON AND NORTHERN CALIFORNIA.

THE student of physical geography who obtains his ideas of mountains from maps, often imagines that the elevated chain is a narrow line of lofty heights, with a distinct foot, steep declivities and pointed summits. The chain of Western America, as commonly delineated on charts, appears to be confined to a strip of land not over fifty miles wide; and mountains in other parts of the world are generally made to occupy nearly the same limits, whatever their extent. The slopes are all reduced to a map-maker's standard.

The errors flowing naturally from this source are nowhere greater than in the case of the Rocky Mountains; and the correction of any false impression thus derived is of the first importance, as introductory to a study of Oregon. The range is placed in our charts from six to eight hundred miles from the coast, and it seems to stand like a crested wall raised to a vast height between the east and west, with rapid slopes of thirty, forty, or fifty degrees.

The traveller crossing these ridges, finds, on the contrary, as many of them have informed us, that he commences his ascent soon after leaving the valley of the Mississippi; and as he travels onward, although meeting with ridges and valleys as well as extensive plains, still he makes an increasing rise; and when the position marked for the Rocky Mountains is reached, he has already ascended seven or eight thousand feet, though hardly conscious of it during his progress. There are now high ridges in most parts to be crossed, unless he follow some of the passes; yet these ridges are seldom over four or five thousand feet in altitude. Beyond them a descent commences like that on the east; and although broken by high, rugged mountains in some places, it is still a gradual descent, which is hardly finished before

reaching Fort Vancouver, less than a hundred miles from the coast. This great mountain, the backbone of Western America, is, therefore, no narrow line of summits, but spreads out over a base of more than fourteen hundred miles, one foot literally bathed by the waters of the Mississippi, and the other dipping beneath the Pacific. This fact is well shown in a sectional view by Fremont,* one of the interesting results of his valuable explorations. Two hundred and fifty miles from the Mississippi, at the mouth of the Kansas, the height above the sea was found to be nine hundred feet. For one hundred and twenty-five miles beyond, the whole ascent was but one hundred feet; in the next one hundred and thirty-five miles, there was a rise of one thousand feet, making two thousand feet above the sea; the next one hundred and thirty-five miles, another one thousand feet, making three thousand feet; the next two hundred and fifty miles, a rise of two thousand feet; making, in all, five thousand feet in a distance of six hundred and thirty miles, or very nearly eight feet to the mile. Over the next four hundred miles, the route travelled ranged between five thousand and eight thousand feet;† this was the summit region of the Rocky Mountains, upon which the Wind River Mountains stand, with their summits about six thousand feet above the country around them, or thirteen thousand five hundred and seventy feet above the sea. Beyond, to the westward, the section shows very remarkably that the descent was gradual like the ascent, excepting irregularities arising from some high ridges.

The Rocky Mountains are properly, therefore, a gentle swelling of the surface, whose average inclination is between seven and eight feet to the mile. Over the surface, on the declivities as well as at top, are lofty ridges or mountains, and of these the Wind River chain is one of the most prominent. In many parts at top there are extensive plains; and Humboldt long ago informed us that in the Mexican portion, wheeled vehicles may travel along the range for two

* Report of the Exploring Expeditions to the Rocky Mountains in the year 1842, and to Oregon and North California in the years 1843 and 1844, by Brevet Captain J. C. Frémont, of the Topographical Engineers, under the orders of Col. J. J. Abert, Chief of the Topographical Bureau. Printed by Order of the Senate of the United States. Washington, 1845.

The same extremely gradual slope characterizes the Andes of South America, as is well shown in a sectional view of the Bolivian chain, by M. Alcide D'Orbigny, in his *Voyage dans l'Amérique Meridionale*, Geologie, Plate 8, fig. 1, bis.

† The pass was found to have a height of seven thousand four hundred and ninety feet.

thousand miles. The whole is literally a vast shed, whose summit divides the waters that flow on either side.

Nearly all the rivers of America, excepting those east of the Mississippi, take their rise in this chain. We observe the Rio Grande del Norte and Arkansas on one side, and the Colorado on the other, draining the same heights; the Nebraska, Yellowstone and Missouri flowing from the very snows that form the head waters of the Lewis or Snake; while the Saskatchewan, whose waters reach the Atlantic through the Great Lakes and the St. Lawrence, and the Athabasca, which runs by the Slave Lake to the Arctic Ocean, slope off from the heights which contribute on the west in the same vicinity to the Columbia and to Fraser's River.

From these preliminary observations we pass to the consideration of the region west of the dividing summit of the Rocky Mountains, and particularly that portion belonging to the territory of the United States.

GENERAL FEATURES.

The coast, the mountains, the rivers, and the plains, are subjects severally demanding a brief notice.

A. *Features of the Coast.*

The outline of the coast of western North America, from the California Gulf to Puget's Sound, has few indentations. The harbour of Monterey is a small open roadstead. The Bay of San Francisco is a deep gulf of irregular form, consisting mainly of two broad arms, one twenty-five and the other thirty-five miles long, opening upon the sea through a single channel a mile wide and five long. Sacramento River flows into the northern arm, and the San José into the southern. Between San Francisco and the Columbia, are the Clammat and Umpqua Rivers, and at the mouth of the latter there is anchorage for vessels drawing not over eight feet. The Columbia has a mouth seven miles in width, and the waters within afford good anchorage, though reached by a somewhat difficult channel, which is wholly impassable in bad weather. The Chekelis River, sixty miles to the north, empties into a large shallow bay called Gray's Harbour, the bar of which prevents the ingress of vessels drawing over ten feet.

From the Straits of De Fuca north, there is a total change of character. The continent is abruptly narrowed a hundred and fifty miles, and Vancouver's Island appears as the proper continuation of

the coast line. This island has the Straits of De Fuca on the south, and an extensive sound and a complexity of channels on the east. These channels run into the land often some scores of miles, and form in many parts an irregular network of canals, as is well seen about Nisqually; and they have great depth of water, even allowing large vessels to rub their sides against the rocky shore, before the keel touches bottom. They are in great numbers along the whole coast, up to the Russian settlements in latitude sixty degrees. As a part of the same system, this coast has its thousand islands of all shapes and sizes. Even the islands have deep bays cutting in far towards their centre; thus on the sea-shore side of Vancouver, the bays are singularly intricate, and twenty miles deep. Some remarks on the origin of these features will be given in the sequel.

B. *The Mountains*.—The grand features of the country on the Pacific side of the Rocky Mountain chain, arise to a considerable extent from a general parallelism in the ranges of heights intersecting the country, a fact apparent in the courses of the rivers were the elevations unmarked on a map.

There are three of these north-and-south ranges, the *Coast Range*, the *Cascade Range*, and the *Blue Mountains*. The first lies near the coast, the second, one hundred and thirty miles inland, and the third, three hundred and fifty miles from the sea.

The *Cascade Range* is much the most extensive of the three, and even rivals the Rocky Mountains in the height of some of its peaks. It may be traced far into California, and north beyond Puget's Sound, retaining throughout a direction nearly parallel with the coast. It constitutes a strong line of territorial demarcation in Western America, separating a coast section from the interior, and forming a barrier to commercial intercourse, excepting along the single great highway, the Columbia. The two sections, moreover, are widely different in character.

This range, though in general over a hundred miles from the sea, approaches the coast at the south near the Gulf of California, and north at Puget's Sound, and obviously because the waters of the ocean in both cases make deep inroads into the land, rather than from a change in the direction of the range. In the course of the six hundred miles from Puget's Sound to the Sacramento, latitudes 50° to 40° , the range contains seven or eight snowy peaks varying from ten to fifteen thousand feet in height,—three north of the Columbia, and the others south. Commencing at the north, they are, *Baker*, *Rainier*,

St. Helens, Hood, Jefferson or Vancouver, M'Laughlin or Pitt, and Shasty. To the southward other high peaks range along the Sierra Nevada, whose snowy tops are occasionally seen from Sutter's, sixty miles up the Sacramento. At the pass near the head of the American Fork, Captain Fremont found the height 9,338 feet, which exceeds by nearly two thousand feet the elevation of the South Pass in the Rocky Mountains; and points in the range near by were still higher by several thousand feet. The Sierra appears to extend into the Californian Peninsula.

The main body of the Cascade Range in Oregon, is seldom over five or six thousand feet in elevation. Its heights are therefore but hills in comparison with the lofty cones above enumerated, which rise out of the chain. These towering summits stand in solitary grandeur, wrapped about in perpetual snows.

Off the mouth of the Columbia, at sea, Mount St. Helens may be seen in the eastern horizon. The snows descend with unbroken surface halfway to its base. It is not less than fifteen thousand feet in height, and has been estimated at sixteen thousand. Mount Hood, thirty miles south of the Columbia, is scarcely as elevated, for the black rocks of its summit show through a ragged coat of snow. Yet it is not less majestic. It opens to view from the southern gateway of Vancouver, rising in lofty sublimity above the crouching hills at its base. Mount Rainier, to the east of Nisqually, and Mount Baker farther north, have the same bold features. Mount Shasty is another of these hoary summits. A heavy mist covered the region as we approached it. Gazing up intently for the peak, visible in the earlier part of the day, we barely discovered some lights and shades far above us, which produced, through the indefiniteness of the view, a vision of immensity such as pertains to the vast universe rather than to our own planet. The Cascade Range is, therefore, of interest, not only topographically, but also for the sublimity of its views; and we shall also find, as we proceed, that its economical and geological importance cannot be over-estimated.

The *Coast Range* is a region of hills, ridges, and peaks, mostly from a few hundred to three thousand feet in height, and rarely rising to twice this elevation. It lies directly along the coast, forming a border of ten to thirty miles, and presenting in general little that is striking in outline. Viewed from the mouth of the Columbia, there was one broken summit to the southeast, calculated to engage the attention; it is called by the Indians, Swàlalàhos, and has also been

named Saddle Hill. The whole region elsewhere is broken with hills of little seeming interest, and bristled with evergreens. Near the Straits of De Fuca stands the high peak of Mount Olympus, eight thousand feet in altitude.

This range may be traced south beyond San Francisco, nearly to the peninsula of California. To the north it is continued along the coast, and in the islands which border it, to the Russian settlements.

The *Blue Mountains* form the western boundary of the Snake River region. Immediately to the north of the Columbia, and as far as Fort Colville, they are interrupted by an extensive level tract. But to the north of Fort Colville there is a range of heights which extends along to the west of the Columbia River, and may be considered a part of the same general chain. The Peak Mountains, north of 55° , though not a continuation of the Blue Mountain chain, may yet be mentioned in connexion, as they lie in like manner to the west of the summit of the Rocky Mountains. From Fort Colville there extends a *transverse* range, called the Spokane Mountains, having a course nearly east-by-south; and the Salmon River Mountains a little farther south have nearly the same direction.

The elevation of the Blue Mountains is eight or nine thousand feet; and where crossed on the usual route from the United States to Wallawalla, five thousand feet. On the east of the summit there is a fine circular valley, about fifteen miles in diameter, called the Grand Rond.

The influence of the position of the mountain ranges on the courses of the rivers, is worthy of attention. Between the Coast and the Cascade Ranges lies one of the great longitudinal depressions of the surface. Here the Columbia receives a northern and a southern tributary, the Cowlitz and the Willammet Rivers, and the latter has a length of one hundred and fifty miles. The Bay of San Francisco, in the same manner, stretches one arm, the Sacramento, three hundred miles to the north in the same great trough, and another river, the Joaquin, flows from the south two hundred and fifty miles. In the interval separating the Cascade Range and the Blue Mountains, the Columbia receives two southern tributaries, the Falls (Chutes) and the John Day's Rivers.

Between the Blue Mountains and the summit of the Rocky Mountains, the southern fork of the Columbia (Lewis River) stretches south as far as latitude 42° , draining the whole of this part of the interior section. The northern fork of the same river has a north-and-south

course, west of the longitude of the Blue Range, but turns east near Okanagan, and having crossed this longitude, it forks again just beyond Fort Colville, one affluent coming from the north in latitude 52° , and the other from the southeast. Fraser's River, which empties north of latitude 49° , has a nearly parallel course with the north branch of the Columbia, and flows from the Rocky Mountains, rising in latitude 54° . The mountain range north of Fort Colville forms the boundary between the two great river depressions, Fraser's and the North Columbia.

We observe therefore that the arrangement of the mountains has given the remarkable expansion and length to the Oregon rivers. Instead of many small streams flowing direct from the mountains to the sea over the narrow western slopes of the Rocky Mountains, the waters of the great interior section are gathered along the range for seven hundred miles from north to south, into a common channel, and this channel has found a passage through the great barrier, the Cascade Range. Fraser's River, to the north, is the only other river which intersects this range, and this is north of the parallel of forty-nine. So the Cascade Range, without the Coast Mountains, would have given rise to a number of little streams, with small and narrow alluvial flats, flowing with few turns to the coast. But with the existing features of the surface, the streamlets collect into the larger rivers; and these flow long distances north or south, to find their exit either into the Columbia or the Bay of San Francisco. They flow, too, in consequence of this arrangement, notwithstanding the general slopes of the country, over a nearly level tract, lying at almost a uniform distance from the ocean, and they there spread their alluvial plains to the great improvement of the country. The Willammet Valley is a striking example of this, and the Sacramento and Joaquin, with their broad alluvial lands, are others. Between the head waters of the Sacramento and Willammet there are the Umpqua and Clammat rivers, crossing the Coast Range to the sea, and illustrating, by their small bottom plains, the principles here explained.

South of the region drained by the Columbia, spurs from the Blue Mountains stretch along to the east, parallel with the Salmon River Range. These form the northern boundary of the great Colorado territory, which lies between the summit of the Rocky Mountains, (or the *Anahuac* Range, as they have been called,) and the Californian portion of the Cascade Range, or the Sierra Nevada. The Colorado

drains this region, and flows south into the Gulf of California, being the third great river of Western America.

Thus, from latitude 32° to 55°, the waters of the Rocky Mountains reach the sea through only three channels. On the east side of the Rocky Mountain chain, at the same distance from the summit as the Pacific coast, the number of distinct rivers that may be counted is much larger. This peculiarity of Western America is of great agricultural advantage, as already remarked. This is farther obvious when we consider the dryness of the climate, (the rains being confined to the winter seasons,) and the importance, therefore, not only that there should be lofty mountains and a second range of snowy heights to afford supplies, but also that the waters should flow in few channels to diminish the surface for evaporation. Their influence, moreover, in the production of alluvial lands, is therefore the more widely felt.

C. General Features of the different Sections.

We have mentioned the division of Oregon into a coast, a middle and an inner section, by means of the Cascade Range and Blue Mountains. These sections differ much in topography, but still more in climate and vegetation.

Coast Section.—The coast section has strongly-drawn boundaries in the ocean on one side, and the Cascade Mountains on the other. The Coast Range of mountains gives a very broken character to a band fifteen to thirty miles wide along the sea. Over this region there is scarcely a level tract in any part beyond a few acres in extent. In an excursion from Astoria to Swalahos, (figure on p. 644,) twenty miles south of the Columbia, the surface was a succession of high hills and deep valleys; and the same features appear to extend south to California. Lieutenant Eld traversed the region north of the Columbia to Puget's Sound, over a still more uneven country. These shore hills and mountains are covered with forests of cedars, pines and other Coniferæ, and among the trees, three hundred feet is a common height, and fifty feet occasionally their circumference, as we can attest from actual observation. It is not surprising, therefore, that in many places the forests should be obstructed by fallen timber piled up ten and twenty feet above the ground. Long distances may be travelled by walking from log to log, with the ground far below, and accessible only with much difficulty. The soil over this portion of the district is generally fertile; and the proximity of the sea gives the advantage of frequent heavy mists or rains, when other parts of the country are dry. Thus in July, the weather at Astoria was almost constantly wet,

though rather from dripping fogs and drizzling rains than from heavy showers. On descending the Columbia in a boat, when approaching the wet region, the mist is seen standing before the observer like a high wall, forming an abrupt transition line, stretching from north to south. There is another advantage possessed by this coast section,—that the settlers are free from the fever and ague, which prevails almost universally over the drier prairie districts. The settlers on the Willammet expect a summer attack as a matter of course, and quinine in 1841 had almost become an article of diet. Yet notwithstanding these advantages, it is obvious that the difficulties in the way of cultivation, arising from the forests, are insuperable, except at an expense which a new country will not warrant.

East of the Coast Range, in this section of Oregon, lie the plains of the Willammet and Cowlitz, a region of prairie hills.

Willammet District.—The Willammet district commences a few miles south of Vancouver, and extends about one hundred and twenty miles to the southward, as far as the Elk Mountains—an east and west ridge about fifteen hundred feet high, forming the northern boundary of the *Umpqua* district. The average breadth has been estimated at sixty or seventy miles, including therein the high sloping hills which border the river plains. These hills are occasionally a thousand feet in height. In a view from one of them, in the vicinity of the Willammet, wide grassy flats lie spread out before the observer, which rise into gentle undulations on either side, and the sunny fields and slopes are dotted with scattered oaks and their dark shadows. A brook coming from among the hills leaves its little valley, launching out into the wide prairie to join the river, and its course is distinguished by a border of pines, cottonwood and oaks. Other streamlets, also, are traced from the more distant hills over the prairie plain by means of the meandering forest lines along their banks; and the Willammet is followed by the eye in the same manner till the trees in the far distance seem like a forest on the horizon. The beauty of the prospect is farther enhanced by the gradations of light and shade produced by the varied slopes of the surface. Such are common scenes through the prairie portion of the coast section. There are no trees in view but the few that line the streams, and the oaks, which are a rod or two apart, excepting on elevations above a thousand feet in height; and here the vegetation resembles that of the hills nearer the coast.

The flats, or proper alluvial district of the Willammet and its tributaries, are divided into the upper and lower prairies, the former sepa-

rated from the latter by a steep slope fifty or sixty feet in vertical height. The *lower* prairie is sometimes four or five miles wide on either side of the river, and the stream flows through it with alluvial banks twenty or twenty-five feet high, except during freshets, when the waters overflow the banks, and the whole plain is often flooded. The border of the stream is usually a little higher than the country back. The *upper* prairie extends sometimes to a distance of twelve or fifteen miles from the river, and is occasionally cut through by gullies or valleys, and reduced to a succession of low hills.

The grass of these prairies is in scattered tufts, one tuft every eighteen or twenty inches, and it is usually eighteen to twenty-four inches high. It grows so thinly that "a prairie on fire" is no very terrific spectacle. With a few green branches, the fires, at any time, may be brushed out. A line of flame creeps along slowly over the field, blazing up only a foot or two, and smoking abundantly, but leaving unhurt the larger shrubs and the coarser green grass or sedge along the rivulets.

The Willammet district abounds in lands fitted both for tillage and pasturage. The soil of the lower prairie is, in general, a light alluvial loam, which becomes dry and dusty during the summer droughts. It has not the usual mellowness of the bottom-lands of our western rivers on the eastern side of the mountains, and apparently for the reason that the stream flows through a dry region, which can contribute little comparatively that is nutritious to the waters. Yet the grass, though thin, is excellent, and the soil affords profitable crops. The upper prairie has commonly a more clayey soil about the Willammet settlement, and forms a deep adhesive mud in the rainy season, which becomes so hardened in the summer sun as scarcely to receive any impression from the hoofs of horses. Yet the proportion of clay is not such as to render it sterile, and it is generally preferred for tillage. In some places it is sufficiently plastic for brick-making.

The peculiarities of the upper and lower prairies are by no means constant, and the characters here given to one sometimes belong to the other. In the vicinity of basaltic rocks the soil is often of a dark chocolate colour, and is loose and highly fertile, while near the argillaceous sandstone hills, it is of a dirty grayish colour, and often stiff and clayey, sometimes so barren as to produce nothing but stunted ferns. Pebbles of agate, chalcedony and carnelian are strewed along the streams, and in some places are scattered over the prairies. The loose basaltic soil at times opens in deep cracks on drying, which

are wide enough for the arm to be thrust in ; they form a network over large areas.

The hill prairies are often too dry for cultivation, yet afford good pasturage. The soil varies in character with the subjacent rocks, on the principle just stated.

As the rains of this part of Oregon are confined to six months out of the twelve—from October to May,—the aspect of the country is wholly different at different seasons of the year. In the summer it is very seldom that a shower passes over the Willammet plains. The lofty summits, St. Helen's and Mount Hood, are mountain hygrometers, attesting to the general dryness of the atmosphere ; it is very rare that a cloud appears in this season about their snowy summits, though they are at times partially obscured by a light haze. The consequence is that nothing grows from June till the rains set in again. The whole country is without a green blade of grass, except along the edge of some rivulet. The drought is so complete that the dried grass remains as good food for the cattle till the change in autumn. It gives a dreary appearance to the summer prospect of these prairies, but little exceeded when later in the season, they are left black after the charring fires. During winter, the fields offer fresh feed, and as the weather is mild, with rarely any snow, the herds are kept out at pasture through the season, housing being unnecessary.

It is probable that by discontinuing the burning of these prairies the grass would grow more closely, and other species might be made to spring up. The fires destroy the annual plants and all the smaller kinds of vegetation, excepting species with bulbous roots. A system of irrigation would bring under cultivation large districts which are now unfit for tillage. Yet there is some difficulty in irrigating the upper prairies and hills, as there are no sources of water, excepting the streams meandering through wide alluvial plains, and lying twenty or twenty-five feet below their banks.

Vancouver, Cowlitz and Nisqually districts.—The prairie land in the vicinity of Fort Vancouver, in the Cowlitz valley and about Nisqually, has a general resemblance to that of the Willammet. The Vancouver farms, in the hands of the Hudson's Bay Company, are small but productive. In the Cowlitz, the plains lie near the head of the river. They cover but a few square miles, and six hundred acres were under cultivation in 1841. They are described as clayey, and similar to much of the Upper Willammet prairies. The region about Nisqually on Puget's Sound, offers great commercial advantages on

account of its harbour privileges and its connexion with extensive internal waters to the north. But its lands are described by the officers of the Expedition who were over that district as generally poor, being dry and pebbly, and requiring abundant rains to render them productive.*

Umpqua District to California.—On a land tour from the Columbia River to San Francisco, in California, a distance, as travelled by us, of about seven hundred and fifty miles, we left the Willammet district near latitude 44° , and on the way south traversed the valleys of the Umpqua and Clammat rivers, and thence entered the Shasty Mountains to the head waters of the Sacramento, which river we followed down to its mouth.

Between the Elk Mountains and the north fork of the Umpqua, a breadth of thirty miles, there is a succession of hilly and level prairie quite equal to the Willammet, though the variations in the soil are more frequent and abrupt. Sandstone hills often alternate with basaltic, and substitute a dry, harsh soil, for the dark reddish-brown loam of the basalt; and the subjacent rocks are at once distinguished by the colour of the earth above them. Beyond the Umpqua, the plains are of small extent, and the country is in general covered with a harsh gravelly soil. The hills are more abrupt, indicating a change in their geological constitution; and though still grassy, the silico-tal-cose rocks that compose them often project in jagged points.

Fifty miles south of Elk Mountain we left the Umpqua region by crossing the Umpqua Mountains—a most disorderly collection of high precipitous ridges and deep secluded valleys enveloped in forests. We estimated their height at twenty-four hundred feet. After travelling forty miles over an uninviting region, the latter part dry and sandy, we crossed the Shasty River, and continued through an unproductive country to a range of hills about fifteen hundred feet in height. Crossing this ridge, (named by us the Boundary Range, as it was near latitude 42° ;) we entered upon an undulating region abounding in gravel and little else, and thence passed to the plains of the Clammat.

The Clammat is a fine river, about one hundred yards wide, where forded by the party, thirty miles from the sea. Beyond this river, the hills and plains for forty miles contained some arable spots; but

* The Cowlitz and Nisqually districts are particularly described by Captain Wilkes in his Narrative of the Expedition, and we refer to that work for an account of them. They were not visited by the writer.

the greater part of the surface consisted of gravel. After leaving the Umpqua, on our way south, we seldom met with a patch of good soil, and found in the country little to encourage the agriculturist. This remark should be understood, however, as applying to the region along our track.

Leaving the Clammat region just south of 42° , we entered the Shasty Mountains, and were nearly a week ascending and descending steep and sharp ridges, from a few hundred to two thousand feet high; we at last opened on the plains of the Sacramento, two hundred and fifty miles above its mouth. Instead of rich alluvial plains, we were destined to journey another forty miles over a harder pebbly soil than any we had seen on the whole route. The river has its upper and lower plains, differing sixty feet in height. The former were found to have this pebbly character wherever examined; they were often broken into rolling hills, and were dismally scanty in vegetation. The lower prairie or bottom-lands reminded us of the Willammet, and compensated in part for the barrenness of the upper country. The soil was in general a rich loam, and in a moister climate would rank high for its agricultural resources; and with only three months of rainy season followed by eight or nine of drought, it is by no means unfavourable for tillage. The alluvial region of this river, two hundred miles from its mouth, is twenty miles wide; and one hundred miles from San Francisco has twice this extent. In the season when traversed by us, the month of October, there was no green grass to be seen, excepting immediately along the water; and the whole surface was the Willammet over again. The cattle during this season graze over the dried grass of the fields, which looks like a growth of ready made hay. The same features continued to characterize the country to the Bay of San Francisco. The valley of the San Joaquin is described as one of great fertility. The only drawback in the region, and it belongs to all Northern California, arises from the short season of rains, and the long one of drought; and when the rains fail altogether, as occasionally happens, the country yields almost nothing, except where artificially irrigated.

Middle and Inner Sections.—Exploring parties from the vessels of the Expedition penetrated towards the interior, to Forts Wallawalla, Okanagan, and Colville. From these sources and the reports of others who have traversed these regions, we learn that dry, drier, driest, expresses the character of the country as we go east. Between the Cascade Range and the Blue Mountains, and over the region

northward about Fort Colville, there are some spots favourable for cultivation, but they are very small. In general it is an indifferent grazing country, where in some parts, with a sufficiently wide range, horses may be profitably raised. It should be understood, however, that the unproductiveness is in general a result of the dryness of the climate; and where irrigation is practicable the land will often yield abundantly. The plains south of Fort Colville are of a most unpromising rocky character. Ascending the Columbia, about two hundred and fifty miles from its mouth, there is what has been called "the last tree," as it is literally the last on its banks for a long distance. It affords a good index of the dry climate, and shows that it is increasingly dry as we go eastward towards the summit of the mountains.

Beyond the Blue Range, there are wide plains and rolling prairies, and some districts of high mountains. But it is mostly a dry waste, yielding little besides wormwood and some equally profitless plants, and those sparingly.

The rivers through both of these sections lie in channels, often one or two thousand feet below the general level of the plains. Dr. Pickering informed me that this is the general character of the Columbia north of Wallawalla, and also of the Kooskooski River, which have in many parts beds two thousand feet deep. A remarkable valley, two to three miles wide, resembling one of these river gorges, intersects the bed of the Columbia below Fort Colville, (see map of Oregon, by the Expedition.) It commences about thirty miles east of Okanagan, and after a somewhat curving course of one hundred and fifty miles, meets the river again seventy-five miles above its junction with the Snake River. It is called the *Grande Coulée*. Precipitous walls, generally of rock, and eight hundred to one thousand feet high, bound it on either side. Rocky peaks, some of them as high as the walls, partially obstruct the northern entrance. Its bed to the southward is strewed with granite boulders, which came from the northern portion of the gorge.

We might dwell farther upon the features of the Columbia in this section, its "Cascades," "Falls," and "Grand Rapids;" but they did not come within the observation of the writer, and are already described in the Narrative of the Expedition by Captain Wilkes.

Passing beyond Oregon, either to the north or south, the country does not improve in its agricultural resources. North of Oregon the country is poor, and is especially difficult of cultivation on account of the severity of the climate. The Cascade Range borders the coast, and

the land belongs, therefore, to the inner section. It is consequently bounded on both sides by snowy summits through a great part of the year, the Rocky Mountains on the east and the Cascade Range on the west; and at the same time it is nowhere less than a thousand feet above the sea. There is good reason, therefore, for its cold, inhospitable character. South of Oregon, the inner section is barren, and is well known as the Great Californian Desert. It is properly a semi-desert, rather than a desert, as it bears some vegetation over its surface, though scanty in quantity and useless in kind. It is reported to contain some salt and fresh lakes, and to abound in salt efflorescences; but no stream flows from it, as the latest explorations show, except the Colorado, which empties into the head of the Gulf of California.

Although Oregon may rank as the best portion of Western America, still it appears that the land available for the support of man is small. Out of the whole area, about three hundred and fifty thousand square miles, only the coast section within one hundred miles of the sea, including in all hardly a sixth of the whole, is at all fitted for agriculture. And in this coast section there is a large part which is mountainous, or buried beneath heavy forests. The forests may be felled more easily than the mountains, and notwithstanding their size, they will not long bid defiance to the hardy axeman of America. The middle section is in some parts a good grazing tract; the interior is good for little or nothing.

The Oregon territory has great advantages in being the region of the Columbia, including both of its widespread tributaries and its outlet. The course of this river forms the only pass for merchandise from the coast to the interior; the Cascade Range elsewhere is unbroken, except by the impassable torrent called Fraser's River, just north of 49°. The trade, therefore, of the whole interior section, from the Russian settlements to California, must make use of this channel in its way to the sea.

GEOLOGICAL STRUCTURE OF OREGON AND NORTHERN CALIFORNIA.

The most striking peculiarity in the geological structure of Oregon is the abundance of basaltic or volcanic rocks over its surface, both in

the vicinity of the lofty cones of the Cascade Range, and elsewhere throughout the territory. The region more especially thus characterized, includes the greater part of the inner section, and the Columbia River, Willammet and Cowlitz districts in the coast section. But beside basaltic rocks, there are, in the districts last mentioned, tertiary sandstones and shales, and basaltic conglomerates, prevailing to a very large extent, and continuing some distance—the limits yet undetermined—up the Columbia. There are also granitic and allied rocks along with serpentine, besides some ancient conglomerates and shale in the Umpqua and Shasty regions, and in different parts of the Cascade and shore ranges at a distance from the volcanic peaks. Before entering upon the description of these rocks, we may glance at their geographical distribution, as far as ascertained by the observations of the writer and others connected with the Expedition.

The tertiary rocks were first seen on the Columbia in the vicinity of Astoria. They occur along the shores of this river for twenty miles from the sea, though occasionally interrupted by basalt, as at the settlement Astoria. They were met with over the country south of this part of the Columbia, on a jaunt to Swalalahos; but among the sandstone hills of this region were others of basalt; and Swalalahos itself is the remains of an ancient volcanic mountain or crater, consisting principally of volcanic conglomerate. These sedimentary deposits, according to the reports of the officers of the Vincennes, prevail to the north of the Columbia, and upon the shores of Puget's Sound. They were observed by the writer ten miles north of the Columbia, in a stream emptying near Gray's Bay.

Above the lower twenty miles of the Columbia, the banks are mostly basaltic; and in some places these rocks constitute a long wall or palisade, nearly bare, from one to three hundred feet high. Basalt continues to be the rock of the river, except where the shores are alluvial, as far as the forks, though for a portion of the distance it is interstratified with basaltic conglomerate or tufa. Alluvial shores occur for a long reach above the mouth of the Willammet. Twenty miles east of Vancouver the basalt begins again to line the river, and six miles beyond it stands out in needles and slender cones, forming what is called Lower Cape Horn. At the Cascades, forty-five miles from Vancouver, the basalt, as shown by Mr. Drayton's specimens, is very cellular, and in some places a scoriaceous lava. Both here and at the Dalles, the basaltic rocks, as I am informed, are associated with basaltic conglomerate. Thirty-five miles above the Dalles, commences

a flat country, which continues for sixty miles to the Grand Rapids. Ledges of basaltic rocks crop out at intervals along these low shores; and at the Grand Rapids, they stand in high broken walls, peaks and needles, on both sides of the river. These rocks cease again at Wallawalla, twenty miles beyond.

The south fork of the Columbia was examined by Dr. Pickering as far as the Kooskooski; basalt continued to be the rock of the shores. The reports of travellers state that the whole Snake River region is characterized by the same basalt, either cellular or compact, and basaltic conglomerate, with intervals of basaltic lavas. Although the conclusion may be too comprehensive, we may safely infer from it that basalt is the prevailing rock throughout this region.

With relation to the north branch of the Columbia, and the region between Nisqually and Fort Colville, around by Wallawalla, I extract the following from the journal of my friend Dr. C. Pickering. The party left Nisqually, and crossed the Cascade Range, twenty miles to the north of Mount Rainier. On the ascent, pebbles of granite and porphyry were found in the beds of the streams, the first signs of granite being observed about twenty miles from Nisqually. Near the summit of the range the rocks were trachytic, and contained black crystals (probably hornblende). After descending and passing a rolling country to the northeast for three days, they crossed a ridge still higher by a thousand feet, and then made the descent to the bed of the Columbia. The rocks on this route were seldom in view; where exposed, they consisted of basalt, much of which was very cellular. They reached the Columbia at the mouth of the Pescaos River, and leaving a fine-grained granite on the west side, they crossed over and found basalt at the summit on the east side. Granitic rocks appeared to characterize the country north of Okanagan, and so on east to Fort Colville. The northern entrance of the Grande Coulee consists of granite, although the country in this region to the south of the Columbia is mostly basaltic. Many hills of granite occur in this part of the gorge, and some, whose tops reach the general height of the plains above, have the upper three or four hundred feet basaltic, while the base is granitic.

At the Kettle Falls, near Fort Colville, the rock is a quartz rock containing a little mica, and breaks out in large slabs. No granular limestone was met with, but it is said to occur near the mouth of the Spokane River.

From Fort Colville the party traversed the dreary plains which lie

south, to the Kooskooski. On the Spokane, sixty miles south of Colville, they again met with granite, and this seemed to be the rock of the hills to the eastward. But with this exception, they found nothing but basaltic rocks along the whole route to the Snake River.

The party returning to Nisqually followed the Eyakema River, a small western branch of the Columbia, and found basalt, basaltic lavas, and basaltic conglomerate the prevailing rocks.

I have seen specimens from the north, of garnet in trapezohedral crystals two-thirds of an inch in diameter, of pyrites in cubes, chalcidony, opal, kyanite, graphite, oxyds of manganese and iron, besides different varieties of granite, serpentine of light and dark shades, calc spar, argillite, and compact and porphyritic basalt. But the particular localities of the specimens, beyond the statement that they were from the Northwest Coast and New Caledonia, were not given. The Salmon River region is described by Mr. Parker* as containing horizontal sandstone and shale of various colours, with rock salt, besides basaltic and granitic rocks.

The country from Nisqually to the Chekelis, and thence to the coast, was traversed by Mr. Eld, who remarks that there were bluffs of a soft sandstone and crumbling clay on the banks of the river, and in many places along the route. Boulders of granite also were observed by him on the Chekelis, some of which were four and five feet in diameter.

On the tour to California, basaltic rocks were met with along the Willammet nearly to the settlement, a distance of thirty miles. At the Willammet Falls, the rock is a cellular lava, in some parts nearly scoriaceous. Over the plains and rolling prairies to the Elk Mountains, the tertiary sandstone and shale are intermingled, as near Astoria, and the same rock constituted these mountains at the pass, and the country onward to Elk River. Basaltic hills were distinguished not far distant on our left, and a line of basaltic rocks crossed this river just above our place of encampment. Beyond the Elk to the Umpqua, basalt and tertiary sandstone were passed in alternate hills, till we reached the latter river.

At this place commenced the first of the granitic series of rocks met with by us. Talcoose rock is largely developed, and is the surface rock through the greater part of the way to the Umpqua Mountains. A considerable region of an older secondary conglomerate—a siliceous

* Parker's Exploring Tour beyond the Rocky Mountains, Ithaca, New York, 1 vol. 12mo. 1838. pp. 105, 108, 109.

puddingstone—was crossed upon the south fork of the Umpqua. The Umpqua Mountains consist of the talcose rock, some portions of which are slaty.

Twenty-five miles to the southward of the Umpqua Range, we passed a region of hornblende rocks and syenite. Twelve miles farther south, as we approached the Shasty, the rock was granite, and the same was found on the south side. We here deviated from our southerly course, and for fifteen miles followed the banks of the river eastward, passing soon into a region of hornblende rocks, some of which were imperfect syenite. After making about twelve miles of easting, we again turned south, and twenty miles beyond reached a wide prairie. A few outcropping basaltic rocks were crossed as we entered it, and hills, apparently basaltic, were seen to the eastward; but in our course, after travelling ten or twelve miles, we reached a region of granitic hills. A short distance farther south, we crossed what we designated the Boundary Range; it consisted of basaltic sandstone or conglomerate, and what appeared to be the Astoria tertiary sandstone containing fossils. Southward, the basalt and sandstone run side by side nearly to the Shasty Mountains. Fronting the Shasty Peak, the plain is covered with hillocks of a porphyritic lava, while the hills to the westward consist of sandstone, and then change to serpentine and syenite.

Entering the Shasty Mountains, we travelled for twenty miles over trachytic rocks; then passed to granite, which graduated into syenite, hornblende rock, hypersthene rock, protogine, talcose rock, and talcose slate. The talcose rocks constitute the greater part of the ridges along the upper part of the Sacramento Valley. During one day, in the Shasty Mountains, we passed over a formation of shale, sandstone, and puddingstone of early origin.

On the plains of the Sacramento, we met with nothing but alluvial deposits, till reaching the Sacramento Bute, eighty miles north of San Francisco, (or about one hundred and fifty miles following the course of the river.) The Bute is an ancient crater, and consists of trachyte and trachytic porphyry.

Near the head of the bay of San Francisco, the rocks are composed of a soft sandstone like that of Astoria. Half way down the bay, about Sansalito, and below to the sea, the hills consist of red and green chert and shale, which are subordinate members of the talcose rock formation. Some beds of soapstone and talcose slate, with actinolite, and an impure serpentine, exist on the borders of the bay.

In the farther description of these rock-formations, we may take them up in the following order:—

1. Ancient Plutonic rocks, or the granitic, hornblendic, and talcose.
2. Early sandstone and conglomerate.
3. Basalt, trachyte, and lavas.
4. Tertiary formation.
5. Alluvial deposits.

ANCIENT PLUTONIC ROCKS.

The various rocks included in this division are intimately associated with one another, and belong to a single series; and much that is interesting, geologically, is to be learnt from a study of their transitions and relations. The granitic and talcose rocks are found to pass into one another through the hornblendic varieties, and the serpentine is one form of the rock in this gradation.

Mineral Characters and Relations.

Granitic Rocks.—The granite of the Shasty region is mostly albitic; it is very light coloured, and along the beds of streams, often has the whiteness of chalk.

In the Shasty Mountains it is a fine-grained rock containing colourless quartz along with the albite, besides scales of mica, which are black in the common variety, though occasionally silvery. At other localities, the mica is wholly wanting, and the rock is a granular mixture of albite and quartz. Albite and feldspar were contained together in much of the rock, the former being easily distinguished by a flesh-red colour, while the latter is white. This feldspar is usually in coarse crystals, measuring sometimes half an inch by an inch and a half: this rock is, therefore, an albitic granite porphyritic with feldspar.

True granite, containing no albite, occurs sparingly in the Shasty Mountains, and more abundantly near the Shasty River, where some of it is coarsely porphyritic, with but little mica and quartz. The mica of the rock is in wedge-shaped scales.

These granites are handsome durable rocks, and have no trace of a schistose structure. A gneissoid variety passing into a gneissoid mica

slate was, however, met with in the granite ridge fifteen miles south of the Boundary Range. The granite at this place is almost purely a mixture of feldspar and quartz. No true gneiss was seen in the Shasty Mountains.

Not less common than either of the above varieties is a granite containing small grains or crystals of hornblende in addition to the mica. The hornblende is in some cases very sparsely disseminated, and there is an imperceptible gradation from this kind to a fine-grained *syenite*, in which the mica is wholly replaced by hornblende. Both feldspathic and albitic granites show these transitions. This syenitic rock contains the hornblende in large shining crystals, an inch or two long, near the entrance to the Shasty Mountains, about twenty miles northwest of the peak. The light and dark green crystals, contrasting with the white albite, make a handsome rock. Many of the syenitic rocks contain little or no quartz.

In the Shasty Mountains we met with a fine-grained, nearly compact, porphyritic rock, of a grayish colour, formed of an intimate mixture of albite and quartz speckled with points of hornblende, and spotted white with crystals of albite a fourth of an inch long. This grayish rock, hardly granular in texture, has little resemblance to the other syenites or granites, though intimately associated with an albitic granite.

A rock consisting wholly of greenish-black crystals of hornblende was occasionally met with in the Shasty Mountains; and also a variety containing acicular crystals of white hornblende or tremolite.

There are other compact hornblendic rocks, black and uncrystalline, which are but a step removed from the syenites, although very unlike in appearance; for we find the transition through a variety in which the hornblende is partially crystallized. The rock is tough, and looks somewhat like certain compact basalts, but is much harder and breaks with sharper edges. It gives extremely rough features to the landscape. This rock occurs upon the Shasty River, near where the party diverged from it to go southward. It is much fissured or cracked, without any appearance of regularity of structure; and owing to this peculiarity, the action of the weather or of water, instead of smoothing down the points and crests, only makes them more rugged. A slaty structure is only imperfectly developed in a few isolated spots of small extent.

The syenites and compact hornblendic rocks also pass into a compact hypersthene rock, which is abundant along Destruction River, (the head

waters of the Sacramento,) in the Shasty Mountains. It occurs of various shades of gray, green, and brown, and the worn masses appear spangled with the pearly crystallization of the light grayish-green hypersthene. Hypersthene and hornblende are different varieties of the same mineral, the former having a pearly or submetallic lustre.

Talcosc Rocks and associated Siliceous Rocks.—The talcosc rocks of this region have seldom the usual schistose structure; they are generally compact, and irregularly fissured like the hornblendic rock above described. These compact varieties contain little talc, or graduate into a siliceous homogeneous rock, breaking with a smooth surface, consisting probably, for the most part, of silica and feldspar, or of silica alone, excepting some included clay.

A fissile variety having imperfectly the lustre of talc occurs in some of the ridges of the Umpqua Range; it is a grayish-green or grayish-white rock, too fragile and soft to break out in slabs. It occurs along with the hard compact rock alluded to. This compact rock has a grayish or olive-green or brownish colour, with none of the greasy feel of talc, and breaks into angular fragments, four or five inches through. No trace of crystallization could be distinguished, except in the quartz veins which thickly intersect it. It contains little or no talc, excepting as colouring material, and it is possible that the colour may be owing to a trace of hornblende. Other portions of the same rock are nearly pure silica.

In the Shasty Mountains there is a talcosc slate of a dark grayish-black colour, breaking into thin slates with a fine surface, and but slightly greasy in feel. This slate graduates into a compact rock resembling that just described. The colours of the latter, besides those stated, are often light bluish-green and greenish-white or grayish-green; and when forming the bed of a river, the waters have consequently the same mellow tint. Veins of milky quartz are common. This greenish rock would be called prase in hand specimens, and is often more or less translucent, with a smooth conchoidal fracture. It is very siliceous, consisting probably of silica and feldspar, with a trace of colouring material, yet the feldspar is nowhere in crystals or grains, and in much of the rock must be sparingly present. We may distinguish it as *prasoid rock*, for it is abundant wherever the talcosc formation occurs. Fragments of handsome prase are occasionally met with in these regions, which have sometimes the oily surface of talc.

A light greenish variety of this rock, near San Francisco, is associated with red and yellow jasper; some hills consist wholly of the latter

material, while in others both the green and red rocks are associated, showing, by their gradations, the close relation between the jasper and the prase rock.

A variety resembling bloodstone is also met with at times; it has a dark rich green colour and jasper-like fracture, though no specimens were seen with the red spots of true bloodstone.

From the transitions here pointed out, it appears that the jasper and prase rocks are closely connected with the talcose series; and that the translucent prases and bloodstones here found are only varieties of its condition.

A *chloritic* rock occurs on the northern declivities of the Umpqua Mountains, closely associated with the talcose varieties, and forming part of the same series. It is a granular olive-green rock, and is speckled white with feldspar. It resembles some greenstones. It is rather soft, and breaks readily with a rough surface. Isolated masses of foliated chlorite sometimes occur in this rock, and are generally associated with interlamination of quartz. A prasoid variety in the same region has a light grayish-green colour, compact texture, and smooth fracture, and contains disseminated grains of quartz. The quartz may be seen gradually disappearing or blending with the mass, and the transition may thus be traced to a green jasper or prase.

No granular steatite of good quality was observed in place. An imperfect soapstone was occasionally met with, and fragments of a purer kind occur in the Shasty Mountains, leaving little doubt that large beds may yet be discovered. These fragments were of a grayish-green colour, and had the usual characters of this rock. On the north shores of the bay of San Francisco, near the prominent point in the straits, just east of Sansalito Harbour, there is a steatitic rock intermediate between true steatite and laminated talc. It is a fragile, soapy rock, breaking irregularly into curved or lenticular laminæ, apparently indicating an approach to a concentric structure. The colour is gray or grayish-green, sometimes mottled with darker shades of green. Round and semi-angular masses of a dark green rock, resembling serpentine, are imbedded in the bank of talc rock; they are harder than ordinary serpentine, yet have the same features and fracture. Large portions of the bank, in some places, consist of this impure serpentine. The talc rock near by on the same shores passes into a talcose slate, very evenly fissile. The slates have the greasy feel of talc, and are of various colours, as white, gray, green, brown and dull black; they have a speckled appearance owing to the disse-

mination of talcose spots of a lighter shade than the colour of the slates. Some of the slates contain actinolite in slender crystals, and large nests of this mineral are not uncommon near the first locality mentioned, presenting radiated and fan-like crystallizations.

In these talcose slates, near Yerba Buena, I observed, in two instances, an imbedded fragment which appeared, at the time, to be a fossil, half obliterated in its characters. The specimens were afterwards misplaced, and I cannot decide, in my own mind, whether these were actual organic remains or not.

A *protogine* or *talcose granite* is another of the varieties connected with the talcose series. It was met with in the Shasty Mountains, having milk-white and grayish colours. One variety consisted of quartz and albite, with sufficient talc to give the rock a greasy lustre. Another variety, resembling much a granite, was composed of white quartz and yellowish feldspar in rather coarse grains, with spots of chlorite or olive-green talc. The rock is not durable, owing, in part, to some iron in its composition which rusts on exposure and colours the rock red. This protogine may be seen passing into the common talcose and prasoid rock, with which it occurs, and not into the granites. It occasionally contains yellowish or greenish-white pieces of a compact material, appearing like an imbedded fragment of indurated clay.

Much of the hornblende schist in the Shasty Mountains contains talc, and specimens of both hornblende and talcose rocks may be collected, in some instances, from the same square rod. Some portions of the diallage rock are also talcose.

Serpentine is largely developed in high ridges to the northwest of the Shasty Mountains, (west of the last encampment before entering the mountains,) where it has the softness and translucent edges that usually characterize this mineral. The general colour is a dark green; but it is sometimes mottled with a light grass green, and green diallage is abundantly disseminated through certain portions of the rock. There are also seams of amianthus or asbestos. This rock is also found in the Shasty Mountains, but where examined by the writer it was a harder variety; it may be traced in its passage into the ordinary talcose rock. Its colours are often variegated like verd antique marble.

From the above descriptions it is obvious that all the rocks enumerated, from the serpentines to the granite, belong to one and the same series. In the Shasty Mountains, the pure albitic and feldspathic

granite may be detected receiving at first a mere sprinkling of hornblende points among the scales of mica. These pass into syenites, and the syenites into hypersthene rock, and into a compact hornblendic rock which has no trace of crystallization. The passage to talcose rocks is equally distinct and gradual. Both the granitic and hornblende rocks become, at times, very gradually talcose, so that it is often difficult to say whether the rock should be classed with the talcose series or not. The talcose rocks graduate as imperceptibly into the prase rock, in which the talc is nearly or wholly wanting; and this again into the red and yellow jaspers. The transition to serpentine from the hornblendic and talcose rocks has been mentioned. The diallage of the serpentine is nothing but hornblende, and seems to correspond to the hornblende crystals in the syenite. The mineral hornblende is common in most serpentine rocks, either as asbestos, actinolite or diallage. We have described an imperfect serpentine in the talc near San Francisco, and mentioned that actinolite occurs abundantly at the same locality; indeed the serpentine at this place appears to owe its hardness to an excess of hornblende in its composition. At the same localities, the green and red cherts or jasper occur along with the talcose slates.

Topographical Relations.—The various rocks under consideration have appeared to follow some kind of system or regularity in their associations with one another.

The talcose formation was first met with, travelling south from the Umpqua; next we came upon syenite, then true granite upon the Shasty River. Leaving our southerly course, and travelling eastward on the Shasty, we passed again to the hornblende rocks, syenitic and compact. Returning to our southerly course, after twenty-five miles, we again fell in with granitic rocks, at first passing over gneiss, and soon after, granulite and some true granite. The granite continued to the Boundary Range, where it was syenitic.

After passing a region of basalt and sandstone in the vicinity of the Clammat, we crossed a prairie covered in many parts with pebbles from the talcose formation; then the foot of a ridge of serpentine; and then entered into a region of syenite at the foot of the Shasty Mountains. For twenty miles in these mountains, these rocks were interrupted by trachytes; yet a few pebbles or stones from the talcose formation were found in the narrow beds of small mountain streams. Leaving the trachyte, boulders of talcose rock and syenite occurred abundantly along the head waters of the Sacramento, and within a

mile, granite boulders were intermingled. A mile beyond, granite became the prevailing rock, and at the centre of the granite region, lofty pinnacles and needle peaks peered above the forests around to a height of three thousand feet. From granites and syenites we next passed successively to hornblende rocks, talcose and prasoid rocks, with protogine and some serpentine. The rocks of the talcose series constitute the greater part of the ridges about the head waters of the Sacramento, to the emergence of the stream from the mountains. The protogine in the talcose region was met with about fifteen miles before reaching the Sacramento plains. Talcose rocks and slates were again met with near San Francisco.

In this route we three times passed from talcose, through hornblendic regions, to granite, or its next akin, syenite; and as many times returned again nearly in the same order to compact talcose or prasoid rocks.

The great preponderance of talcose rocks and others related having a prasoid character, is another fact of interest; it is but part of a still more general fact,—the great preponderance of this part of the Plutonic series over the globe. Although we have not specific facts and localities, we have sufficient evidence, from specimens examined, that it is abundant in New Caledonia to the north of Oregon. The serpentine, soapstone, and the material carved into pipes by the Northwest Indians, appear to come from this formation. The greenstone, usually called jade, used for ornaments, and also in making hatchets, probably has a similar origin.

The relation of serpentine to other rocks of the series is also placed beyond doubt by the facts observed.

Structure—Dip.—The hornblendic and talcose rocks have been described as rarely schistose; and when this structure is apparent, it is seldom retained long enough to show the direction of the layers. The cleavages of the talcose argillite in the Shasty Mountains were often vertical, with numerous windings and contortions; and they varied from perpendicularity to a dip of sixty degrees. I traversed these rocks in a single direction only, and was of necessity obliged to keep with the party; and but few facts on this subject were therefore collected.

The structure of the jaspery rock of San Francisco, is worthy of description. The green, red and yellow varieties occur in the same vicinity. They form a series of layers, averaging two inches in thickness, and varying from half an inch to four inches. The layers are

very distinct, and are partially separated by open seams, and on the front of bluffs or ledges the rock has consequently a riband-like appearance. The layers often coalesce and subdivide without regularity, though uniformly parallel. They are frequently twisted, and thus change, at short intervals, from a vertical position to a dip of twenty degrees. The colours, red and yellow, are often mingled, and sometimes appear as parallel bands. In some instances the surface is red, while the rock is yellow beneath: this has resulted from the burning of a tree on the spot; for by heat the yellow variety readily changes to red. A small specimen of the green variety had an agate-like structure, as if it had been formed from an aqueous solution.

The rocks which have been described illustrate metamorphic action in an interesting manner; but we content ourselves here with simply stating the facts. The term *Plutonic* has been here used for convenience in an extended sense.

Decomposition.—The granitic regions of South Oregon are mostly covered with a dry gravelly soil or fine sand, from the granulation of the material instead of its decomposition. The sterile sands near the Shasty River, and over the country for fifteen miles north of the Boundary Range, arise from the disintegrated granitic rocks. The contrast of granitic and basaltic soil was strikingly displayed in the latter region: we passed abruptly from the unproductive sands of the feldspathic granite to a mellow loam arising from a basaltic dike. The dike was half a mile wide; and on leaving it, the transition was as abrupt again to granite sands.

The compact hornblende and talcose rocks undergo slow change, and give a rough, bristly appearance to the country, owing to the many projecting points of ragged rock. The plains in the vicinity of these rocks are strewed with pebbles they have afforded, among which there is a large proportion of milky quartz from the veins or seams. The soil from these rocks may be at once distinguished by its harsh gravelly character, and a pale brick-red colour. The semi-translucent prase on exposure becomes opaque-white, showing that, although nearly as hard as quartz, there is still some other mineral, (probably feldspar,) in its constitution.

With regard to the *mineral productions* of the rocks described, we have only the negative fact that nothing of interest has yet been discovered within the limits of Oregon. The talcose and allied rocks of the Umpqua and Shasty districts resemble in many parts the gold-bearing rocks of other regions: but the gold, if any there be, remains

to be discovered.* We know nothing respecting the position of the manganese ores on the Northwest Coast. The granites passed over by us were singularly free from even the more common granite minerals.

Ancient Sandstone, Shale, and Conglomerate.

The rocks of this formation were found associated with the ancient Plutonic rocks, and the coarser varieties consist of materials derived mostly from the talcose and prasoid beds.

The largest beds of these conglomerates and sandstone were found in the Shasty Mountains, where no other deposits of any kind were seen excepting the Plutonic and metamorphic described. Following down Destruction River, we travelled for eighteen miles over this formation, and left it again for talcose and prasoid beds, about thirty miles before reaching the Sacramento plains. On the south fork of the Umpqua, the formation was observed with the same characters, and associated with similar talcose and prasoid rocks.

The *sandstone* is a fine-grained rock, hard and gritty, yet argillaceous in its appearance, and presenting brownish or bluish-black and grayish-green colours. Though dull, it glistens faintly with minute scales of mica or talc, and with a lens, grains of quartz may be dis-

* Since the above was written, gold has been found on several of the eastern tributaries of the Sacramento. It was first detected, in the spring of the present year, (1848,) on the "American fork," a stream forded by us just before reaching Sutter's, a settlement on the Sacramento, about eighty miles above San Francisco. Since then, not only the affluents of this fork, and ravines opening into it, but other streams, flowing from the same great range, the Sierra Nevada, have been found to be highly auriferous. The gold occurs in the sand and gravel in grains, and occasionally in pieces weighing several ounces. There is little doubt that this gold district will be found to have very wide limits. The upper prairie of the Sacramento, from where we reached the Sacramento plains, was everywhere covered with the kind of quartzose pebbles that indicated a wide prevalence of the same rocks of the talcose series that we had traversed for a long distance in the Shasty Mountains and farther north.

The rocks most likely to afford gold are more or less slaty in structure, being either talcose, chloritic or micaceous slates, or argillite, and containing white quartz in inter-laminations and beds, and also in large or small veins. The quartz, the common matrix of the gold, is frequently cellular, and is sometimes rusty from the decomposition of pyrites. True granites and gneiss having quartz veins may afford gold, but this is not common. The puddingstone described on page 639, is not an unlikely place for gold, judging from the gold region of Brazil and other countries.

The extensive mines of *cinnabar* recently discovered in this region, about twelve miles south of San José, will add greatly to the convenience of gold mining.

tinguished. In the bluffs, the sandstone is divided into distinct layers of deposition, of varying thickness, from a few inches to several feet. These layers are very irregularly fissured or cracked, and break into wedge-shape and rhombic fragments. Some of the layers are imperfectly schistose, and others pass into a *slate rock*, which splits easily into thin plates. The latter resembles the talcose argillite already described; but the laminæ are less smooth and shining, and moreover, the rock contains the same glistening scales as the sandstone.

The *puddingstone* of the Shasty Mountains is a very hard, compact rock, composed of pebbles of quartz, flint, jasper, and others from the talcose and prasoid rocks. The pebbles are often smoothly polished, and of various fancy colours: black, red, rose-red, green, and gray of various shades are the more common tints. Coarser conglomerates contain rounded stones five or six inches in diameter.

The puddingstone of the Umpqua is very similar to the rock just described. The pebbles averaged half an inch in diameter, and were mostly quartzose, some of them like flint.

A conglomerate and shale, the latter resembling somewhat the rock of the Shasty Mountains, occur near the Bay of San Francisco, and probably pertain to this formation. I observed them on the shores of the harbour of Sansalito.

These rocks give very rough features to the landscape, resembling much the features of the talcose regions. On Destruction River, deep holes, roughened with points, had been eroded by the action of the stream on this rock, and jagged ridgelets and miniature peaks were left standing along the shores. Where the puddingstone prevailed, the country was covered with pebbles, and the soil was nearly as unproductive as the bare sides of the rock itself.

The slate appears to be the lower member of the series in the Shasty Mountains, and the puddingstone the upper. The latter occurs in thick deposits between layers of the compact and schistose sandstone, and also constitutes steep ridges seven or eight hundred feet high. Numerous veins and seams of quartz intersect the rock as in the members of the talcose series.

The dip and strike of the layers are constantly changing, and show that there have been great displacements and contortions. The angle of dip is commonly between thirty and sixty degrees; yet it varies from thirty degrees to verticality often within a distance of twenty yards. The layers are sometimes twisted around and folded over on themselves. The general direction is north and south, though there

are frequent oscillations of forty-five degrees either side. Along Destruction River, at the encampment of October 7th, the rock dipped sixty degrees to the northeast. The next day, while fording the river, the layers inclined sixty-five degrees to the northwest and north-northwest, varying from this to verticality. Still lower down the stream, the layers dipped from thirty-five to seventy degrees to the southeast and east-southeast, the smaller dip occurring alongside of a fissure four to ten inches wide, which was filled with fragments of the schistose rock; receding from the fissure, the layers were curved, and the dip increased to seventy degrees in the course of thirty feet.

Although we have no fossils to guide us to a knowledge of the age of this formation, yet its associations incline us to place it near the talcose and prasoid rocks, from whose material it is formed; and it is quite probable that a passage of the so-called Plutonic and metamorphic rocks into beds obviously sedimentary or even fragmentary, is here exemplified.

Basalt and other recent Igneous Rocks.

Many a frosted peak stands to attest the former activity of volcanic fires in Oregon. Baker, Rainier, St. Helen's, Hood, and others of the series, have been partially described. These isolated cones so resemble the lofty summits of Mexico, that we cannot doubt, although they have not been ascended, that they once formed a line of volcanoes through the whole extent of Oregon, and far into California. It is reported that St. Helen's and Rainier have shown evidences of action within the three or four years past,* and an account is on record of ashes falling fifty years since. But these centres have not been the sole or even the principal sources of eruption. There are craters in the Coast Range, and others over the interior section. Mount Swalahos south-southeast of Astoria is one of the former; several summits beyond Fort Hall are among the latter; and many peaks may be added to the number when the country is fully explored. But besides these vents, there have been still wider eruptions from fissures over the country, near the peaks and subordinate to them as well as in more distant regions, and from this source extensive beds

* Fremont mentions that on the 23d of November, 1842, ashes were ejected by St. Helen's.—Rep. Exp. ii. 1842, '43, '44, p. 193.

of basalt or basaltic lava have flowed throughout the land. We have shown, in another place, that fissure eruptions are common in all volcanic regions, (at least in recent periods,) and the same fact is sustained by a survey of Oregon.

The three peaks of the Cascade Range, Rainier, St. Helen's and Mount Hood, were so far examined by the surveying parties of the Expedition, as to determine that the rocks became more cellular and lava-like as the mountains were approached. Near Mount Rainier, Dr. Pickering found trachytes abundant; over the foot of St. Helen's, the rocks were cellular basaltic lavas; along the Cascades of the Columbia, and on the John Day's and Chutes rivers, which are properly at the foot of Mount Hood, there were similar cellular lavas, as ascertained by Mr. Drayton. It also appears that remains of a crater may be distinguished in the summit of Mount Rainier. These cones have similar features, as already described, and slope at an angle of about thirty degrees. Mount Saint Helen's is quite regularly conical.

Shasty Volcanic Region.—The Shasty Peak first came in view on the expedition to California, fifty miles to the north of it, where a wide prairie opened before us, and stretched away to the foot of the mountains. Travelling on six miles, a low ledge of the tertiary sandstone extended across the prairie from east to west, dipping fifteen degrees to the northward. Six miles farther, we passed a heap of volcanic rocks, consisting of large masses of grayish and reddish porphyritic lava, one to ten cubic feet in size, lying together in a disorderly pile. As we continued on, these heaps of lava blocks became frequent, and the plain was found covered with rounded and conical hillocks from twenty to two hundred feet in height, but averaging sixty feet. Some few had table summits. Although mostly covered with soil, the black rocks outcrop at top, and lie scattered over the surface; and notwithstanding they are covered with a red or brownish-red earth from decomposition, this earth is scarcely at all mingled with the alluvium of the plain. On the contrary, the prairie soil was of sandstone origin, and proved that this *hillock* prairie had been levelled under water since the volcanic rocks were thrown up.

Five miles from the first appearance of these lava hillocks, they are so crowded together that the plains almost disappear between their approaching declivities. Nearing the mountains, the country becomes a region of rough rounded hills, which increase in extent, and rise into high ridges lying at the base of the Shasty Peak. Some of these

hillocks lie within half a mile of the sandstone and serpentine hills on the west, and one was only a hundred yards distant.

Such was our approach to the Shasty Peak. We entered the mountains the next day, and travelled along to the west of it, within fifteen miles of its base. The hills were trachytic, and blocks of this light gray rock lay piled on one another through the forests, or were raised in mounds and hills, and long low ridges. We observed, however, no continuous bed of trachyte. The blocks were generally from six inches to a foot through.

In one view, from the west, the steep and even slopes of a black "sugar-loaf" rose from a deep valley below us; it was one object in the distant prospect from the prairie, the day before. The top of this volcanic cone was a little broken, and probably contained a crater, though none could be seen from the direction observed. We estimated the height at three thousand feet above its base, or four thousand five hundred feet above the sea. The sides were enveloped in pines or cedars, except about the summit, where only a few stunted trees made out to grow.

The trachyte had the usual rough fracture and feel of this rock. It was generally compact; yet some blocks were minutely cellular, and a spongy variety approached pumice, though no specimens of true pumice were seen. On decomposition it forms an ashy dust, which flies like dry ashes on riding through it. In some instances burning timber had changed the gray colour to a faint reddish tinge.

The appearance of the Shasty Peak has been already described. Its summit had been so much broken and denuded since the period of its activity that the crater features were mostly lost. The higher peak may have been the original crater; and there appeared to be a depressed plain at its summit. The lower peak stands a little like Vesuvius in the arms of Somma, and may have been the site of later eruptions. No time was allowed for closer exploration, as the party continued its course without stopping. The slopes in the distant view appeared to be covered with loose fragments, and had the light gray colour of the trachyte seen on our route. The ragged walls that project above the surface on the southwest side of the higher peak, extending down its steep sides through three or four thousand feet, are probably the lines of fractures or the courses of dikes. The long shadows of the needles and long points of rock in these walls, showed that they project to a great height, probably at least five hundred feet.

The only traces of existing fires in the vicinity are found in a hot spring on the east side of the Shasty Peak, near a track pursued occasionally by parties to California. Mr. McKay of the Willammet, who has visited it, described it to me as boiling up from among the rocks to a height of two or three feet, and says that he has cooked eggs in it. The water as it runs off in a small stream has worn the rocks smooth, and formed a small basin below, which is much frequented by the mountain sheep.

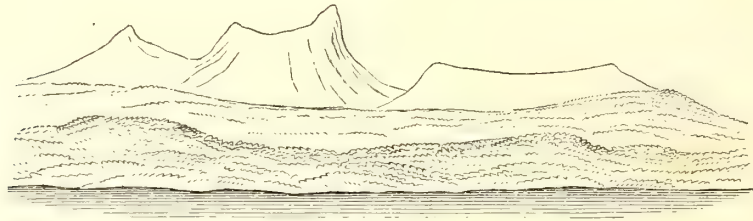
A mile and a half before leaving the trachytic region, we passed a small chalybeate spring. Descending a few yards to a small plain on the borders of Destruction River, the spring was observed just around on our left. The water oozes out from among the rocks into a basin scarcely holding a gallon, and flows down over a small marshy spot thickly covered with iron-rust; it is brisk and pungent with carbonic acid, and has therefore been called by the trappers *soda water*. The taste is very agreeably acidulous and chalybeate, and no saline or alkaline ingredients could be perceived. The temperature is as cold as that of the mountain torrent near by. Fifty yards beyond the spring, there is a shallow ditch a hundred yards long, containing about half a foot of water similarly chalybeate, but less brisk with carbonic acid. Our horses drank freely of it, and with good relish.

In the course of the following three days over the granites, talcose and hornblendic rocks of the Shasty Mountains, we frequently passed dikes or ledges of a porphyritic basaltic lava, very similar to the rocks of *Hillock Prairie*, north of the Shasty Peak. Many were three or four hundred feet in width, and some were much more extensive. The rock had a dark grayish colour; it was generally cellular and sometimes so coarsely so as to become a ragged lava. It contained tables of feldspar, mostly compound crystals, which were from a tenth to a third of an inch long.

Obsidian or volcanic glass is said to occur in some parts of the Shasty region; but we met with none of it. The Shasty Indians use this material for their arrow-heads, which they work out with great skill.

Swalalahos or Saddle Hill.—On the jaunt to Swalalahos, we ascended for ten miles Young's River, (a stream entering Young's Bay, on the south side of the Columbia,) and then struck through the forests to the south-southeast, twenty-five miles. When at the base of

the Peak, we were already twelve or fifteen hundred feet above the sea. Blocks of conglomerate of various sizes up to thirty cubic feet lay around among the heavy hemlocks and spruces of the forest. We



MOUNT SWALALAHOS, OR SADDLE HILL.

ascended by a difficult path sloping between forty and forty-five degrees. Up eight hundred feet, the forests were replaced by a grassy surface wherever the bare rocks were not projecting; and four hundred beyond, we stood under a high beetling bluff which forms the western brow of Swalalahos. We next followed the foot of the rocky precipice around to the northward, descending again about two hundred feet, and thence were finally guided to the top by a narrow gap on the north-northeast side.

The summit ridge forms a narrow wall on the east, north, and west sides around a large crater, which appeared to be at least five hundred feet deep. For half the depth within, the wall was nearly vertical; and then commenced a rapid slope towards the bottom. A dense forest covers its depths, and extending up the southern and southwestern declivities, is continuous with the forests of the range. The breadth of the crater is not less than two miles.

The walls on the sides examined, from the west to the northeast, consist of a volcanic conglomerate or breccia, which was composed mostly of angular fragments of basalt and pitchstone, some of it of an ochreous colour, and other portions, especially the coarser beds, dark like the basalt. The fragments of basalt seldom exceeded ten inches in diameter; they were compact or sparingly cellular, but not scoriaeous. The pitchstone was in pieces one or two inches through, and had nearly the lustre and colour of asphaltum.

On the sides explored, no lava streams or beds of basalt were seen, as the material was the conglomerate just described. There were some intersecting dikes; and the gap by which we ascended was the course of one of them. At the summit, the basalt of the dike projected

in a wall twenty feet high and twelve wide, and the same wall may be traced into the crater following a north-northeast course. The basalt was a compact brownish-black rock, wholly uncrystalline and imperfectly columnar in structure. It resembles the basalt of Astoria and other parts of the Columbia.

It is remarkable that the volcanic material of Swalalahos should be confined within three miles of the mountain on the northwest side.

We know nothing with reference to other volcanic peaks in the Coast Range. From the descriptions received, it is probable that Mount Olympus is of the same character; but this should be received as a mere conjecture on imperfect evidence.

Basaltic Rocks and Dikes of the Columbia and Willammet.—The remarks on a preceding page, have made it apparent that basaltic rocks or lavas extend widely over the territory of Oregon, occurring along the Columbia to the sources of the Snake River, over the plains south of Okanagan, about St. Helen's, and at short intervals through the Willammet Valley and the country south. These rocks in some instances form the surface of extensive territories, especially about the Upper Columbia. Again, as in the Willammet and Lower Columbia, they occur in isolated patches or ridges through a country of tertiary sandstones. The hills of basalt are in some places very numerous and range for miles with characteristic bluff summits. For twelve miles north of the Boundary Range, these crested hills stretched along in an interrupted line; and south of the range, similar hills continued about fifteen miles farther, through a region of the tertiary sandstone—the Astoria rock. The sandstone here dipped from twenty to twenty-five degrees to the east-northeast, or towards the basaltic hills. The ridges were in three or more interrupted lines, having the same general course. Near the southern extremity of the line, there was a small hillock of basalt; just back of it, there commenced an acclivity of sandstone, and after an ascent of two hundred feet, the hill declined a little, and then basalt commenced, which continued to the summit. Other hills beyond appeared to be sandstone, and others still were crested with imperfectly columnar basalt. Between the Elk Mountains and the Umpqua, basaltic ridges face others of sandstone on opposite sides of a plain not half a mile wide. The line of intersection of the two rocks in the bed of the Umpqua was concealed by the loose stones. Astoria is situated on a broad dike of basalt in a region of tertiary shale and sandstone. Two miles to the west of Astoria, there is another dike;

and ten miles to the east commences the basaltic region, which is continued up the Columbia.

The eruptions of these basalts and lavas have taken place from fissures throughout the country,—fissures which were more numerous and extensive near the volcanic peaks, but also intersected the whole region to the coast. They cut through the tertiary rocks, and are also interstratified with them. At the Boundary Range, a sandstone containing fossils graduates into a volcanic tufa or conglomerate.

The basalts are generally compact, without a granular or crystalline texture, and they vary in colour from grayish-blue to black; they are also cellular of all degrees and pass into a scoriaceous lava. Chrysolite in minute grains is usually present. At the Willammet Falls, both the cellular and compact varieties occur together, the same bed having the two characters in different parts, and in some places becoming scoriaceous. Along the Columbia below Vancouver, the rock is usually compact, with few cellules or none; and the same is the case with the variety near the grist-mill above Vancouver. On Elk River, both the compact and cellular varieties occur together, and the latter passes into an amygdaloid containing nodules of stilbite, natrolite, and chalcedony. At the Dalles, the basalt graduates into a lava of black and brownish-red colours. The rock of the Grand Rapids below Wallawalla, of the plains between Wallawalla and Colville, and of the country between the Columbia and Nisqually, is compact basalt and basaltic lava. On the Snake River, there are compact and cellular basalts and basaltic lava.

These rocks, whether compact or cellular, are occasionally porphyritic, as is observed at Killimook Head, and in some parts of the Willammet district. Just north of the Elk Mountain, there is a grayish-green variety, which consists mostly of feldspar in semi-translucent crystals, with olive-green augite in grains. A mile to the southward, it becomes a dirty grayish feldspathic rock, consisting of opaque feldspar in small imperfect crystals, and disseminated points of augite.

Chalcedony and carbonate of lime are of frequent occurrence in some cellular varieties, changing them to an amygdaloid. Near the Clammat the chalcedony formed large plates in fissures, and also filled cavities. The chalcedony and agates which abound on the Willammet and in other parts of the territory appear to come from the basaltic rocks.

These rocks, whose different varieties we have been describing,

often constitute a series of layers. Along the Columbia and Willammet the layers are from fifteen to fifty feet thick: they average thirty-five feet. Such beds piled upon one another form the palisades of the Columbia,—bluff walls two hundred feet high. The layers are very distinctly separated, and often cavernous recesses intervene; they frequently project in shelves, and the banks then appear terraced with vegetation. Up the Willammet, below the Falls, the east bank consists, for some distance, of the edge of a single layer, fifteen to twenty feet thick. Ascending farther, another layer is seen, and at the Falls a third is added. Others may be distinguished in the steep declivities forming the high banks of the river above the Falls. The rock is often extremely ragged and cellular at the junction of two layers, although elsewhere compact.

This occurrence in layers is the prevailing character of the rock high up the Columbia; and in some places, as at the Dalles, there is an alternation of the basalt with basaltic conglomerate or tufa. On the Snake River, similar basaltic layers have been described by Mr. Parker, as forming the steep walls. These walls are three hundred feet high, and in some places six to eight feet of conglomerate intervene between the solid layers.

Since each layer is evidence of a distinct flow of melted basalt, we may gather from these facts some idea of the vast inundations of liquid rock which have covered this country.

Some traces of a *columnar structure* may generally be detected in the basaltic rocks along the Columbia. Half a mile below Lower Cape Horn there is a natural wharf extending out into the river, which Lieutenant Walker described to me as consisting of hexagonal columns neatly fitted together; and there are also isolated columns, which are called the *Ten-pins*. Below Wallawalla, towards the Grand Rapids, there are fine exhibitions of basaltic columns. One peak, composed of these columns, looks like a square tower upon a conical base, and is called "The Windmill." Other table summits, with bluff fronts, exhibit basaltic prisms in fine perfection. A still more remarkable example of basaltic architecture occurs on the Snake River. As there are several layers of basalt, so there are several successive ranges of columns, differing a little in size and perfection, yet all remarkable for their regularity.

On the Willammet, below the Falls, there are imperfect prisms, eight feet in diameter, in a bed of basalt but twenty feet thick. In the vicinity of the Boundary Range, (lat. 42°,) the bluff fronts of basaltic

hills, which extend along for many miles, show an imperfectly columnar structure.

Besides the columnar structure, there is often a tendency to *lamination* in the basalt. The laminæ, in some places, are parallel with the bases of the columns, and arise from a concentric structure. In other instances, when the structure is not columnar, the rock splits into large slabs, sometimes less than an inch thick. This structure may often be detected on a worn or exposed surface, when it is not apparent on a fresh fracture. This lamination may be observed in the grayish-blue basalt, four or five miles above Vancouver. A still more perfect example of it was observed by the writer in a broad basaltic wall that crosses a ridge north of Elk Mountains. The laminæ run lengthwise with the wall, parallel with the sides of the dike, and separate easily.

Decomposition.—The compact basalts are firm and durable rocks. Decomposition takes place slowly, and produces a chocolate-coloured soil, sufficiently loose in its texture, and always fertile. The basaltic hills of the prairie region are usually covered with soil, except at top, where the rock generally outcrops.

In a section of the soil near Elk River, there was one foot of dark-coloured soil, and four feet of deep-red earth below, resting upon a bluish-gray basalt, without cellules. All of this earth had proceeded, beyond doubt, from the decomposition of the basalt; yet this rock was perfectly fresh and unaltered to within a sixteenth of an inch of the surface; and this exterior discoloured crust was nearly as hard and firm as the part below. I looked in vain for any intermediate step in the process of decomposition between the red earth above and the grayish-white or yellowish surface of the rock. It appears that when decomposition proceeds beyond this discoloration, the altered rock separates at once in scales or grains, which unite with the earth (or bed of decomposed basalt) that lies above. The iron of the rock, visible in minute grains, is set free, and probably promotes the decomposition; changing to a red oxyd it gives the red colour to the earth. Large rounded masses of superficially discoloured basalt lie imbedded in the lower part of the basaltic earth, which appear to have been separated from one another by this process of decomposition. In this manner a concentric structure is indicated which otherwise we should not have suspected in this compact rock. These facts are similar to those observed in New South Wales. (p. 513.)

Basaltic Conglomerates.—Conglomerates, tufas, and breccias of basaltic or volcanic origin, occur with the basaltic rocks and lavas in

many parts of the Columbia and Willammet regions, as we have already intimated. These conglomerates are coarse or fine, including sometimes large masses of basalt, and again consisting of pebbles or fragments, and earth; and they graduate into the stratified tufas, which consist of earthy material alone. Under these different forms, the rock is associated with the tertiary sandstone of Oregon, and it will come again under consideration on a following page.

Sacramento Bute.—Passing from Oregon to California we observed a single extinct volcano in the Sacramento Valley, one hundred and twenty miles from the mouth of the river; it is called the Sacramento Bute. Ninety miles above the Bute, to the east of the river, the prairie, for a few miles, was thinly strewed with rounded pieces of a vesicular lava; and the dry beds of some streams, running from the eastward, were composed of similar pebbles and stones. On the preceding day, there were three or four conical peaks in sight, rising a little above the lower hills of the region; but we did not pass within fifteen miles of them, and I could only suspect their volcanic nature: the pebbles observed indicated that there were extinct craters in that direction.

The Bute stands solitary in a wide prairie, the flat bottom-land of the Sacramento, and is about five miles from the banks of the river. It is a mass of mountain peaks, (as here represented,) with the lower

Fig. 1.



SACRAMENTO BUTE, BEARING SOUTHEAST-BY-EAST.

slopes long and gentle. It consists of an outer belt, and an inner area, as shown in the annexed profile. The inner area is an irregular

Fig. 2.



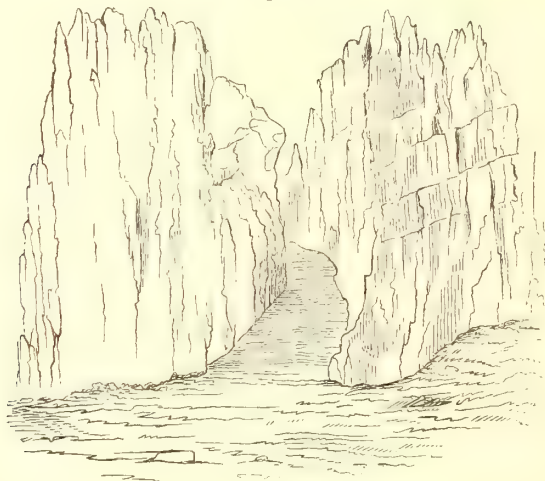
collection of summits,* encircled by a flat valley, which forms a kind of highway, three to four hundred yards wide, around the moun-

* The section of the inner mountains in the second view is ideal; we suspected, from the distant views, that the mass of peaks and ridges surround a central depression; but there was no time to verify this conclusion.

tainous centre. The belt, which is nothing but the lower slopes of a former peak, consists of a series of sloping layers, and is about a mile in width; the angle of ascent without is very gradual, not exceeding five degrees, while within, it faces the interior with a bluff front, one to three hundred feet high. There are several passages, one to three hundred yards wide, opening into the interior through the belt; and during freshets, the annular valley within is partly flooded, as well as the prairie around, so that both are a continuous level, excepting some undulations of fifty or sixty feet that rise from this inner plain. Our party entered by a passage on the south side, travelled in the valley for seven miles, and left the crater again by a passage opening eastward.

The central peaks are steep and rugged, and two or three are about eighteen hundred feet high above the plain; their summits are, in general, bold crests of rocks. On the ascent of one of the peaks, the rock proved to be a laminated trachyte, the lamination changing frequently in direction from horizontal to vertical. The annexed cut

Fig. 3.



shows one of the castellated peaks on the way up, and exhibits the vertical lamination.

The rocks are all of trachyte or trachytic porphyry, and contain, besides glassy feldspar, disseminated crystals of hornblende and hexagonal scales of mica. In some places the feldspar and hornblende give it very much the appearance of a coarse syenitic gneiss. The usual colours are gray, reddish or purplish, and white. A common variety

has a light grayish feldspathic base, and is thickly spotted with translucent crystals of feldspar one to two thirds of an inch long, besides mica, and hornblende in small black crystals; this is the syenitic gneiss just alluded to. The same rock occurs of reddish and purplish shades. Another form of the porphyry is laminated, the laminæ being very thin and easily separable: it contains mica, arranged parallel with the plains of lamination.

This laminated porphyry has, at times, a porcelain aspect; and some specimens consist of an alternation of chalky and compact layers. In other parts the fine lamination is rendered distinct by a difference in shade of colour. One block was broken which consisted of delicate stripes of white, light sepia brown, and bright purple colours. Glassy feldspar and hornblende are frequently disseminated with the mica through this laminated rock, though less abundantly than in the compact trachytic porphyry.

The outer slopes of the belt were covered with loose masses of the compact rock, and layers of the same constituted the belt ridge. These slopes are intersected by ravines made by water, as well as by the passages described.

In the annular valley, near the passage that opens through the belt eastward, there is an isolated hill, about one hundred and twenty feet high, and four hundred and fifty in diameter, the surface of which consists of large blocks of grayish and reddish trachytic porphyry lying loose, some of them eight cubic feet in size.

The Bute was evidently a volcanic cone. It is probable that the centre, at some period in its history, fell in, leaving only the lower part of the slopes entire. As rocks and fragments from ejections are not found over the prairie around, it was extinct before the river flats were formed; and the overflow of the river has since filled up and levelled off the surrounding country, as well as a large part of the annular plain. The hill of trachytic blocks near the eastern entrance may have been one of the later points of eruption. As the cone is partly buried in the river detritus, we evidently see only a portion of its original elevation, and it may be but a very small portion.

Tertiary Formation.

We have already stated that the tertiary formation of Oregon occurs in various places from Puget's Sound to San Francisco, along the

coast section of Oregon. It characterizes many of the hills and plains along the Straits of De Fuca, the Cowlitz, the Lower Columbia, the Willammet Valley, and the Elk; and although interrupted by more ancient rocks between the Umpqua, (on the route to California,) and the Boundary Range, it appeared again in this range, and continued nearly to the Shasty Mountains; here commenced a second interruption by the older rocks, and we found the tertiary again only on the San Francisco Bay, near its head. How far the same deposits extend toward the interior, we had no satisfactory means of ascertaining. On the Columbia banks, it is replaced by basalt above twenty-five miles from the sea; but the country either side is still characterized by sandstone or shale, with intermingled basaltic hills. High up, at the Cascades, and beyond for some distance, there are basaltic conglomerates, believed to be of the same age. Some vegetable impressions from Fraser's River, imbedded in a blue shale, (fig. 10, plate 21,) belong apparently to this formation.

The thickness of the formation on the Columbia and Willammet, is in many places, a thousand or twelve hundred feet. We ascended twelve or fifteen hundred feet of the sandstone, in the Elk Mountains; for fragments at top, and exposed horizontal layers at the southern foot, indicated that the whole was sandstone. Killimook Head, on the coast just south of the Columbia, consists of clayey layers alone, and is nine hundred feet in height. As in both of these instances the rocks had evidently been much removed by denudation, it is probable that fifteen hundred feet is even too low an estimate for the whole height above the present sea level.

Lithological Characters.—The rocks of the formation are soft sandstones, more or less argillaceous and schistose, and clay shales, either firm or crumbling, besides basaltic tufa or conglomerate.

The sandstone consists generally of granitic material, though sometimes of basaltic. In the former case, (as it occurs on both sides of the Columbia east of Astoria,) the constituents of granite,—feldspar, quartz and mica,—are readily distinguished, and especially the mica, in silvery scales. The rock has a sandy colour, and is usually brittle, or even friable; yet some deposits afford a firm and durable building-stone.

As the rock becomes argillaceous, the sandstone assumes a laminated structure, exhibiting each successive layer of deposition; and these laminæ are generally less than an eighth of an inch thick. The laminated variety of sandstone is, perhaps, more common than the

compact. The colour is often quite light, from the white clay that is combined with the sand.

With still more clay, the rock is a slate or a crumbling shale. The shale rock often appears like a bank of clay, and is so slightly compacted that a mere touch of the hammer crumbles large masses to pieces. Its colours, besides those of the sandstone, are often dark blue, dull green, brown, and blue-black; and the last is one of the most common. Some of the firm shales of this dark colour, could not be distinguished in their characters from the older secondary or silurian deposits. At Killimook Head, south of the mouth of the Columbia, the cliff, nine hundred feet high, (as ascertained by Mr. Drayton,) consists, for the lower two-thirds of its height, of a dark-blue clay rock, somewhat slaty. Above this the clay has a white colour, and so much resembles chalk as to have been thus called by the settlers.

The compact sandstones are in general very irregular in the extent and thickness of the layers. Layers apparently distinct at one place are coalesced at another place near by, and again they become subdivided, as in the Sydney sandstone, New South Wales, (page 462.) Thin layers of clay or clay shale often intervene, which disappear after running on for a short distance. Besides the interpolated beds of clay, there are also fragments or small masses of clay imbedded in the compact rock, and in some parts the clay thickly mottles the sandstone.

The shales appear in some cases to be largely developed in the lower part of this formation, while the upper layers consist mostly of sandstone. This was found to be the fact at Elk River, where hills of sandstone four or five hundred feet high overlie the shale. On the Columbia, the two rocks were seldom seen closely associated. The shales are in general most abundant on the south side of the river, and the sandstones on the north. At the west cape of Gray's Bay, the lowest layer is shale. We cannot say from our own observations whether the shale will prove to be generally the lowermost of the series.

The *basaltic* conglomerate and sand-rock vary much in texture, but the finer varieties are usually of a dirty ochreous colour. They occur in the Willammet Valley, about fifty miles north of the Elk Mountains, forming hills and underlying the plains, and also in the Boundary Range and the adjoining country. In these regions, the transitions to the granitic tertiary sandstone may be distinctly ob-

served. The localities high up the Columbia were not visited by the writer.

Concretions.—In many localities the argillaceous shale contains nodular concretions of limestone. These concretions are often very regularly spherical, and vary from half an inch to six feet in diameter, though if exceeding a foot, the form is more irregular. The size is nearly uniform at particular localities: in one place they were about half an inch through, or like bullets; a few rods distant they were an inch and a half; at another locality, all were two or two and a half inches in diameter; at another, the general size was four inches. They are often very abundant, and as they fall out from the crumbling precipice, the plain at foot becomes covered with these balls of stone.

The concretions often contain a fragment of wood or a fossil shell, a crab's leg or bones of fish. Yet in some localities no nucleus was apparent. Fossils rarely occur in the shale where these concretions are found, except they are inclosed in some of the concretions. No solid layer of limestone was observed in any part of the sandstone formation. These nodules occur along the Columbia, east of Astoria, in sufficient abundance to be procured and burnt for lime. They were also observed in the shale of Elk River.

Dip—Displacements.—The layers of sandstone and shale are generally horizontal. This is the case along the Columbia River. Near Elk River the rock is either horizontal, or dips six or eight degrees to the southwest, away from the basaltic ridges. South of the Boundary Range, the dip is from twenty to twenty-five degrees to the east-northeast, giving the hills a slope to the eastward and abrupt fronts to the westward. Across the Clammat Prairie there is a distinct line of elevation, as already mentioned, running east and west; the sandstone is raised about twenty feet above the plain, and inclines fifteen degrees to the northward. It appears then that horizontality is the prevailing feature; and that variations from this position are connected with the basaltic eruptions of the country.

The rock has been variously fissured, and it is a singular fact, that in many cases the fissures opened have been filled with sands like those of the sandstone, so that dikes of solid sandstone actually intersect the shales. Half a mile above Astoria, a sandstone dike five feet wide intersects the bluff from top to bottom, and may be traced following an east-by-south course, across the flat shores to the edge of the river. The rock resembles a half-decomposed granite, and seemed at

first to be an instance of granite intersecting tertiary shale; but a farther examination proved it to be identical with the granitic sandstone of the opposite shores of the Columbia. Large fragments and chips of the adjoining argillaceous beds are imbedded in the sandstone of the dike. Twenty feet up the face of the bluff there is a fault of eight

Fig. 1.

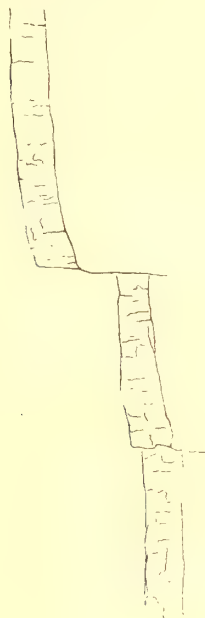


Fig. 2.



feet, (figure 1,) and below, near the bottom, there is another lateral slide of less extent.

Towards Tongue Point, two and a half miles above Astoria, there are several of these pseudo-dikes; and they are generally faulted. One of them is represented in figure 2; the width is eighteen inches, and the course east-by-south. It has been faulted obliquely six feet above the foot of the cliff; the upper part was carried to the left, and fell three feet below its former position. The concussion at the time of the fracture almost obliterated the lower extremity of the upper part. Near this place, there is another small pseudo-dike, six inches wide, running east and west. Fifty yards farther to the eastward, there are two dikes, the left of which is six inches wide near the top of the cliff, and eight inches below; the one to the right is five inches wide. The fault which they have experienced is oblique and irregular.

On the opposite shores of the Columbia, at the west cape of Gray's

Bay, there are veins of sandstone in a platform of shale, running as shown in the figure here given. A vein six inches wide has a course to the south-west-by-south, and dips a little to the southeast. On one side of the vein there is a branch an inch wide, which is soon lost in a mere thread. The sketch is a bird's eye view, and represents a length of eight feet.



These pseudo-dikes of sandstone, were probably formed after or during the deposition of the sandstone while the region was yet under water. Fissures were opened, perhaps by the same cause that ejected the basalt of the intersecting dikes; and the fissures were filled at once by the granitic sands, along with an occasional fragment of shale from the walls of the fissure. Their number and irregularity evince that these regions have been often shaken by subterranean forces.

The bearing of these facts upon the relative position of the shale and sandstone will be perceived; they afford presumptive evidence that the sandstone is the upper deposit. Moreover, if this be true, there has been a large fault in the line of the Columbia. The sandstone continues to the water's edge on the north shores, while on the south, banks of shale, at least two hundred feet thick, border the river; above this height, the shale is covered by the soil.

Minerals.—Besides the limestone nodules, no minerals of any importance were discovered in the tertiary formation, and there is little to encourage expectation. There are traces of gypsum in the shale near Astoria; and in the same rock on the Bay of San Francisco, it is more abundant. On a small island in this bay, just northeast of the Caquines Straits, Dr. Pickering observed that it had fallen from a seam in masses four inches thick, and he states that several tons might be procured there. A specimen of fine alabaster, or snowy gypsum, labelled John Day's River, was handed me by Mr. Drayton, who received it from Mr. Gray; nothing more definite is known of the locality.

Many of the concretions in the shale are deeply stained with iron, and a trace of iron pyrites was occasionally met with.

Some of the limestone nodules near Astoria, contain a centre or axis of a brown calcareous material, having an external crystalline form, but a granular texture within like the prismatic concretions from Glendon, New South Wales. They have a rhombic prismatic shape, like the Australian concretions; yet it is evident that the prisms are made from

a series of rhombohedrons. This is seen in the first of the following figures, which may be conceived of as made by the superposition of

Fig. 1.

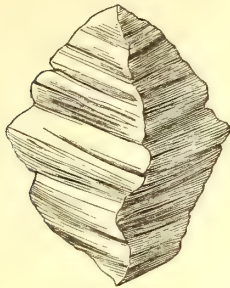
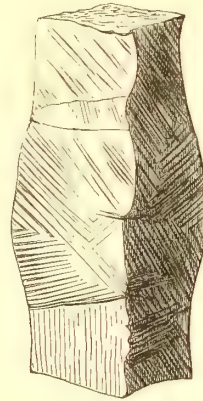


Fig. 2.



one rhombohedron upon a face of another in a continued series. It is a kind of interrupted crystallization, resulting in producing a rhombic prism or lengthened rhombohedron, which is farther obscured by a gradual diminution of the prism toward either end. The extremities are turned a little in different directions in consequence of this mode of formation, and in the same manner as the prisms from Glendon. The Glendon prisms differ in nothing except their having a smoother exterior, a result of more uniform crystallization. The granular interior is evidence that the crystals have undergone some change since their formation; but what is the nature of that change remains to be explained.

The following is the result of an analysis of one of these concretions, by Prof. B. Silliman, Jr.

Carbonate of lime,	-	-	-	-	93.60
Carbonate of magnesia,	-	-	-	-	1.65
Oxyd of iron and alumina,	-	-	-	-	1.55
Sand,	-	-	-	-	2.20
Water,	-	-	-	-	0.60
Loss,	-	-	-	-	0.40

Fossils.—The shale, in the vicinity of Astoria, contains numerous fossils. Those to the eastward are imbedded in calcareous nodules, and are consequently well preserved, while those in the cliffs down the river lie unprotected in the shale, and have suffered from compression. The specimens collected include numerous shells of mol-

lusca, minute Polythalamia, besides the legs of a Crustacean, an Echinoderm, the remains of four species of fish, and some Cetacean vertebræ. The descriptions of the species, as far as determined, are given in the Appendix.

This formation abounds in fossil wood, either silicified or carbonized. Stumps of trees and large trunks are occasionally found, and near Astoria, where it is common, it is called by the Indians *stick-stone*. We met with it on the California trip; and at one encampment, just above the bay of San Francisco, a mass was laid hold of by one of our party with the intention of using it for kindling. Near the Cascades it is very abundant. A specimen of the basaltic conglomerate collected there by Mr. Drayton contains a large piece of fossil wood; and the scattered fragments of that region probably came from the same formation. A stump, three feet in diameter, projects six feet out of the soil, in the vicinity of the Cascades. About forty miles above the forks of the Columbia, on the north branch, a long trunk of a silicified tree projects from the face of the precipice, at a height beyond the reach of anything but a rifle-ball. The rifle has been used to collect specimens of it, and its fossil nature was thus proved. It is described as lying between layers of the basaltic rock, and it is probably imbedded in an intervening layer of basaltic conglomerate.

Many of the specimens are very beautifully agatized, and the woody structure is distinctly retained. Some of the wood was thickly worm-eaten before being petrified, and it now contains vermiform pieces of chalcedony or quartz, filling the ramifying worm-holes. Some fragments are so completely riddled that only a thin partition of wood remains; these partitions retain the grain of the wood, and explain the ambiguous character of the specimens. Masses partly carbonized and partly silicified, and in intermediate stages, are not uncommon, both in Oregon and in California on the Lower Sacramento.

Thin seams of coal occur in the shale near Astoria; and in the Cowlitz, larger deposits of lignite have been opened. The coal of the Cowlitz is poor, containing considerable pyrites, and, moreover, it is not abundant. It burns with much smoke, caking completely. An analysis, by Prof. B. Silliman, Jr., obtained for the composition of this coal—

Carbon,	.	.	.	.	.	45.56
Volatile ingredients,	.	.	.	.	.	52.08
Ashes,	.	.	.	.	.	2.36

Impressions of leaves were occasionally observed, as in the sand-

stone near Elk River, and the basaltic sand-rock towards the head of the Willammet Plains. Fine specimens, probably from the same formation, were obtained by Mr. Elliott, of the Expedition, from the neighbourhood of Fraser's River. They occur thickly together in a firm blue shale.

Mineral coal is said to occur on the coast north of Oregon, and on Vancouver's Island; but as I had no opportunity of visiting the region, and have not seen specimens, I cannot speak of its quality or abundance.

Age of the Tertiary.—The fossils of Astoria have been examined and described for this report by Mr. T. Conrad, and the following are his conclusions with regard to the age of the deposits.

“From the investigation of the fossils previously received from Mr. Townsend, I had arrived at the conclusion that they were of the geological era of the Miocene, and the specimens you sent confirm the opinion. I do not recognise, it is true, any recent species of the coast of California or elsewhere, but neither is there any shell of the Eocene period, nor has the group any resemblance to that of the Eocene. On the contrary, the forms are decidedly approximate to those of the Miocene period which occur in Great Britain and the United States. *Nucula divaricata*, for instance, closely resembles *N. Cobboldiæ* (Sowerby) of the English Miocene, and *Lucina acutilineata* can scarcely be distinguished from *L. contracta*, (Say,) a recent species of the Atlantic coast and fossil in the Miocene beds of Virginia. *Natica heros*, a shell of similar range, is quite as nearly related to the *N. saxea*. A similar number of species might be obtained from some of the Miocene localities of Maryland or Virginia, and yet no recent species be observed among them. In the Eocene, and also in the Miocene strata, there are peculiar forms which obtain in Europe and America, and although the species differ, yet they are so nearly allied that this character alone, independent of the percentage of extinct forms, is quite a safe guide to the relative ages of remote fossiliferous rocks. On this foundation, I speak with confidence when I assign the fossils of the Columbia River to the era of the Miocene.”

River Terraces and Beach Formations.

Oregon, west of the Cascade Range, is covered with extensive tracts of alluvial country. Every river has its bottom-lands, and, in general,

they form broad plains on each shore. East of the Cascade Range, beyond Wallawalla, alluvial plains are said to be comparatively uncommon. As the rivers flow in a deep bed, usually several hundred feet below the table-land above, they only wash the sides of the enclosing gorge during freshets. Yet small flats, half a mile wide, not unfrequently border the river, even in these deep channels.

The alluvial tracts along the rivers of the coast section, have been described as lying in two separate plains, styled the upper and lower prairies. We proceed to give some particulars respecting the extent and features of these river flats.

Willammet Plains to the Mission Settlement.—I first observed the upper terrace of the Willammet Valley, below the Willammet Falls, fifteen or twenty miles from the Columbia. The forests of the shore occasionally opened, and exposed to view from the river, a steeply sloping bank forty feet in height. Going up the stream, the terrace continued along, varying in its distance from half a mile to a mile. The banks of the river, in this part of its course, are twelve feet high at low water. Twenty miles up the river, the shores were rocky; yet even here, the terraces were often distinct. The upper of the two layers of basalt bordering the river, retreats in an undulating line, from a few rods to half a mile from the stream, leaving small flats, like bays or coves, bounded by a steep, rocky wall, fifteen to twenty feet high.

Above the Falls to Champooig, a distance of twenty miles, (ascended by the writer in a canoe,) the high, wooded bank of the river shut out of sight the terrace which is said to exist on the east shore. At Champooig, we passed up the bank, (here twenty-five feet high, M, fig. 1,) and for a mile inland, travelled over an alluvial plain, the proper

Fig. 1.



SECTION OF THE ALLUVIAL PLAIN OF THE WILLAMMET.

bottom-land; thence we made a rapid rise of fifty feet, which brought us to an upper prairie, the height of which was estimated to be in no part over sixty feet above the lower plain, or eighty-five above the river level. We continued on the high prairie for twelve miles, crossing a great bend in the river, and then by a steep path descended fifty-five or sixty feet to a small valley, which soon opened upon the

Willammet, the river here running in rapids, between steep alluvial banks twenty-five feet high. In the course of a mile along the river, the terrace neared the banks to within a few rods. Its height was still about sixty feet. We forded the river two miles beyond, and on the opposite side found the terrace again of the same height, about a quarter of a mile back from the river.

This terrace is described by the settlers, as characterizing the alluvial plains throughout the Willammet District. It is generally within one or two miles of the river, but retreats at times four or five miles, and in other parts borders the stream. The upper plain is occasionally fifteen miles wide, but the ordinary breadth is less than four miles. The slope between the upper and lower prairies is usually inclined at an angle of thirty degrees, and in most places it is densely overgrown with trees and shrubbery. High rolling prairie hills bound the alluvial district, and occasionally a hill stands isolated in the plains.

The sections of the lower plain, exposed along the banks of the stream, present successive deposits of a grayish, friable loam, and pebbly or gravelly layers. The lower *five* feet usually consist of stones and pebbles, while the upper *twenty* are mostly a sandy loam. I observed no good section of the upper plain, and therefore can add nothing to the statements respecting the surface, on page 619.

Willammet Plains and Country south to San Francisco.—On the trip to California, we did not see the Willammet again after leaving the Mission Settlement, although we were traversing its prairies, till we reached the Elk Mountains. Passing a region of hills on the first day out, we came upon the upper prairie, and shortly after descended fifty feet to the lower; from which, in less than a mile, we ascended again the same slope.

On a small rivulet, we found the upper and lower flats to differ twenty feet in height.

On another small stream, a few yards wide, about nineteen miles from the settlement, there was a similar upper and lower flat, twenty feet apart.

Twenty-five miles beyond, after six miles of flat prairie, there was another streamlet, not knee deep, called Marsh Creek, with fifteen feet between the height of the upper and lower plains bordering it.

Sixty-five miles from the Mission Settlement, Lumtumbuf Creek, another small affluent to the Willammet, is bordered in some parts by a lower prairie lying ten feet below the upper, and fifteen above the

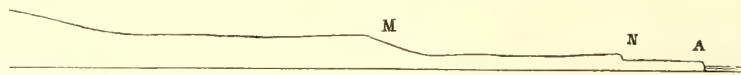
level of the stream at low water. The creek is about ten yards wide.

The following day we travelled fourteen miles across a flat plain, the lower of the Willammet, and then ascended fifty or sixty feet to an undulating plain, having a dry pebbly surface, and producing only ferns. After travelling three miles, we descended again to the lower prairie.

Elk River is a small stream, twenty yards wide and a foot deep where forded. I observed at this place no distinct terrace.

The north fork of the Umpqua is a large river, eighty yards wide, running over a rocky bed. The north bank was twenty-five feet high.

Fig. 2.



SECTION SHOWING THE TERRACES ON THE UMPQUA.

The opposite was but fifteen feet; but there was a rise of eight feet at N, (fig. 2,) at which level there was a plain fifty yards wide, and then a rise of fifteen feet (M) to the upper prairie. A corresponding terrace was noticed the two days following in several places on the south fork, a turbulent stream resembling the north fork. In one place for half a mile the terrace continued uninterrupted; the lower plain was generally about three hundred yards wide, and the river banks eighteen feet high. The river in this part was a quiet stream flowing over an alluvial bottom; and the terrace was alike on both shores.

The Shasty River was forded about forty-five miles from the coast, where it is a fine stream, about a hundred yards wide, and two to four

Fig. 3.

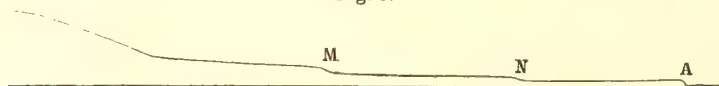
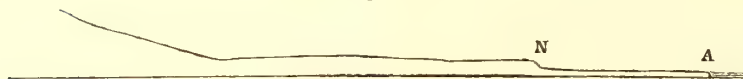


Fig. 4.



SECTIONS ILLUSTRATING THE TERRACES ON THE SHASTY.

feet in depth, with banks of twelve to eighteen feet. At one place (figure 4) on the north side, there was a terrace twenty feet in height,

(N, fig. 4.) Along another part of the river, half a mile from this, (figure 3,) there were two terraces; the *first* of eight feet (N, fig. 3), two hundred and fifty yards from the river, the *second* (M, fig. 3) of ten feet, two hundred yards. The soil continues to be alluvial for fifty yards beyond the last rise; then changes to a granitic sand, and slopes into the gentle declivities of the granite hills. A few fragments of pumice were found at the top of one of these terraces.

On the Clammat, I observed no terrace at the place where we passed it.

The Sacramento terraces are far more extensive than those of the Willammet. Where we first made the alluvial country, in latitude $40\frac{3}{4}^{\circ}$, the region, according to our estimate, was between two and three hundred feet above the river. From this place the surface was pebbly, and sloped very gradually for three miles; then we descended a steep terrace-slope of sixty feet vertical height (M, figure 5). In a

Fig. 5.



Fig. 6.



Fig. 7.

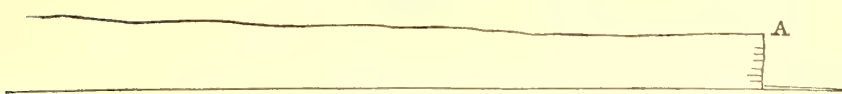


Fig. 8.



SECTIONS ILLUSTRATING THE TERRACES OF THE SACRAMENTO.

view from here, the upper plain on the opposite side of the river, appeared to us to be full three hundred feet high. The terrace of sixty feet extends around to the southward. In the lower prairie there were two small terraces, one of six feet, (N, fig. 5,) and another four hundred yards nearer the river of eight feet (O, fig. 5). The

latter was properly part of the bank of the river, as the usual height of the bank in that vicinity is twenty feet, and at this part it was only twelve feet. These small terraces were common in the lower prairie; in figure 6 at N there is one of five feet. They disappear after continuing on a mile or two, and at times commence again at different distances from the river.

The day following we left the lower prairie again, by ascending first a terrace of twenty feet, and half a mile back, another steep slope of eighty feet, making the whole ascent to the upper prairie one hundred feet. It was a region of hills of nearly uniform height, but very gradually rising back to two hundred feet. The hills were usually rounded; but in occasional sections they were found to consist of horizontal beds of clayey and sandy loam, gravel and pebbles, proving them to be alluvial, of which, however, there could be no doubt, judging from their situation and general features. In the course of ten hours' riding we descended again to the bottom-land of the Sacramento. The upper alluvial region here faced the lower prairie with a line of steep fronts seventy to one hundred feet high; and half a mile below, they bordered the river in a bluff of one hundred feet (figure 7).

In the bluff of one hundred feet, just alluded to, the lower portions of the alluvium consisted of a sandy loam, while the upper were beds of gravel and pebbles. The layers were several feet thick, and did not appear to be subdivided into thin laminæ or layers of deposition. They were slightly consolidated into an argillaceous sandstone, and this half-formed rock was occasionally hard enough to fall to the bottom in compact masses ten to twenty cubic feet in size: the lower layer projects into the river, and forms a platform much eroded by the current.

The following day, in latitude $40\frac{1}{4}^{\circ}$, we ascended again to the upper prairie, which in this part was less broken, being mostly an undulating plain. Descending at one place, we found a slope of thirty-five feet (M, fig. 8), and three hundred yards beyond (at N, fig. 8), a second terrace of twenty-five feet; two hundred yards from here, the river lay between banks twenty feet high.

We forded the Sacramento to its east bank, about forty miles from where we first made the alluvial region, and travelled for the remainder of the way, till we took boats, on the lower prairie. We approached the upper prairie in but one instance; and at this place it was fifty feet high, and was as pebbly as the same plain on the other side of the river. A trace of the upper prairie is found on the

Sacramento Bute. There is no regular deposit of alluvium on its sides, but pebbles of quartz and jasper, like those of the pebbly upper plain, cover the outer declivities to a height of one hundred and fifty feet above the level of the prairie.

The Sacramento Plains were estimated to be six miles wide where we first reached them. At the Bute, the width is about thirty miles, and at Captain Suter's, as he informed me, near fifty miles. The plains continue to Caquines Straits, at the head of the Bay of San Francisco, twenty miles from the sea, where the hills of the Coast Range confine the river, and intercept the alluvial flats.

Columbia River.—The only place on the Columbia where I observed the terrace of this region was at Vancouver. Back of the fort, about half a mile from the river, there is a terrace of forty-five or fifty feet. To the westward the terrace gradually melts away into a longer and more gentle slope. Eastward, it may be traced for three miles, nearly to the grist-mill, where it meets the river bank; but it is mostly covered with forests. At the grist-mill, in the bed of the stream, there is a compacted deposit of pebbles, about thirty-five feet above the river, which resists the action of the water, and stands out in projecting ledges, though still so yielding that it may be dug out with a pickaxe. This bed is probably a part of the old or upper alluvium.

The river at Fort Vancouver has banks twenty feet high; but here, as elsewhere about the rivers, the bottom-land situated at this height, is mostly flooded during the freshets.

In the Upper Columbia, about Wallawalla, the same terrace was observed by Mr. Drayton, and the following particulars have been furnished by him. The great Wallawalla plain lies about ten feet above flood water in the Columbia. This plain is nearly level, but rises a little from the shores. Ten miles east, there is a series of gravel hills, showing a perpendicular front towards the plain, thirty or thirty-five yards high, consisting of alternating beds of earth, gravel, pebbles and large rounded stones. The pebbly layers were most abundant one-third of the way to the top. The base of these bluffs is forty or forty-five yards above the river. They stretch around to the southward, at the base of the higher basaltic hills, and may be traced for several miles.

From our philologist, H. E. Hale, we learn that above the Dalles, for a long distance, the valley of the Columbia widens to two miles, and is enclosed between two unbroken lines of basaltic hills, five hundred

to one thousand feet high; and there are two or three successive ranges of precipices, at nearly the same height, on both sides of the river. There are no alluvial flats along the shores.

Alluvial Islands and lower Prairie of the Columbia.—The Columbia, below Vancouver, abounds in alluvial islands as well as submerged flats. The islands have generally the same height as the lower prairie, but are usually depressed at centre. From the broad line of cottonwood and willows which borders them, the surface gradually declines inward to a low flat, sometimes below low water level, though generally somewhat above it. A few of them consequently contain a permanent lagoon; and as remarked by Mr. Douglass, of the Hudson's Bay Company, they resemble in form the coral islands of the Pacific. All are filled during the freshets, and only a narrow rim of land remains above the surface.

The island of Multnomah, at the mouth of the Willammet, is mostly alluvial, but in the western part it is basaltic.

The lower prairies of the river, like the alluvial islands, are generally highest along the shores, and covered with a forest line, (fig. 1,) while the surface back is much depressed, and a bare meadow. In sinking a well near Vancouver, two or three feet of soil were first passed through; then nearly thirty feet of gravel; below this, a light quicksand, too loose and mobile to be penetrated without much difficulty, on account of its falling in. We observed here, as we had elsewhere, that these alluvial deposits were not minutely divided into thin layers of deposition, but were in thick, compact layers, unlike the gradual depositions over most alluvial flats.

During freshets, the water usually commences to flood the prairies by rising through the soil, instead of overflowing the more elevated banks. The turf is seen to swell in small spots over the surface; and if these swellings of the turf at this time are pierced with a cane, the waters spout out in a stream. They break as the pressure increases, and the ponds then begin to fill, and the flats to be overflowed. It was the opinion of Dr. McLaughlin that the water penetrated laterally along the quicksand layer, and thence rose, by the pressure, to the surface. At the usual floods in June, the water of the Columbia rises from sixteen to nineteen feet.

The less height of the land back from the shores may be owing to the following causes: the fact that the waters flowing along tend to heap up material on the banks, from the counter-currents produced along the shores; that the shores are covered with shrubbery and

trees, which are calculated to entangle or stop the floating leaves and branches of the river, and secure a considerable part of its detritus; that the vegetation of the shores is contributing to the accumulations; that the roots, also, of the trees raise the surface by adding their own bulk to that of the soil; that the plain, back from the shores, lies for some time under water during freshets, which water exerts a pressure upon the material below, and may render it more compact than the alluvium of the shores.

Deposits at the mouth of the Columbia.—The Columbia, for the last fifteen miles of its course, averages four miles in width. Extensive submerged flats occupy nearly the whole breadth, leaving a channel along either shore. From the capes, which are six miles apart, there stretch out large sand-banks, the southern five miles long, and nearly two wide, extending a little north of east; and the northern four miles long, and a mile wide, stretching nearly to the south. Between the extremities of the two, there is a passage a mile wide, which divides and turns both to the right and left, around a large sand-patch, lying at the middle of the mouth. The whole surface of the submerged alluvial flats is about forty square miles in area.

The shores of the river are gaining little from these depositions except about the south cape, and, especially, just outside of the southern breaker, between Killimook Head and the river. The sea-beach south of the river is about sixteen miles in length. From a chart of the region by Mr. Drayton, and from his observations, we ascertain that back of the beach there are three drift ridges of sand. They are a little broken and uneven, but have a general parallelism with the beach, and in consequence of their positions, a stream of water, rising near Killimook Head, flows first far to the north, back of the third ridge, and then returns between the second and third, to Killimook Head, where it enters the sea. The *first* of the ridges is a fourth of a mile from the sea, and ten to fifteen feet high. The *second*, three-fourths of a mile back of the first, and twenty to twenty-five feet high; the *third*, one and one-fourth miles from the second, and fifteen or eighteen feet above the sea. The prairie plain extends for a mile back of these ridges, and then becomes densely wooded, and rises forty feet above its former level, which is the greatest height between the sea-beach referred to, and Young's Bay, an indentation in the south shore of the Columbia, just within the south cape. The whole point between the beach and Young's Bay, is, apparently, the result of river and marine action combined. The soil of the inner portion is a

light alluvium, though sandy along the shores. A mile and a half to two miles back, it is a fertile loam, covered with a luxuriant growth of grass. The soil is, however, but five or six inches deep, and lies upon the white beach-sand.

Cowlitz Valley.—The distinction of upper and lower prairie exists in the Cowlitz plains, and the two are similar to those of the Willammet. Mr. Drayton states that the upper prairie is raised forty feet above the lower.

CAUSES OF THE FEATURES OF OREGON AND CHANGES IN ELEVATION.

The great contrast between the east and west sides of the Rocky Mountains has been often mentioned, the one abounding in sandstones, with some argillaceous limestones, without volcanoes or volcanic rocks, while, on the other side, recent igneous rocks prevail, (basalts, basaltic lavas and trachytes,) and the sandstones are comparatively of small extent. Granites and allied rocks occur on both sides; they form the crest of the Cascade Range in most parts, and also the body of the range, with the exception of its conical peaks and their vicinities. The sedimentary deposits of the eastern foot, near the Mississippi, and south in Texas, are, to a great extent, cretaceous in era; and the same rocks, according to recent observations, extend to a height of five thousand feet on the eastern slopes, to Fort St. Vrain's, and also occur about Poblazon west of the del Norte, situated six thousand feet above the sea. About the summit, the formation, according to some imperfect data, has been considered of the Oolitic age. At the western foot, there are tertiary rocks to a height of fifteen hundred feet, and, perhaps, two thousand; whether cretaceous deposits occur above, before reaching Poblazon, has not been ascertained.

These observations teach us that the Rocky Mountains were beneath the sea, to a very great extent, till a comparatively recent epoch. We cannot say when the crests of the range, the Wind River chain and other granitic summits, first arose from the waves; the period may have been very distant. But the Oolitic rocks of the summit, if such is their real character, (and there is no probability of their being older,) show that till then nearly the whole mountain territory was submerged. Since that time, the dry land has been extending its limits, and increasing in elevation above the water level. The investigations in South America prove that there a very large portion of this great

chain of the continent was beneath the sea until the cretaceous epoch.* The Rocky chain, at this period, was still five thousand feet below its present level. Since the tertiary era, the coast on the Pacific shore has probably been increased in altitude above the sea at least fifteen hundred feet.

The parallelism of the chains of mountains has been particularly considered; and we have also pointed out, in another place, the probable connexion between the depressing of the Pacific Ocean and the formation of the great parallel lines of elevation that form the western border of North America. Whether these lines commenced to form together, or were begun in succession, we cannot now decide. Granitic rocks occur in both the summit crest and the Cascade Range. The lofty cones of the latter are proof of the great depth and extent of the rupturings that marked the commencement or progress of this volcanic chain.

Basaltic eruptions have continued in Oregon to a late period, and even now some of the volcanic peaks, as has been stated, still eject ashes. These rocks may, in some parts, be of very early age; on this point no definite information was obtained. That ejections took place before and during the miocene tertiary period, and have occurred since, is beyond doubt; for they occur below the sandstone; and, as dikes, they intersect it. The surface basaltic lavas are probably of comparatively recent date. Those of the Willammet Falls and John Day's River resemble a recent scoria: this fact, however, is no evidence, by itself, of modern origin; except so far as it proves that the eruptions producing them were subaerial, and therefore must have happened since the cretaceous period, when a large part of the elevation of the Rocky Mountains took place.

The vast amount of silicified wood throughout Oregon may be readily accounted for, in a region where igneous action has been so extensive, and siliceous waters, from submarine eruptions or from springs, must have been abundant. The chalcedony and agate of the country, which come from the amygdaloidal basalt, have evidently had a similar origin. The zeolites of the same rock may have been formed in part from similar siliceous waters, or from waters infiltrating through the rock, and carrying along some of the decomposed material.

The deposition of the tertiary sandstone took place along a sea-shore, while igneous operations were going on in the same region, and

* Darwin on South America, 8vo., London, 1846; page 238.

the shales, as the fossils show, were formed over the flats that border a sea-shore. The material of the sandstone is, however, in general purely granitic, except in the neighbourhood of the volcanic regions, where it varies to a tufa and conglomerate. These deposits indicate an elevation, as we have said, of at least fifteen hundred feet since the upper layers were formed.

The sandstone and shale have been denuded on a vast scale. Although the rocks are nearly or quite horizontal, wherever examined, there are no plains in the coast section excepting those of alluvial origin. The sandstone has been excavated till the country has become a region of hills and valleys and alluvial flats. Some of the hills rise a thousand feet above the lower prairies, affording thus some measure of the extent of the denudation. These are the effects of water, aided, probably, by the fractures attending the igneous operations of the land.

The elevation of the Rocky Mountains, whenever it took place, left here and there a depression filled with salt water, and the great lake Timpanogos, one hundred miles long, appears to be of this character. Others that may have existed were drained off and rendered fresh. Much salt, however, impregnates the sandy plains, both about the summits of the chain, and upon the country below, especially over the great semi-desert of California, a region mostly shut off from the sea, except in the direction of the Colorado. Indeed, no part of the territory seems to be wholly exempt from these saline efflorescences, except the forest region of the shore. Lieutenant Johnson observed salt pools in the Grande Coulée, and specimens of salt were brought by him from the vicinity of the Spokane. I met with incrustations on the Clammat prairie, and patches of *Salsola* were not uncommon. They occur also near the Bay of San Francisco; and near the Caquines Straits there is a copious stream of salt water. This prevalence of salt may be viewed only as an indication that the country has been beneath the ocean. Its continuance in the soil is favoured by the comparative dryness of the climate, especially in the upper country.

Evidence of Change of Level in the River Terraces.—Another epoch in the geological history of Oregon is indicated by the river terraces. These terraces, as the facts detailed show, occur over a wide extent of country. We have traced them from the Cowlitz to the mouth of the Sacramento, and along many of the smaller streams, as well as the rivers. The following table presents a review of the facts, showing their height above the bottom-land of the rivers:

Cowlitz River,	-	-	-	-	-	40 to 45 feet.
Columbia, at Vancouver,	-	-	-	-	-	45 feet.
Columbia, at Wallawalla,	-	-	-	-	-	150 (?) feet.
Columbia, south of mouth,	-	-	-	-	-	35 feet.
Willammet River,	-	-	-	-	-	50 to 60 feet.
Umpqua River,	-	-	-	-	-	15 feet.
Shasty River,	-	-	-	-	-	20 feet.
Sacramento,	-	-	-	-	-	60 or 70 feet, and

country rising gradually above the slope to two hundred feet.

There appear to be but two ways of accounting for these river terraces: either lakes have existed along the rivers, which have burst their barriers, or the rivers have excavated the country in consequence of an elevation.

The existence of lakes throughout a whole country, connected with all its rivers, is highly improbable, and requires for its proof the strongest evidence. Rivers cut out their channels by a gradual process, as a country is raised above the ocean, forming, with few exceptions, a complete drainage for the land. Lakes could not, therefore, exist to the universal extent implied by the facts, except, perhaps, as the result of a sudden rising of the land from the ocean.

The formation of such lakes, by an abrupt elevation, in a region having the ranges of heights parallel with the coast, as in Oregon, is certainly a possibility. But the water, to make the alluvial accumulations, must be running water, and it must be in operation in its channels for a long period. And how long would such lakes exist after an elevation? If the violence attending the change of level did not at once open for them a passage, the accumulation of water going on during a single flood, would break a passage through such soft sandstone beds as occur about the mouth of the Sacramento.* The valley of the Sacramento is one hundred and fifty miles long, and twenty to fifty miles wide; and is it possible that this vast area could have been filled with waters, and they not soon have channelled out a course through a low sandstone barrier near the sea? If the reader will bring before him the necessary circumstances attending such phenomena, the impossibility of this mode of forming these flats will be evident. But we are not left to this kind of evidence alone.

These terraces on the Sacramento occur to a distance of at least one

* This river enters the Bay of San Francisco through the Caquines Straits, which are a mile wide and three long, and are bounded by hills and bluffs of soft sandstone, one to three hundred feet high.

hundred and fifty miles from the sea ; thus far, they were examined by the writer ; and they appeared to extend up the larger branch, as far beyond as the eye could reach. At the point here referred to, they were as high as at any point lower on the river, having nearly the same elevation, in all parts examined, above the existing level of the river. The flats were many miles in width, until reaching the Caquines Straits, near the Bay of San Francisco, and here is the only place where any barrier could have existed. In the first place, a permanent barrier of at least four hundred feet would be required to set the waters back so as to cover the upper terrace one hundred and fifty miles above the mouth of the river ; and in the second place, such a lake should have its surface slope like the present bed of the river, for that is the fact with the level of the terrace,—of course an impossibility. Wherever the bed of the river was four hundred feet above the sea, there the terraces should die out, or have the level of the present lower flat, instead of having a corresponding height along its whole course, or, perhaps, a greater one in the upper part of the valley.

It is therefore impossible that one or many lakes should accomplish such a result as we have before us ; it is the proper effect of river floods, and the terraces must be received as indicating a change of level in the country.

The utter inability of the lake or barrier theory, will be farther evident when the extent of terraces over the United States, east of the Rocky Mountains, is understood. Unfortunately, this branch of American geology has not yet received the attention it deserves. Still we know the general fact, that there are terraced alluvial plains along all the rivers that have been examined on this point. The writer has traced them for a long distance up the Connecticut, from Massachusetts into New Hampshire, and observed that they have no less height up the river than below, and have a near parallelism with its surface, instead of conforming to the level that the surface of a lake or lakes would have. He observed particularly that where the river passed through rocky gorges, a fit place for a barrier, if there had been such, the terraces were at the same height above and below the gorge, although wanting along these narrow places, where they would necessarily have been washed away by the river, if they had existed there. Even along the tributaries, far towards the White Mountain Notch, similar terraces existed. In the case of this river, no lake or lakes could account for the facts ; and we feel persuaded that in most others over the land, this is also true. The country

must have been a wonderful network of lakes if, formerly, every river was a string of them; and still more wonderful, if it should be found, as we believe it will, that the terraces are so far a continuous part of a single system, that a river and its branches must have been a single, tortuous, many-armed lake. But it is unnecessary to dwell longer upon this question. We found no evidence that the terraces were of marine origin.

In this change of level indicated by the terraces, the country from beyond the Columbia to the Sacramento region evidently participated in different degrees; how far beyond these limits it extended, we have as yet no knowledge. The amount of elevation about the Cowlitz and the Columbia at Vancouver, was forty or fifty feet; that about the Willammet, near the settlement, fifty or sixty feet; that upon the Sacramento, shown by the terrace, sixty to seventy feet, or if we judge from the greatest height of the alluvial deposits where we first made the river, two hundred or two hundred and fifty feet. Higher up on the Columbia, at Wallawalla, the height may be one hundred and fifty feet; but of this we cannot speak from observation. The height on the Umpqua and Shasty rivers does not indicate correctly the amount of rise, as they are small streams full of rapids.

Was this change of level an abrupt one, or was it slow and gradual? This seems at first to be a question easily answered. We may best understand it, by considering the changes that would take place during the elevation of a region of alluvial flats. If a country rise abruptly, the river will commence to work itself to a lower level, and proceed with rapidity, ending finally in attaining the very gradual slope of ordinary rivers, a descent of one to two feet to the mile. At the same time, in the seasons of floods, the river would wear into the former alluvium, (now its banks,) and widen its surface; and this widening would go on every successive freshet, till the river had a new *lower* plain on its borders. The material being easily worn away, these results would not require a long time. This effect—the formation of a river plain for the river to meander through—we have shown, in our remarks on the valleys of the Pacific and those of Australia, to be a necessary result of flowing waters.

But would not the effect be the same during a gradual rise? As the country rose slowly, the excavation of the river's bed and the lateral widening during freshets would go on gradually with the same results, producing a deeper bed and a new lower flat, both of which would change as the change of level progressed. If the lower flat in

the course of its changes resisted removal in any part, the part left standing would form a subordinate terrace between the upper level, or that of the plain before the rise began, and the lower level, or that attained when the elevation ceased.

If this be a true statement of the effects, a terrace slope might be formed by a gradual elevation; and also without any intermission in the process, there might be intermediate terraces in some parts of the same region. We cannot therefore consider a terrace in an alluvial region certain evidence of an abrupt rise of the country,—or, what is the same in its results, an abrupt sinking of the sea level.

We may hope that at some future period, the observations on terraces east of the Rocky Mountains will enable us to give the whole throughout the Continent a general survey. They point to a grand geological phenomenon, in which a continent was concerned; and, if properly studied, they must throw new light on the great geological changes that have been in progress throughout the globe.

Boulders at Wallawalla.—The plains about Wallawalla, within two miles of the river, are covered with granite boulders, some of which are six feet in diameter. The whole region around is basaltic, and the nearest granite occurs seventy miles up the north fork of the Columbia. Granite is also found in place on the south fork of the Kooskooski.

The *submerged forest* in the Columbia above the Cascades has been supposed to indicate a change of level; but it is referred with more reason to slides from the banks of the stream, occasioned by the undermining action of the water. It extends up the river at intervals for five miles, and the trees stand erect, apparently as they grew; the stumps project above water when it is low. The wood is soft and rotten without being at all petrified.

The *Grande Coulée*, cutting across the great bend below Fort Colville, is another evidence of change at some former period. There can be but two ways by which valleys can originate in a country of horizontal rocks, (indicating, therefore, no upturning,)—one by denudation, the other by rupture and subsidence. The question with regard to the origin of this gorge is therefore narrowed down to a decision between the two. The fact that some of the granite hills in the gorge are capped with basalt at the same height as the basaltic layers of the sides, sets aside the idea of subsidence; for we cannot assume a subsidence of a large area to have taken place, and leave at the same time

some points over it at their original elevation. We must therefore believe denudation to have been the cause, and admit that it was a former course of the Columbia before the river's bed was furrowed to its present depth. Some of the upheavals the country has experienced, may have opened fissures, to give a new direction to the waters; or, the sudden increased force the river may have received from an elevation, might have led to wearing a bed along a new course, provided the surface of the country at all favoured it.

FIORDS, OR DEEP COAST CHANNELS, EVIDENCE OF A
CHANGE OF LEVEL.

In the course of our remarks on the general features of Oregon, we have briefly mentioned the narrow channels which cut into the coast to a great depth, like artificial canals, occurring in great numbers, from Puget's Sound to Behring's Straits. The origin of these channels is an interesting inquiry.

An important fact, in connexion with this subject, is the frequent existence of these fiords in the higher latitudes, and their almost total absence from coasts in the lower temperate and torrid zones. Along the west coast of America, they abound to the north above 48° ; and to the south, in Lower Patagonia and Tierra del Fuego, south of 48° , there are similar passages, intersecting the land, and often cutting it into islands. But between these limits, the coast has few bays, and fewer still of these channel-like indentations. On the eastern coast of this continent, we observe the same general fact. To the north of the equator, the coast is singularly even in its outline until we reach Maine, north of latitude 43° , where, as may be seen on a good map, the fiords become very numerous and deep, and complex in their long windings and ramifications.

The same remarks apply to the Eastern Continent. The fiords of Norway are well known, and this coast is a singular contrast to that of France, Spain, and Africa. Southern Africa does not reach below the parallel of 35° , and has a simple outline throughout.

These fiords must have been formed, in general, either by *marine denudation*, by *subaerial denudation*, or by *rupturings of the earth's crust*.

When we consider their extent and number, and the fact that they

are generally confined to certain latitudes, we see that it is altogether improbable that they are a result of fissures or subsidences of the crust. To suppose that these particular regions, mostly destitute of traces of volcanic action, should be thus rent, while other regions, the most remarkable for volcanoes and earthquakes in the world, have a nearly unbroken coast, would be an assumption wholly unwarranted.

Denudation, then, by some means, was probably their origin. We have already shown that the sea is incapable of excavating valleys in coasts. These fiords would seem at first to be direct evidence to the contrary. But those who have examined them know that the waters within have the quietness of an inland stream, and rise and fall with the tides without commotion, unless passages open through from one to another, so as to produce a complete circuit for the waters. These channels, therefore, are not increasing in depth by the action of the sea. The waves wear the capes, as elsewhere on coasts, and tend to fill up the narrow bay at its head. The exceptions in the case of those channels which have openings by two channels to their head, do not affect the general question, as this is not their usual character.

Subaerial denudation is our last cause,—the only other mode of origin to which we can appeal. And this implies that the land was higher above the sea when subjected to this wear; and also that the fiords were originally the valleys of the land. The subsidence of a country, continued till its alluvial region along the coast is submerged, will necessarily make deep bays of its long linear valleys; and this is the view to which we are directed by the investigation of this subject. In our remarks on the Pacific Ocean, we presented the same argument, applying it to the Gambier Islands. Mangareva, in its long projecting points stretching out on every side, with deep bays between, so resembles what Tahiti would become, if submerged to the extent which has undoubtedly taken place at the Gambiers, that the evidence there cannot be mistaken. And it must be acknowledged that the same kind of evidence of a submergence is applicable to other coasts. The countries where these fiords occur are mountainous regions, whose interior is deeply cut up with valleys having the same general direction, that is, towards the sea. The cases, therefore, are exactly parallel with that of the Pacific island, and consequently we must admit an extensive submergence of all the coasts where these fiords occur.

The fact of such a submergence is also evident from the great number of rocky islands and islets off such coasts, as may be seen on any

map of Northwest America, Maine, Tierra del Fuego, and Norway. We also may often trace the gradual increase of this submergence as we pass from the more even coasts near the equator to these broken regions. On the northwest coast of America, the mass of islands, from Vancouver's north, appear like the proper continuation of the coast. At the Straits of De Fuca commences this narrowing of the continent, and the separation of Vancouver's Island from the main is an obvious result of the submergence. Along New England, the coast gradually increases in its broken character from Rhode Island to the north.

We would not be understood as saying that all these fiords occupy valleys of denudation; for some may evidently be the site of valleys of other kinds. Yet that many are of this character is evident from the existing valleys in the same countries. The absence of fiords, also, is not necessary evidence that a coast has not partaken in the submergence; for their formation, in such a case, depends on the topographical character of the country submerged, and also, to some extent, on the enduring nature of its rocks.

The inquiry still remains, whether the valleys of denudation, which have become fiords by submergence, have been excavated by running water alone, or more or less by glaciers. The greater elevation of the country, previous to this submergence, would undoubtedly render it more favourable than at present for glacier phenomena. The question is one that actual examination must determine.

These evidences of submergence prove that a change of level has taken place on our globe which has similarly affected many regions north of the parallel of forty-five or fifty, while south of this latitude, this change was experienced, if at all, to a less and less degree, as we approach the tropics. It indicates the probable subsidence of the surface of our earth towards the higher latitudes, while about the equator, if there has been any corresponding change, it has been an elevation. Perhaps it is for this reason, that the great chain of America is highest in the equatorial regions, and diminishes in altitude towards either pole. It may be for the same reason, that both continents narrow so rapidly to the southward, and finally yield place to the ocean; and a somewhat similar effect is apparent on the north.

The period of this submergence, we do not attempt to indicate. The land was formerly much above its present elevation, and for a period long enough for the valleys to have been formed. Neither would we imply that the submergence is still in progress; for these regions, in some parts, give evidence of subsequent elevation. It may

have long ago ceased. We only point out that the fact belongs to some period in geological history.

These observations bear us on to the grand conclusion, that the changes on our globe have not been produced by any fitful earthquakes or local changes of limited cause, but rather that they belong to a single system,—the same system which, under a Divine hand, originated the great lineaments of the earth, giving shape to its continents, and courses to its mountain chains.

A P P E N D I X .



A P P E N D I X I.

DESCRIPTIONS OF FOSSILS.

I. FOSSILS OF NEW SOUTH WALES.

THE fossils of New South Wales here described come from four regions—the District of Illawarra, the Newcastle coal beds, the sandstone of Harper's Hill, and the schistose sandstone of Glendon on the Hunter. A valuable collection of specimens from Illawarra and Harper's Hill were received from Major-General Barry. These localities were afterwards visited by the writer, who observed the same species in place, and added many others to the collections. Our indebtedness, also, to the Rev. Mr. Wilton of Newcastle, and Mrs. Scott of Glendon, for Glendon specimens, has been mentioned.

We describe first the fossils of the sandstone below the coal beds, and next, those of the coal beds themselves. The former are nearly all zoological, embracing molluscs and some corals. The latter are vegetable, excepting a single fossil fish.

A. FOSSILS OF THE SANDSTONE BEDS BELOW THE COAL.

I. PISCES.

GENUS UROSTHENES (*Dana*).—Related to Palæoniscus. Body elongate, prolonged into upper lobe of tail nearly to apex. Caudal fin but little furcate. Anal fin triangular, attached to body quite to the caudal. Dorsal fin directly over anterior part of the anal, broad spatulate. Ventral fin spatulate, distant from anal. Rays of fins very numerous and fine, jointed, with 2 to 4 free spines anterior to the fins. Scales naked, without markings.

UROSTHENES AUSTRALIS.—Body narrow, oblong. Scales subquadrate over the middle and anterior part of the body; oblong rectangular and smaller, posteriorly. Rays of fins slender and crowded, subdividing outward; articulations oblong, surface of each

strongly fluted-excavate. Plate 1, fig. 1, natural size, 1 *a*, part of two rays of the dorsal fin, enlarged.

The specimen of this remarkable fossil fish was wanting in its head, together with the anterior part of the body and pectoral fin. The part remaining has the following dimensions:—

Length of body 12 inches; of which $2\frac{3}{8}$ inches are anterior to the ventral fin, $3\frac{1}{2}$ inches from the anterior part of ventral fin to anterior part of anal fin; $3\frac{1}{8}$ inches from the anterior part of anal fin to the anterior part of caudal, or the length of anal fin along the body; 3 inches or more, length of caudal fin.

Breadth of the body from the anterior part of specimen nearly to anal fin, $2\frac{1}{2}$ inches; at posterior part of anal fin 1 inch.

Ventral fin $\frac{1}{2}$ inch broad at base; 2 inches or more long.

Dorsal fin, $1\frac{1}{4}$ inch broad at base; $2\frac{3}{4}$ inches long, on its anterior margin. Articulations of anterior rays near base, about a line long, and 3 or 4 times as long as broad.

Free spines anterior to rays $\frac{1}{8}$ to $\frac{3}{8}$ of an inch long.

Scales $\frac{1}{4}$ inch broad over middle of body; posteriorly, breadth diminishing and height half the breadth or less.

This specimen is from the B Coal Pit, Newcastle, and was taken out by Mr. James Steel, as already stated on page 482.

2. MOLLUSCA.

a. *Mollusca Brachiopoda.*

1. *TEREBRATULA AMYGDALA* (*Dana*).—Regularly oblong ovate, and regularly and nearly equally convex on the two surfaces; thickest at middle; lower margin arcuate. Surface smooth, with usually a few obsolescent concentric folds and some faint radiations. Smaller valve neatly ovate, with the cardinal margin very nearly straight. Beak reflexed close to apex of smaller valve, and having the aperture rather small. No cardinal area. Cardinal angle 82° . Height $1\frac{1}{8}$ inches; * length $\frac{7\frac{2}{10}}{100}$ H.; thickness $\frac{4\frac{6}{10}}{100}$ H. Plate 1, figure 2; *a*, *b*, *c*, *d*, different views, natural size; *e*, from another specimen; *f*, internal structure magnified 40 diameters.

Black Head, District of Illawarra.

This species resembles some specimens of the *T. hastata*. It is more regularly ovate in outline, and more attenuate than that species, and either surface is quite evenly convex. In an end view, the anterior and posterior margins are nearly straight and vertical, as in fig. *d*; in this respect it differs from the following species. In this same view the outline of the larger valve appears a little flattened along the middle, or less convex than that of the smaller. The punctations in the internal texture are minute, and partly in linear series (fig. 2 *f*.) They are $\frac{1}{100}$ to $\frac{1}{200}$ of an inch apart.

T. amygdala, Exped. Foss., Amer. Jour. Sci. ii. Ser., iv. 152.

2. *TEREBRATULA ELONGATA*.—Plate 1, figure 3 *a*, *b*, different views, natural size; *c*, *d*, internal structure, magnified forty diameters, natural size. District of Illawarra.

* The shell is here supposed to be in its natural position,—the beak up, and that edge in front which will make the larger valve the right valve, and the smaller the left.

The *T. elongata*, as figured by Verneuil in his Russian Palæontology, Pl. ix, fig. 9, does not appear to differ essentially from our species, except that the Australian specimen has greater thickness for its length. The *height* is 1 inch; *length* $\frac{7.2}{100}$ H.; *thickness* $\frac{5.5}{100}$ H. The cardinal edges of the smaller valve are quite sinuous, in an end view especially, and are concave either side in a direct view. The shell is smooth, with a few delicate concentric furrows. The valves are about equally and regularly convex, and have the greatest thickness about the centre. Cardinal angle near 70° . Beak reflexed close to the apex of the smaller valve, and aperture round and large. The punctations in the internal texture (figs. 3 *c*, *d*) are in linear series, and hardly larger than in the preceding.

3. TEREBRATULA —? Plate 1, fig. 4 *a*, *b*, different views, natural size. District of Illawarra.

The specimen from which this figure was made was lost before a description was drawn up. It may be a young state of the *T. amygdala*. It also resembles the *P. virgo* of Phillips (Pal. Foss. p. 91, pl. 35, fig. 167).

4. TEREBRATULA ?—Plate 1, fig. 5. This figure represents a small shell from Glendon, altered in shape by compression. The surface is smooth, without striæ, but slightly concentric undulate.

5. SPIRIFER GLABER.—Plate 1, fig. 6; *a*, *b*, specimen from Black Head, Illawarra, natural size; *c*, *d*, specimen from Harper's Hill, natural size; *e*, *f*, distorted specimen from Harper's Hill; *g*, surface of figure 6 *c*, magnified 3 diameters.

Black Head, Illawarra and Harper's Hill.

Specimens from Harper's Hill are usually rather thicker in proportion to the length, and are less distinctly subradiate, especially when small. These smaller specimens (figs. 6 *c*, 6 *d*) have also a deeper medial sinus, and a more abruptly prominent fold to the opposite valve. They have distinct concentric ridges of growth, and the exterior surface is longitudinally marked with minute short lines, giving it, under the lens, a kind of fibrous appearance. The layers beneath appear as above stated. The larger specimens from this locality are closely like those of Illawarra.

Two individuals among our specimens from Harper's Hill are obliquely distorted as shown in figures 6 *e*, 6 *f*.

This species was briefly described by G. Sowerby as the *Spirifer subradiata* from a Van Diemen's Land specimen. Morris, in Strzelecki's work, says that it is abundant at Mount Wellington, Van Diemen's Land, where some individuals are four inches in breadth; and that it occurs also at Glendon on the Hunter. McCoy mentions Darling-ton, New South Wales, as another locality.

The specimens from Illawarra agree with the figures plate 15 and 16, in Strzelecki's New South Wales. The apical angle is about 106 degrees; height (from the beak to the opposite margin) $2\frac{3}{4}$ inches; length 1.06 H.; thickness 0.56 H. The surface is faintly and unevenly subradiate, with some irregular concentric lines of growth. The shell, in calcareous specimens, often shows a tendency to peel off in layers, and thin fragments under the microscope have a somewhat fibrous appearance. In worn specimens the internal spires are often shown, and the convolutions towards the middle of the shell are from a line to a sixteenth of an inch apart. The medial depression of the dorsal valve is very broad and concave, and not deep.

The Harper's Hill specimens so closely resemble some varieties of the *Spirifer glaber*, especially the *Sp. oblata* of Sowerby, that I believe the whole should be referred to that widespread species, which occurs among the carboniferous rocks of Russia and other parts of Europe and Britain, and also less abundantly in the Devonian; also in our own Western States. Verneuil refers to Van Diemen's Land as one of its localities.

Spirifera subradiata, G. Sowerby, in Darwin's Volcanic Islands, London, 1844, p. 159.

Spirifer subradiatus, J. Morris, in Strzelecki's New South Wales, London, 1845, p. 281, plate 15, fig. 5, pl. 16, figs. 1—4.

Spirifera subradiata, M'Coy, Ann. and Mag. Nat. Hist., 1847, xx. 233.

Spirifer glaber, Sowerby, Min. Conchology. For its synonymy see the recent works, L. de Koninck's Desc. des An. Foss. Belg., Liège, 4to., 1842, p. 267, and Verneuil and Keyserling's Palæontology of Russia, 4to., p. 144.

6. *SPIRIFER DARWINII* (*J. Morris*).—Plate 1, fig. 7 *a*, cast, with internal spiral support in view.

Glendon, New South Wales.

Morris's specimens were also from Glendon. The species is transversely oval. Height of cast 1.4 inches; length $1\frac{3.5}{100}$ H.; thickness $\frac{7.5}{100}$ H. The costæ are four on either side of the mesial fold, the outer obsolescent, the others large and rounded. The mesial lobe is divided by a furrow.

Figure 7 *b*, appears to be the same species, and represents a broken right-hand valve. It is close like Morris's *Spirifer Hawkinsii* from the Falkland Islands, and the species may be identical.

Spirifer Darwinii, J. Morris, in Strzelecki, op. cit., p. 279.

Spirifer Hawkinsii, *ibid.*, in Quart. Journ. Geol. Soc., ii. 276, pl. 11, figs. 1 *a*, 1 *b*.

Spirifera paucicostata [?], G. Sowerby, in Darwin's Volcanic Islands, p. 160.

Spirifera Darwinii, M'Coy, loc. cit., p. 233.

7. *SPIRIFER DUODECICOSTATUS* (*M'Coy*).—Plate 2, figs. 1 *a*, 1 *b*, different views, natural size.

District of Illawarra.

This species appears to be the *Sp. duodecicostata* of M'Coy. It is near the *Darwinii*, but has five large costæ either side of the mesial fold. M'Coy mentions Muree and Wollongong as its localities. Height of one specimen $1\frac{4}{10}$ inches; length 1.49 H. ($1\frac{9}{10}$ in.); thickness $\frac{7.0}{100}$ H. A smaller specimen is $1\frac{1}{10}$ inches in length. The mesial fold is divided. The costæ are smooth and rounded, with transverse lines of growth towards the lower margin.

Spirifera duodecicostata, M'Coy, loc. cit., p. 234, pl. 17, figs. 2, 3.

8. *SPIRIFER* ——. Plate 2, fig. 2, natural size.

Black Hill, Illawarra, and Glendon on the Hunter.

In the characters and number of plications, the specimens of this small and rather thin species, agree with Koninck's *acuticostatus*, found in the carboniferous system of Belgium. (Desc. des An. Foss. p. 265, pl. xvii. figs. 6 *a*, *b*, *c*.) The specimen here figured is imperfect, and does not show all the outer costæ. The costæ are seven to nine on either side of the mesial fold; they are acutely triangular and prominent, and the lower margin of the shell is in consequence neatly dentate. The mesial fold is tri-

angular, but has a furrow along the middle, and a small ridge in the corresponding depression in the other valve.

9. *SPIRIFER VESPERTILIO* (*G. Sowerby*).—Plate 2, figs. 3 *a*, *b*, *c*, natural size.
Black Head, District of Illawarra.

The length of our specimens of this species is $3\frac{1}{2}$ to 4 inches, which is 2 to $2\frac{1}{2}$ times greater than the height. The specimens agree with the figures in Strzelecki, (plate 17, figs. 1 and 2,) whose specimens were from Eagle Hawk's Neck, Van Diemen's Land. The costæ are variable in number. In one specimen there are ten or twelve either side of the mesial fold, in another six to eight, and the rest exterior to these are obsolete. There are three small ribs in the mesial depression, besides an obsolescent one either side. The mesial fold of the other valve is very broad and rounded, and somewhat costate.

Figure 3, *c*, resembles the figures of *Spirifer avicula*, (*G. Sowerby*), a species cited from Eagle Hawk's Neck, Van Diemen's Land, and also by M'Coy from Korinda and Black Head, New South Wales. But it does not appear to differ specifically from figures 3 *a*, 3 *b*.

Spirifer vespertilio, *G. Sowerby*, in Darwin's Volcanic Islands, p. 160.

———, *J. Morris*, in Strzelecki's New South Wales, p. 282, pl. 17, figs. 1 and 2.

———, *M'Coy*, loc. cit., p. 232.

Spirifer antarcticus [?], *J. Morris*, Quart. Journ. Geol. Soc., of London, ii. 276, pl. 11, fig. 2.

10. *SPIRIFER PHALENA* (*Dana*).—Elongate, nearly twice as long as high. Cardinal margin straight and much elongate. Mesial fold large and subangular, divided along the middle. Costæ about twenty-four, neatly triangular and subacute, transversely striate, the striæ (of growth) regularly parallel. Plate 2, fig. 4, portion of a valve.

District of Illawarra.

Our specimen of this species is but a fragment. A perfect specimen is figured by Morris in Strzelecki, (pl. 17, fig. 3,) and referred to the *vespertilio*. The length of the upper margin in his figure is $3\frac{3}{8}$ inches; height, $1\frac{3}{8}$ inches. The shell diminishes in length from the upper margin downward. The costæ are very neatly triangular and prominent, and those near the mesial fold are about $\frac{1}{7}$ or $\frac{1}{8}$ of an inch across.

Spirifer vespertilio, *J. Morris*, in Strzelecki, pl. 17, fig. 3.

11. *SIPHONOTRETA ? CURTA* (*Dana*).—Very short ovate, hardly higher than long; beak acute, and apical angle a right angle or less. Surface smooth, concentrically subplicate.—Height and length about $\frac{1}{4}$ inch.—Plate 2, fig. 5, *a*, *b*; natural size.

Glendon, valley of the Hunter.

Like other specimens from Glendon, this specimen is much injured by compression. I have been unable to ascertain, from the specimens examined, whether the shell has the perforation of *Siphonotreta* or not. The plications are few, irregular and low. Beneath the beak, the surface is flat. The beak itself is quite thin, and projects far beyond the hinge line.

12. *LINGULA OVATA* (*Dana*).—Quite small, much convex, regularly broad ovate, with the front margin not at all truncate. Beak acute. Valves thin, smooth, with faint con-

centric lines of growth.—Height $\frac{1}{8}$ inch; length $\frac{7.5}{100}$ H.—Plate 2, fig. 6, *a*, inner view of a valve; *b*, a worn specimen of shell with one valve broken through.

Black Head, District of Illawarra.

Approaches the *Lingula lata* of Murchison, (Silurian System, pl. 8, fig. 11,) but it is not at all “suarish.”

Lingula ovata, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 152.

13. **PRODUCTUS FRAGILIS** (*Dana*).—Subquadrate, tumid, laterally and in front abrupt, a little longer than high. Cardinal margin straight, about as long as breadth of shell. Beak small, not inflexed. Surface very finely and irregularly striate, with some concentric undulations.—Height $1\frac{1}{4}$ inches; length $1\frac{3}{10}$ H.; thickness between the valves about $\frac{4.0}{100}$ H.—Plate 2, fig. 7, *a*, *b*, *c*, different views, natural size; *d*, profile of section.

Wollongong Point, Illawarra.

This species differs from the *brachytherus* in its much less prominent beak, and its longer hinge line.

Productus fragilis, Exped. Foss., in Amer. Jour. Sci., ii. Ser., iv. 153.

14. **PRODUCTUS BRACHYTHERUS** (*G. Sowerby*).—Plate 2, fig. 8.

Wollongong Point, Illawarra.

A large number of specimens of this species were found clustered together in the Wollongong sandstone. The rudiments of spines are quite distinct.

Productus brachytherus, G. Sowerby, Darwin's Volcanic Islands, p. 158.

—————, J. Morris, Strzelecki, op. cit., p. 284, pl. 14, fig. 4, *a*, *b*, *c*.

b. *Mollusca Acephala*.

15. **SOLECURTUS (?) ELLIPTICUS** (*Dana*).—Scarcely at all convex; oblong and neatly elliptical, with no beak; length twice the breadth, and anterior part half the posterior. Surface smooth, with obsolete striæ of growth. Supero-anterior margin slightly depressed. Teeth of the hinge obsolete.—Length 1.4 inches.—Plate 2, fig. 9; an exterior cast, natural size.

Wollongong Point, Illawarra.

It is difficult to determine whether this and the following species are true Solecurti or not. The hinge, of which we have a good cast in the specimen, shows no appearance of teeth. There is a delicate line extending from the point of the hinge obliquely backward, but whether it arises from a fracture, or a slender rib on the surface, it is difficult to determine. It shows nearly alike on both the exterior and interior casts, and appears rather to be a peculiarity of the shell itself. No palleal or muscular impressions are visible.

Solen (Solecurtus?) ellipticus, Exped. Fossils, Amer. Jour. Sci., ii. Ser., iv. 153.

16. **SOLECURTUS (PSAMMOBIA ?) PLANULATUS** (*Dana*).—Height rather less than half the length; superior and inferior margins nearly straight. Valves nearly flat, with a slight

bending over the postero-dorsal margin. Beak none. Surface smooth, with some faint concentric undulations and lines of growth.—Length $1\frac{2}{3}$ inch; height $\frac{4.8}{100}$ L.—Plate 2, fig. 10, exterior cast of a valve, natural size.

Harper's Hill.

No pallear or muscular impressions are distinguishable.

Solen (Solecurtus?) planulatus, Expedition Fossils, Amer. Jour. Sci., ii. Ser., iv. 153.

17. PHOLADOMYA (PLATYMYA) UNDATA (*Dana*).—Equivalve or nearly so, transverse, inequilateral, compressed, subelliptical, thinning to an acute edge in front, somewhat prolonged and narrowed behind; sides flattened; flank obliquely truncate and subcarinate without. Cardinal area linear, circumscribed. Surface smooth, with a few large irregular concentric undulations, which are crossed, especially below, by faint radiations.—Length $3\frac{1}{6}$ inches; height $\frac{5.9}{100}$ L.; thickness $\frac{3.5}{100}$ L.; distance of summit of beak from anterior margin $\frac{3.3}{100}$ L.; apical angle 138° .—Plate 2, fig. 11, *a*, *b*, views, natural size.

Wollongong Point, Illawarra.

The specimen is an external cast; the beak projects about an eighth of an inch above the cardinal margin. The pallear impression is not seen on the specimens in the collections, of this or either of the three following species, and we cannot say whether it has a sinus or not. We suspect the latter, in which case the species are not Pholadomyæ, and may be near the Mæoniæ.

Pholadomya undata.—Expedition Fossils, in Amer. Jour. Sci., ii. Ser., iv. 153.

18. PHOLADOMYA (HOMOMYA) GLENDONENSIS (*Dana*).—Oblong, inequilateral, subinflated, in front subacute (acute?); posteriorly prolonged and becoming quite thin; flank not carinate. Surface concentrically subplicate and striate, not at all radiate; plicæ unequal, and passing into striæ of growth. Lateral surface not at all flattened.—Length about $2\frac{3}{4}$ inches; anterior part more than half the posterior.—Plate 2, fig. 12; specimen much broken.

Glendon, valley of the Hunter.

19. PHOLADOMYA (HOMOMYA) AUDAX (*Dana*).—Ventricose, oblong, very inequilateral, subequivalve, the left valve larger; thick in front and truncate, and a little concave near the margin; posteriorly prolonged and thinning and narrowing, a little recurved, gaping. Umbos large and prominent, inflated, incurved, contiguous. Lateral surface strongly flattened or subexcavate obliquely downward anterior to middle. Surface longitudinally plicate, and marked posteriorly with obsolete radiations; plications smooth, low and rounded, the alternate towards the middle becoming obsolete, and all obsolescent near posterior margin.—Length $4\frac{1}{4}$ inches; height $\frac{6.3}{100}$ L.; thickness $\frac{4.7}{100}$ L.; the anterior part hardly $\frac{1}{4}$ L.—Plate 3, fig. 1 *a*, *b*, *c*, different views, natural size.

Illawarra, Wollongong Point.

This fine species differs from the following in having the beaks more prominent and the left largest; also in the posterior extremity diminishing more in height, the flank less inflated, and the front more abruptly truncate. There are about twenty-four plications on the anterior half. The cardinal area is hardly circumscribed, and the flanks are not flattened.

Allorisma audax, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 153.

20. PHOLADOMYA (HOMOMYA) CURVATA [?] (*J. Morris*,) *Dana*.—Plate 3, fig. 2, *a, b*, different views, natural size.

District of Illawarra, at Wollongong Point.

Morris's figure, in Strzelecki's New South Wales, represents a proportionally broader shell, but has the general habit of the specimen in our collections, except that the plications seem, in his figure, to pass into striæ, which is not the case as observed by the writer. The right valve is a little the larger; and the radiations, plications and character of the surface, as well as the gaping posterior, are similar to the same in the *audax*. Length $4\frac{1}{4}$ inch; height $\frac{6.0}{10.0}$ L.; thickness $\frac{5.0}{10.0}$ L.

Allorisma curvatum, *J. Morris*, op. cit., p. 270, pl. x, fig. 1.

NOTE.—The above two species may belong to the genus *Allorisma* of King: but it is difficult to detect any sufficient characters for separating them from *Pholadomya* (or *Agassiz's Homomya*,) provided the pallear impression is not entire. The specimens are external casts.

21. ASTARTE GEMMA (*Dana*).—Small. A little oblong, nearly inequilateral. Lateral surface regularly convex; neatly marked with numerous fine deep sulci. Valves crenulate within. Pallear impression faint; impression of larger anterior muscle somewhat excavate, of smaller oblong, of posterior muscle faint.—Length $\frac{3}{5}$ inch; height $\frac{8.3}{10.0}$ L.; thickness $\frac{4.5}{10.0}$ L.; anterior part $\frac{7}{15}$ of the whole length; apical angle 140° .—Plate 3, fig. 4, view of cast, natural size; *a*, cast of exterior surface of an imperfect valve; *b*, enlarged drawing, showing cast of hinge.

Wollongong Point, District of Illawarra.

In this cast, the impression of two divergent teeth is finely preserved. The pallear impression, though faint, is distinctly entire. The fine striæ, or ridges of the surface, number four or five to a line in breadth, and the crenulations, near the margin of the valves, are about four to a line. The cast of the interior has a smooth surface.

Astarte gemma, *Exped. Foss.*, *Amer. Jour. Sci.*, ii. Ser., iv. 154.

GENUS ASTARTILA (*Dana*).—Equivalve, inequilateral, transverse, throughout convex, externally marked with concentric striæ. Ligament external, extending to the posterior extremity of the cardinal area; umbos of moderate size. Pallear impression entire. Muscles two anteriorly and one posteriorly; the smaller interior under the beaks, and directed inward; the larger broad, subelliptical, or suborbicular; the posterior also broad. Valves having the interior surface, from the umbos obliquely downward, flattened, or a little raised, [producing a flattened or excavate area on the lateral surface of a cast.]

This genus has many of the characters belonging to *Astarte*, and perhaps should be considered as only a *subgenus* in that group. The form is more transverse; the beaks are more to one side, the anterior portion of the shell varying from $\frac{1}{4}$ to $\frac{2}{5}$ of the whole length; and the ligament is much longer. Besides, the cast has the beak obliquely truncate at apex, and is flattened laterally on the side of the beak. There is usually one or two folds or lines extending from behind the beak obliquely downward, so as to pass

near the anterior side of, or across, the posterior muscular impression. The valves are very thin at middle, being hardly $\frac{1}{60}$ of an inch in the first of the following species, and are thickened below towards the margin, a short distance from which the same species is half a line thick. The palleal impression stops abruptly just before reaching the posterior muscular impression. Our specimens show well the exterior and interior of different species; but the teeth of the hinge have not been made out. The exterior surface is unevenly marked with concentric striæ of growth, and is convex quite to the anterior margin.

22. *ASTARTILA INTREPIDA* (*Dana*).—Thick, length but little greater than height, anterior part about $\frac{1}{3}$ whole length. Lateral surface evenly convex, marked quite neatly with concentric striæ. Anterior muscular impressions excavate; the smaller subquadrate, the larger transverse, with a number of fine vertical lines on the posterior quarter.—Length $1\frac{3}{4}$ inches; height $\frac{8}{100}$ L.; thickness $\frac{5.2}{100}$ L.; apical angle about 120° .—Plate 3, fig. 5, 5 *a*, different views, natural size; *b*, larger anterior muscular impression enlarged; *c*, smaller anterior muscular impression enlarged.

District of Illawarra at Wollongong Point.

This is a thick species distinguished by its anterior muscular impressions and general proportions. The cast from the beak obliquely downward is strongly flattened; and between this area and the large anterior muscular impression, the surface is somewhat convex, and moreover it is smooth without minute corrugations. The striæ of the exterior surface are strong and quite neat although somewhat irregular, and the surface is a little shining.

Astartila intrepida, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 155.

Pachydomus ovalis, [?] M'Coy, Ann. Mag. Nat. Hist., xx. 302, pl. 14, fig. 4.

23. *ASTARTILA CYPRINA* (*Dana*).—Oblong, thick, length one-third greater than height. Exterior surface coarsely and unevenly concentric striate. Inner surface of valves minutely rugulose, and below the palleal impression vertically subplicate. Muscular impressions excavate; the smaller anterior oblong, sigmoid; the larger subquadrate, very convex, marked vertically with a few lines, the posterior hardly excavate.—Length $2\frac{1}{2}$ inches; height $\frac{7.2}{100}$ L.; thickness $\frac{5.8}{100}$ L.; apical angle about 118° .—Plate 3, fig. 6, 6 *a*, views of cast, natural size; *b*, large anterior muscular impression, (from cast,) with commencement of palleal impression; *c*, *d*, small anterior, from different specimens; *e*, *f*, posterior muscular impressions.

Wollongong Point, District of Illawarra.

The vertical plications below the palleal impression are characteristic. It is also peculiar in the character of its larger anterior muscular impression, and its proportional dimensions. Also, the cast from the beak downward is but slightly flattened, and the space between the flattened area and the muscular impression is convex, owing to the continuation upward of the convexity of the muscular impression itself.

Astartila cyprina, Exped. Fossils, Amer. Jour. Sci., ii. Ser., iv. 155.

24. *ASTARTILA CYTHEREA* (*Dana*).—Thick, a little longer than high. Beak thrown a little forward. Exterior surface very coarsely concentric striate or costate; inner surface of valves smooth. Smaller anterior muscular impressions scarcely excavate, oblong sigmoid; larger strongly excavate and very abruptly so on the upper side, oblong sub-

elliptical, crossed on the lower half posteriorly by a few (four or five) vertical lines, the transverse striæ strong and neat. Posterior muscular impression a little excavate with neat transverse markings.—Length $1\frac{3}{4}$ inches; height $\frac{3.9}{100}$ L.; thickness $\frac{5.7}{100}$ L.; apical angle about 100° .—Plate 4, fig. 1, 1 *a*, shell, natural size; *b*, *c*, *d*, different views of cast; *e*, larger anterior muscular impression; *f*, smaller anterior; *g*, posterior.

Wollongong Point, District of Illawarra.

The proportions of this species; its beak thrown a little forward in the exterior shell as well as cast, so that in the latter the profile of the front below it is strongly concave; the anterior muscular impressions, and especially the abrupt depression (in cast, abrupt elevation, of half a line) at the upper side of each larger, are striking peculiarities of this species. The lateral surface of the beak in the cast is flattened, and this flattened area extends evenly to the large muscular impression. The anterior part is hardly more than one quarter the whole length, while it is one-third in the *cyprina*.

Astartila cytherea, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 155.

Pachydomus? pusillus, [?] M'Coy, loc. cit., p. 302, pl. 16, figs. 1, 2.

25. *ASTARTILA POLITA* (*Dana*).—Rather thin, somewhat longer than high. Exterior surface smooth and shining, with faint concentric lines. Valves thin. Muscular impressions very slightly excavate, palleal faint. Large anterior muscular impression with transverse striæ, but none vertical.—Length 1 to $1\frac{3}{4}$ inches; height $\frac{2.4}{100}$ L.; thickness $\frac{5.0}{100}$ L.; apical angle 114° .—Plate 4, figs. 2, *a*, *b*, *c*, natural size.

Black Head, District of Illawarra.

The shining exterior and thinness of the shell are peculiar, and its texture in the specimens seen was usually rather soft and dark olive-green in colour, like a compact chlorite. The lateral surface of the beak in the cast is flattened, nearly as in the *cytherea*.

Astartila polita, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 155.

26. *ASTARTILA CYCLAS* (*Dana*).—Rather thin, a little longer than high, nearly equilateral, apical angle large. Exterior surface marked unevenly with irregular concentric striæ. Anterior muscular impression strongly excavate; larger suborbicular, without vertical striæ; smaller narrow oblong. Posterior muscular impression hardly excavate.—Length $1\frac{1}{2}$ inches; height $\frac{9.0}{100}$ L.; thickness $\frac{4.5}{100}$ L.; thickness of cast $\frac{4.0}{100}$ L.; apical angle of shell 135° .—Plate 4, fig. 3, 3 *a*, views of shell, natural size; *b*, *c*, cast; *d*, large anterior muscular impression, (from cast,) with commencement of palleal; *e*, posterior muscular impression.

Wollongong Point, District of Illawarra.

This is the thinnest of the species obtained. The beak of the cast is very thin, and the flattened area distinct; the surface between this area and the muscular impression in the cast is flattened or slightly concave. The cast has the margin very thin, as in the *cyprina*. The smaller anterior muscular impression is vertical, and faces very obliquely inward. The palleal impression is very distinct. The anterior portion of the shell is *more than a third* the whole length.

Astartila cyclas, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 155.

27. *ASTARTILA TRANSVERSA* (*Dana*).—Thick, oblong, (length one-third greater than height.) Posterior muscular impression faint; larger anterior subelliptical, somewhat excavate, without vertical striæ; smaller obliquely excavate, sigmoid.—Length of cast

$1\frac{1}{2}$ inches; height $\frac{7.3}{100}$ L.; thickness $\frac{5.5}{100}$ L.; apical angle of cast 105° ; of shell about 115° .—Plate 4, fig. 4 *a, b*, views of cast, natural size; *c*, larger anterior muscular impression, with commencement of palleal; *d*, smaller anterior.

Wollongong Point, District of Illawarra.

This species is remarkable for being a third longer than high. It has the lateral surface of the cast, from the beak downward, strongly flattened, and between this area and the muscular impression, the surface (which is of the same width as the flattened area) is also flattened or a little concave. The palleal impression is faint.

Astartila transversa, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 155.

28. *ASTARTILA? CORPULENTA* (*Dana*).—Ventricose, oblong, a little inequilateral, sub-elliptical, prolonged in front, inferior margin arcuate; umbos elevated. Surface concentrically subrugose.—Length $1\frac{1}{2}$ inches; height $\frac{6.6}{100}$ L.; thickness $\frac{5.4}{100}$ L.; apical angle about 120° .—Plate 3, figs. 3 *a, b, c*.

District of Illawarra.

This species is referred provisionally to this place, as the characters exhibited do not satisfy us of its true genus.

29. *CARDINIA? RECTA* (*Dana*).—Very inequilateral, narrowing behind, length $2\frac{1}{2}$ times the height; dorsal margin a little arcuate, inferior margin straight at middle; sides not flattened, marked with concentric striæ and faint radiations; palleal and posterior muscular impressions, scarcely distinguishable; anterior muscular impressions strong; cardinal area of cast neatly flattened and linear, straight and elongated nearly to posterior margin, with a subacute carinate limit.—Length 2 inches; height $\frac{4.5}{100}$ L.; thickness $\frac{2.0}{100}$ L.; apical angle 125° .—Plate 4, fig. 5, natural size, in part a cast; 5 *a*, cast of the same, imperfect in front; *b*, profile of cast.

District of Illawarra.

This, and the three following species, have the general aspect and the characters nearly of the *Cardiniæ* of Agassiz. They are all oblong transverse, with the sides more or less compressed, or concave at times, the dorsal margin arcuate or nearly straight, and the lower margin straight, or a little concave at middle. The beak projects but slightly. The cardinal area is nearly wanting; in the cast, it is narrow linear, more regularly so than in the described *Cardiniæ*. The front of the cast is truncate in all; the smaller muscular impression is oblong linear; the truncate front surface extends downward so as to separate the larger muscular impression from the medial front line. The palleal impression is nearly parallel with the margin, and abruptly stops just before reaching the anterior muscle. The ligament is external and rather short. The surface is usually more or less faintly radiated, the lines radiating mostly from the upper and anterior part of beak, (and not from a point posterior to the beak, as represented in Morris's figure of the *costata*.) In the cast, the lateral surface from the beak obliquely backward and downward, is flattened or somewhat concave, and faint radiations, corresponding to those of the exterior, are also traceable. The shells are closed posteriorly.

The *C. recta* is distinguished by its form and faint palleal impressions; also by the flat linear cardinal area of the cast, with its subacute carinate limit, and its prominent cardinal margin. The posterior margin is arcuate, and the front obliquely truncate from above, but rounded below. The striæ of the surface are slightly undulated by the radiations. The surface of the cast is very smooth, and marked with faint radiations. The

form of the cast (in a transverse section) is cuneate, it thinning towards the lower margin, which is thin and acute, and slightly arcuate in outline, or nearly straight, instead of excavate, like the following species. The cast much resembles the *Solemya primæva* of Verneuil (Pal. of Russia, pl. 19, fig. 5). The form of the shell approaches that of the *Actinodonta cuneata* of Phillips, (Mem. Geol. Surv. Brit. 1848, ii. 366.)

Cardinia recta, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 156.

30. *CARDINIA ? CUNEATA* (*Dana*).—Very inequilateral, length very nearly twice the height. Narrowing considerably behind. Superior margin strongly arcuate; inferior straight at middle, or slightly excavate; anterior obliquely truncate. Exterior surface with concentric striæ of growth, and without radiations; laterally somewhat compressed. Larger anterior muscular impression deeply excavate; posterior faint; cardinal area of cast long linear, and bounded by a prominent carina, extending quite to the posterior margin.—Length $1\frac{3}{4}$ inches; height $\frac{5.2}{100}$ L.; thickness $\frac{3.3}{100}$ L. Apical angle of cast 110° .—Plate 4, fig. 6, 6 *a*, *b*, different internal casts, natural size; *c*, *d*, other views of *a*; *e*, front view of *b*.

Wollongong Point, District of Illawarra.

This species is proportionally higher, and narrows more rapidly behind than the *recta*, and, moreover, it is much thicker, and the cardinal area in the cast has not the prominent inner margin in that species, while the outer is quite prominent. Along the back, the shell is nearly truncate, and wide, (about $\frac{1}{4}$ inch,) and the surface (as appears from a cast) is marked with fine lines, extending backward from either side of the ligament, slightly divergent. The sides of the cast are strongly compressed, or a little concave, while the sides of the beak are also flattened.

Cardinia cuneata, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 156. July, 1847.

Cardinia exilis, M'Coy, Ann. & Mag. Nat. Hist., xx. 302, Nov. 1847, pl. 15, fig. 1.

31. *CARDINIA ? COSTATA* (*J. Morris*), *Dana*.—This species, described and figured by Morris, has a length *three* times its breadth, and *four* times its thickness. The sides are compressed just posterior to middle. The lower margin is straight, or slightly excavate; the dorsal is very nearly straight, (slightly convex,) and parallel nearly with the lower; the posterior is arcuate. The lateral surface is unevenly concentric striate or rugose, and it is radiate or radiately costate, mostly posterior to a line from the anterior part of the beak to the middle of the lower margin. The posterior muscular impression is large, broad, elliptical, and a little excavate; the larger anterior is deeply excavate; and above it, in the cast, there is an oblique concave surface, from the anterior part of which, obliquely downward and backward, there is, in the cast, a broad, flattened area; and posterior to this, there are some radiations. The cardinal area of the cast is long, narrow linear and concave. The surface adjoining is broadly rounded instead of carinate.—Length $4\frac{1}{2}$ inches; height $\frac{3.3}{100}$ L.; thickness $\frac{2.6}{100}$ L.; apical angle about 130° .—Plate 4, fig. 8 *a*, *b*, views, natural size; *c*, vertical section.

Orthonota ? costata, J. Morris, in Strzelecki's New South Wales, 273, pl. xi., figures 1, 2. Mr. James Hall, of the New York State Geological Survey, agrees with me that the above species cannot belong with the *Orthonota* of Conrad.

GENUS PACHYDOMUS.—This genus, first described by Mr. Sowerby under the name *Megadesmus*, and afterwards designated *Pachydomus* by Morris, (as the previous

name was already used in the science,) has the following characters, as derived from two species in our collections, the *P. antiquatus* and *P. cuneatus*.

Equivalve, inequilateral, more or less oblong, thick, closed. Beaks moderately prominent. Exterior with coarse irregular concentric ridges. Lateral surface a little flattened, and inferior margin straight at middle, or slightly excavate. Ligament large, external. Palleal impression entire, strong and broad, reaching quite to the larger anterior muscular impression. Muscular impressions three to each valve, two anterior strongly excavate, posterior less so. Smaller anterior, situated under the beaks, and the muscle having a direction inward (the impression of a cast facing frontwise or inward). Larger anterior broad, with the upper border broad truncate. Posterior, large and rounded, subquadrate. Cast having the beaks distant; cardinal area broad and long, and with a carinate border; posterior muscular impression situated on the broad flank, and its inner angle produced forward, and extending over the carina; lateral surface, from the beak obliquely downward, flattened or concave. On the surface of the cast there are several small elevated points, which appear to mark attachments of muscular fibres. The valves are thin just anterior to the middle, and thicken towards the margin.

The genus is near *Crassatella*, *Astarte*, *Astartila*, *Cardinia*, and *Mæonia*. The last four genera have the same number of muscular impressions, but *Mæonia* is peculiar in the smaller anterior muscular impression having the same lateral direction as the larger anterior, instead of being directed forward or inward, and the large anterior muscular impression being subacute above instead of broad truncate. The specimens resemble most, in their casts, the species referred to *Cardinia*; but the latter are very much elongated, and have a long linear cardinal area to the cast, and are almost without a beak to the shell, as well as to the cast; moreover, the upper side of the larger anterior muscular impression is not horizontally truncate as in *Pachydomus*. In *Astartila*, the larger anterior impression, besides differing in form, is oblong in the direction of the striæ, and the palleal impression has a gradual curve, instead of the rather abrupt bend posteriorly which characterizes *Pachydomus* and *Mæonia*; the general form, and small cardinal area to cast, are also different.

32. *PACHYDOMUS CUNEATUS* (*J. D. Sowerby*), *Morris*.—From Harper's Hill, valley of the Hunter.—Plate 5, fig. 1, 1 *a*, views of cast, natural size.—Length of cast $2\frac{2}{3}$ inches; height $\frac{7}{100}$ L.; thickness $\frac{5}{100}$ L.; height of shell (from Mitchell's figure) $\frac{6}{100}$ L.

The cardinal area in the cast is very broad; it narrows abruptly at the upper part of the posterior muscular impression, where there is an angle in the carina. The beaks are very distant. The flanks are flattened, the posterior muscular impression is large quadrate, and covers the full breadth of the flank. The palleal impression is hardly half an inch from the lower margin; it is broad and strong, with the surface a little undulate. The large anterior muscular impression is vertically oblong, and deeply excavate. This species is much more oblong than the following, and is peculiar in its truncate front, and the angle over the upper part of the posterior muscular impression; also in the lower margin being somewhat excavate.

Megadesmus cuneatus, J. D. Sowerby, Mitchell's Expeditions into Australia, 8vo. London, 1838, vol. i., pl. 3, fig. 3.

Pachydomus cuneatus.—J. Morris, in Strzelecki's New South Wales, p. 272.

33. *PACHYDOMUS ANTIQUATUS* (*J. D. Sowerby*), *Morris*.—From Harper's Hill.—

Plate 5, fig. 2, natural size.—The form of this species is subrotund, a little oblong. Length of one specimen $3\frac{1}{2}$ inches; height $\frac{8}{100}$ L.; thickness $\frac{5}{100}$ L. The same proportions are represented in Sowerby's figure. The palleal impression, in the specimen above referred to, is nearly an inch from the lower margin. The flanks are flatter, and straighter than in the *cuneatus*. The surface of the cast, from the beak downward, is flattened as in the *cuneatus*. The valves are less than half a line thick in the most prominent part, and just exterior to the palleal impression are nearly two lines thick. The specimens have the shell calcareous, but with the cross cleavage of calc spar.

Megadesmus antiquatus, J. D. Sowerby, Mitchell's Australia, vol. i., pl. 3, fig. 2, pp. 15, 16.

Pachydomus antiquatus, J. Morris, op. cit., p. 272. Wollongong is mentioned as a locality of this and the preceding species, the correctness of which we much doubt.

34. *PACHYDOMUS LEVIS* (J. D. Sowerby), Morris.—One of our specimens from Harper's Hill, resembling in general characters the *antiquatus*, has nearly the proportions of Sowerby's *levis*. Its length is 3 inches, and breadth $2\frac{1}{8}$ inches ($=\frac{7}{100}$ L.)

Megadesmus levis, J. D. Sowerby, loc. cit., pl. 3, fig. 1.

NOTE.—The *Megadesmus globosus* of Sowerby, (loc. cit., pl. i.) is another species from Harper's Hill, which we did not meet with. It is represented with the very thick valves characteristic of this genus, in which particular it differs widely from the Wollongong species, which it externally resembles, and which has apparently been here referred. It has nearly the proportional length and height of the *antiquatus*, but in Mitchell's figure is nearly as thick as it is high.

GENUS MÆONIA (*Dana*).—Slightly inequivalve; oblong, elliptical, or sub-ovate, larger anteriorly, gaping a little or not at all. Beak moderately prominent. Ligament external. Muscular impressions three; the large anterior subovate, and somewhat pointed above; the small anterior, facing the same way with the larger, the muscle having a lateral instead of forward direction. Palleal impression, distinct or indistinct; posteriorly, rather abruptly bent upward to the posterior muscular impression. Lateral surface usually compressed, and in some species strongly concave. Flanks often broadly flattened. Beaks of cast approximate at apex, and acuminate, terminating often in an acute or thin apex, and sometimes a slender process.

The general appearance of a cast of some species of this genus is much like that of the *Pachydomi*. This is strikingly the case in the exterior form, and the palleal impression. But the unequal valves, the form of the large anterior muscular impression, and the reverse position of the smaller anterior, as well as the approximated and acuminating apices of the beaks of a cast, require their separation.

In a brief notice of the Expedition Fossils in the American Journal of Science, vol. iv. ii. series, the species here included under *Mæonia* are referred partly to other genera; yet as they all agree in the character of the anterior muscular impressions, and the transitions in form are quite gradual, they are here brought together. The divisions may, perhaps, form sub-genera, as there are some striking differences, as follows:

MÆONIA.—An accessory excavate muscular impression, about as large as the smaller anterior, situated anteriorly near the summit of the beak. Palleal impression strong. [Species large.]

PYRAMIA.—No accessory muscular impression anteriorly. Lateral surface more or less compressed (observable at least in the cast). Palleal impression distinct or indistinct.

A cast of the hinge of a left valve is well preserved in two of our specimens belonging to two species, which we had referred to this division; and it is possible that when the hinge in other species is made out, a more decided separating line may somewhere be satisfactorily drawn. There are no distinct teeth; the cast has a low, oblong, obtuse, subtriangular prominence, directly under the beak, with an oblique sulcus on its posterior side; in front, a shallow depression, prolonged and diminishing forward; and behind, an oblong depression, slightly deepening, and then diminishing again. Figures 4 *c*, and 6 *a*, plate 6, represent the form of the cast of the hinge, in the two specimens referred to.

CLEOBIS.—No accessory muscular impression anteriorly. Lateral surface not at all compressed. Beaks a little salient, and projecting over the cardinal area. Valves thin. Palleal impression faint.

The genus *Notomya* of M'Coy corresponds to our *Pyramia*, and was subsequently introduced. It is considered by M'Coy as having a relation to the Myidæ, but there is no true sinus to the palleal impression, and besides, they have two anterior muscles; the resemblance appears to be only in external form.

35. **MÆONIA ELONGATA** (*Dana*).—Thick; very inequilateral, oblong, length twice the height; narrowing behind. Right valve slightly highest. Sides obliquely excavate; rounded carinate posteriorly, with the flanks flattened, and slightly bending; inferior margin a little excavate along the middle. Exterior surface strongly concentric striate, and large. Muscular impressions with vertical erosions. A small accessory muscular impression on the front of the beak.—Length $6\frac{1}{2}$ inches; height $\frac{5.0}{100}$ L.; thickness $\frac{4.2}{100}$ L., or $\frac{8.0}{100}$ H.—Plate 5, fig. 3 *a, b, c*, views, natural size.

Black Head, District of Illawarra.

This species has not the flank strongly bent like the following, and is much longer in proportion, and less rapidly narrowing behind. The anterior part is less than one-third the whole length.

Myonia elongata, Exped. Foss., Amer. Jour. Sci., ii. ser., iv. 158.

36. **MÆONIA VALIDA** (*Dana*).—Thick; very inequilateral, oblong, length somewhat less than twice the height, rather rapidly decreasing in height, posteriorly and obliquely truncate behind, strongly carinate, with the flank (in cast) flat and broad, and bent at the posterior muscular impression. Left valve slightly highest. Sides obliquely excavate, inferior margin excavate. Large muscular impressions with strong vertical erosions; the larger anterior produced upward nearly to smaller anterior. Accessory muscular impression on front of beak. Palleal impression very strong, with delicate vermiform erosions running upward from it, and others (attachment of muscular fibres) scattered over the lateral surface.—Length of cast 6 inches; height $\frac{5.8}{100}$ L.; thickness $\frac{4.5}{100}$ L.; apical angle of cast 128° .—Plate 5, fig. 4, *a, b*, views, natural size.

Black Head, District of Illawarra.

We have only a cast of this species. The anterior part is less than one-third the whole length.

Myonia valida, Exped. Foss., loc. cit., p. 158.

37. *MEONIA AXINIA* (*Dana*).—Rather thin; very inequilateral; oblong, length about $1\frac{1}{2}$ times the height, diminishing much in height posteriorly, rounded anteriorly; right valve a little the highest; flank flattened, but no distinct carina. Palleal impression strong, forming a narrow uneven band, abruptly bent below the posterior muscle, not reaching quite to larger anterior muscular impression. This last muscular impression ovate, subacute above, smooth, with faint horizontal lines. No accessory muscular impression on front of beak. Posterior muscular impression quadrate, with upper angle prolonged, smooth, with faint horizontal lines. Apex of beak of cast acutely prolonged. Lateral surface of cast, from the beak obliquely downward, a little excavate.—Length of cast $2\frac{7}{8}$ inches; height $\frac{6.3}{100}$ L., thickness $\frac{3.6}{100}$ L., or $\frac{1}{2}$ H.; apical angle of cast 135° .—Plate 5, fig. 5 *a*, *b*, cast, natural size; *c*, enlarged view of small anterior muscular impression.

District of Illawarra.

Figure 5 *d*, is believed to be an imperfect specimen of the shell of the same species. The flank is flattened and broad, and the sides are compressed and a little excavate along an oblique direction; surface coarsely concentric striate; valves moderately thick. Anterior portion about $\frac{2}{3}$ the whole length. Length $3\frac{2}{3}$ inches; height $\frac{6.0}{100}$ L.; thickness $\frac{3.5}{100}$ L.; apical angle about 142° .—Wollongong, Illawarra.

In the notice of the Expedition Fossils, in the Amer. Jour. Sci., ii. Ser., iv. 157, this specimen is named *Cypricardia ? sinuosa*. Morris's second figure of *Pachydomus carinatus*, (pl. xi., fig. 4, Strzelecki,) represents a cast, much resembling our figure 34; but the posterior muscular impression is marked vertically with strong lines. His figure 3 is altogether different. Both pertain apparently to this genus.

38. *MEONIA ? CARINATA* (*J. Morris*) *Dana*.—Moderately thick; very inequilateral, oblong, height rather more than half the length, narrowing much posteriorly, and rounded truncate behind. Sharply carinate behind, and flank flat, broad, and nearly straight. Lateral surface a little compressed, rugose, rugæ somewhat undulating and irregular. Inferior margin slightly arcuate, (nearly straight,) and forming almost a right angle with the posterior margin; front margin arcuate.—Length 2.9 inches; height $\frac{5.6}{100}$ L.; thickness $\frac{3.3}{100}$ L., or $\frac{6}{10}$ H.; apical angle about 132° .—Plate 6, figs. 1 *a*, *b*, one valve, exterior cast, natural size.

Wollongong, District of Illawarra.

This is a very strongly carinate species, with a rugose surface. The anterior part of the shell is about one-third the whole length. There is a distinct cardinal area, which is profound, and has a carinate outline. The flattened flank makes nearly a right angle with the lateral surface.

Pachydomus carinatus, J. Morris, in Strzelecki's New South Wales, p. 273, pl. 11, fig. 3.

Cypricardia rugulosa, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 157.

39. *MEONIA FRAGILIS* (*Dana*).—A sharply carinate species allied to *carinata*. Plate 6, figs. 2, 3, different specimens much broken, natural size.

Glendon, valley of the Hunter.

This large species is so much compressed and distorted that it cannot be properly characterized. The length is about $4\frac{1}{2}$ inches, and height $2\frac{1}{2}$. It has an acute or subacute carina, situated like that of the *rugulosa*. The surface is very coarsely and unevenly marked with concentric striæ or ridges, and the lines of the flattened flank make

less than a right angle with those of the lateral surface. The shell appears to have been quite thin; portions remaining are much less than half a line in thickness. The lateral surface must have been a little flattened, and the lower margin, judging from the direction of the rugæ, was nearly or quite straight at middle.

40. *MÆONIA MYIFORMIS* (*Dana*).—Rather thin; inequilateral; oblong elliptical, with the beak little prominent, and the lower margin nearly straight; not narrowing behind, nor carinate, posterior and anterior margins equally arcuate. Exterior surface smooth, with only faint striæ of growth. Sides compressed. Palleal impression and posterior muscular indistinct. Larger anterior muscular impression excavate above. Cast of extremity of beak a slender point.—Length 2 inches; height $\frac{6.1}{100}$ L.; thickness about $\frac{3.5}{100}$ L. or $\frac{5.8}{100}$ H.; apical angle about 148° .—Plate 6, fig. 4 *a*, interior cast of a valve; *b*, front view of same; *c*, view of cast of hinge.

Wollongong Point, District of Illawarra.

This species is distinguished by being thin, not narrowing behind nor carinate, and surface smooth. This last character, and its less arcuate lower margin, distinguish it from the following.

Pyramus myiformis, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 157.

41. *MÆONIA ELLIPTICA* (*Dana*).—Rather thin; inequilateral, oblong elliptical, narrowing a little behind, not carinate, lower margin, and also the anterior and posterior, arcuate. Right valve rather highest. Surface evenly convex, concentrically marked with smooth unequal ridges and striæ of growth. Palleal impression faint, anteriorly plicatulate. Posterior muscular impression faint, anterior less so. Lateral surface of cast a little flattened, cast of beak acute.—Length $1\frac{3}{4}$ to 3 inches; height $\frac{7.0}{100}$ L.; thickness $\frac{4.1}{100}$ L., or $\frac{6}{100}$ H.; apical angle 137° .—Plate 6, fig. 5 *a*, *b*, *c*, different views, natural size; fig. 6, cast of a larger specimen; 6 *a*, cast of hinge of left valve.

Harper's Hill, valley of the Hunter?—Wollongong, Illawarra.

The striæ on the smaller muscular impression are distinct; they cover the outer side, and curve around it in front.

Pyramus ellipticus, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 157.

42. *MÆONIA GIGAS* (*McCoy*) *Dana*.—Thick, ventricose, very inequilateral, oblong, height two-thirds the length; beak large and incurved; posteriorly narrowing, somewhat dilated, and behind obliquely truncate; flank flattened, but without a very distinct carina. Sides compressed, or slightly excavate, and inferior margin straight or a little excavate near middle; lateral surface marked with concentric striæ. Valves very thin.—Length $5\frac{1}{2}$ —7 inches; height $\frac{7.3}{100}$ L.

District of Illawarra.

This species has the large size and thin shell of the following species, but is not regularly convex, the sides being somewhat compressed, and it is longer for its height.

Pachydomus gigas, McCoy, loc. cit., p. 301, pl. 16, fig. 3.

43. *MÆONIA GRANDIS* (*Dana*).—Thick, ventricose, inequilateral, sides regularly convex, not at all carinate, narrowing somewhat posteriorly, and posterior margin arcuate;

beak salient and incurved; lower margin arcuate. Exterior surface concentrically striate. Anterior part about one-third the whole length.—Length $7\frac{1}{2}$ inches; height $\frac{6.9}{100}$ L.; thickness $\frac{6.0}{100}$ L., or $\frac{2}{3}$ H. Apical angle 105° .—Plate 6, fig. 7, shell, natural size; *a*, outline of transverse section; 8, 8 *a*, another smaller specimen.

Wollongong Point, District of Illawarra.

This and the following species are similar in the regular convexity of the lateral surface, showing nothing (not even in the cast) of the compression or excavation of the sides along an oblique area, belonging to the several preceding species. It is also remarkable for its salient incurved beak, a characteristic laid down for our genus *Cleobis*. The *M. gigas* is similar in this respect.

Cleobis grandis, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 154.

Pachydomus globosus [?], Morris and M'Coy.

44. *MÆONIA GRACILIS* (*Dana*).—Near *M. grandis*, but having the anterior part about two-fifths the whole length, and a larger apical angle. Length 2.9 inches; height $\frac{7.2}{100}$ L.; thickness $\frac{5.0}{100}$ L.; apical angle 125° .—Plate 7, figure 1 *a, b, c*, different views, natural size.

Wollongong Point, District of Illawarra.

Cleobis gracilis, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 154.

45. *MÆONIA? RECTA* (*Dana*).—Moderately thick; very inequilateral, oblong, sides a little compressed, but not at all excavate; postero-dorsal portion dilated; inferior and superior margins nearly straight at middle and parallel, posterior arcuate, anterior obliquely truncate. Lateral surface concentrically and strongly marked with striæ of growth, nearly smooth.—Length $3\frac{1}{2}$ inches; height $\frac{6.0}{100}$ L.; thickness $\frac{4.1}{100}$ L. or $\frac{7}{10}$ H.—Plate 7, figure 2.

Wollongong Point, District of Illawarra.

The straight lines of growth over the medio-lateral surface and straight medio-inferior margin, parallel with the dorsal, give a peculiar character to this species.

Cleobis recta, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 154.

46. *NUCULA ABRUPTA* (*Dana*).—Thick; much elongate; beaks prominent and inflated; diminishing rapidly behind the beaks and prolonged posteriorly and subacuminate; lower margin arcuate, front narrow arcuate. Cast with a broad flat cardinal area, carinate externally and nearly at right angles with the lateral surface; general surface smooth; muscular impressions excavate, smooth, the posterior overlapping the carina in the cast, and quite prominent at the upper extremity; palleal impression a smooth faint excavation.—Length $1\frac{1}{3}$ inches; height $\frac{6.0}{100}$ L.; thickness about $\frac{4.5}{100}$ L., or $\frac{2}{3}$ H.; apical angle about 135° ; height across the upper part of posterior muscular impression about half the greatest height.—Plate 7, fig. 3, cast, natural size; 3 *a*, posterior muscular impression.

Wollongong Point, District of Illawarra.

The specimen is an internal cast, and shows finely the numerous teeth of the hinge. The palleal impression is about $1\frac{1}{2}$ lines from the inferior margin. There are a few faint rays on the surface of the cast, visible in certain lights.

Nucula abrupta, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 157.

✓ 47. *NUCULA CONCINNA* (*Dana*).—Plate 7, fig. 4, an imperfect specimen, natural size.—We thus name a small delicate species, of which we have but an imperfect specimen. It has a smooth exterior with occasional lines of growth, and the valves thin. The form is oblong ovate, subacuminate and thinning much behind; length nearly twice the height; surface not at all carinated posteriorly; apical angle nearly 150° .—From Harper's Hill.

✓ 48. *NUCULA GLENDONENSIS* (*Dana*).—Plate 7, fig. 5. A compressed specimen, natural size.—This is another species which we characterize from an imperfect individual, the specimen being much flattened. Shell quite thin, short subelliptical in form, broadly arcuate behind; dorsal margin straight; anterior margin nearly at right angles (about 100°) with the dorsal. Length half an inch; breadth two-thirds the length. One valve is slightly convex; the other through compression is concave. From Glendon.

GENUS EURYDESMA.—This genus was instituted by J. Morris, Esq., for a species from Australia, referred doubtfully to *Isocardia* by J. D. Sowerby. He considers it near *Avicula* in essential characters, and describes it as “equivalue, suborbicular, thin, but thick at the umbos; ligamental area elongate and almost wholly internal; a large obtuse tooth in the right valve, none distinct in the left; a byssiferous canal passing out of the umbos at the margin of the shell; several small muscular impressions, situated within anteriorly beneath the umbos, (‘ex internam partem umbonis.’)”

Our collections contain several specimens and two or three species; yet it is difficult to lay down, with certainty, all the characters. The species are evidently *inequivalue*, subequilateral, with the beaks approximate, incurved, and curving a little forward; the left valve, under the beak, is very much thickened, and the hinge line is consequently bent far to the right, as shown in the figures; the valves are very thick beneath the umbos, as is shown in figure 8 *d*, which is a transverse section of a valve across the beak, the outer or lower part of the valve being wanting. In this species, about three inches high, the thickness at the beak is nearly an inch and a quarter. The hinge in the left valve is simply a broad waved surface, with a depression somewhat anteriorly, answering to a large rounded prominence or tooth in the other valve, as described by Morris. The inner surface, of which we have a good specimen, is rather finely and irregularly pitted, without any of the prominences represented in Morris's first figure on plate 12; instead, there are below the beak two small depressions half an inch apart, as shown in figure 8 *e*, and supero-posteriorly there are four smaller pit-like depressions forming a curved line, half an inch long. These depressions have a very similar position and appearance to those of the common *Meleagrina*, and are undoubtedly for muscular attachment. Other muscular impressions are not distinguishable in our specimens, and no palleal impression. There are some analogies to the shell of a *Hippopus* and also to that of a *Meleagrina*. In one fine specimen, in which the beak of one valve is broken half off, there is a tubular cavity (filled with rock) coming up obliquely from between the beaks and passing out anteriorly; and this cavity was probably the byssiferous channel.

49. *EURYDESMA ELLIPTICA* (*Dana*).—Moderately thick; elliptical. Exterior surface evenly convex with faint concentric lines of growth, (elliptical in form,) and no radiations. Inferior margin regularly arcuate.—Length $2\frac{3}{4}$ inches; height $\frac{8.9}{100}$ L.; thickness $\frac{5.5}{100}$ L. or $\frac{6.2}{100}$ H.; apical angle 124° .—Plate 7, figs. 6 *a, b, c, d*, different views, natural size.
Harper's Hill.

Eurydesma elliptica, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 158.

50. *EURYDESMA GLOBOSA* (*Dana*).—Very thick, ventricose; orbicular. Lateral surface evenly convex, with faint concentric lines of growth regularly circular, and no radiations. Inferior margin regularly arcuate.—Length and height $1\frac{1}{2}$ inches; thickness $\frac{7.2}{100}$ L.; apical angle 97° .—Plate 7, figs. 7, 7 *a*, different views, natural size.
District of Illawarra.

Eurydesma globosa, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 158.

51. *EURYDESMA SACCULUS* (*M'Coy*) *Dana*.—Very thick, ventricose, length and height nearly equal. Lateral surface compressed at middle, and the lines of growth bent where leaving this compressed area; also a few distant concentric undulations. Beak prominent and rather narrow. Inferior margin straight at middle or a little excavate.—Length $3\frac{3}{4}$ inches; thickness $\frac{9.6}{100}$ L., or nearly as great as height; apical angle between 90° and 100° .—Plate 7, figures 8 *a, b*, representing an imperfect specimen, natural size; *c*, back view of beak of the left valve and thickened shell below; *d*, sectional view of the valve through the beak and hinge, vertically; *e*, inner view of same, showing the interior surface, and hinge of left valve.
Harper's Hill.

This species is as much thicker than the *globosa*, as the *globosa* is thicker than the *elliptica*. It is also distinguished by its flattened lateral surface and slightly excavate lower margin, the direction of the outline of which is indicated by the concentric striæ of growth, which bend a little downward near the middle with a broad curve. The surface does not appear to have been radiated.

Pachydomus sacculus, M'Coy, Ann. and Mag. Nat. Hist., vol. xx., p. 301, pl. 14, fig. 5.

52. *EURYDESMA CORDATA* (*Morris*).—Rather thick, ventricose, orbicular. Lateral surface slightly compressed at middle, marked with concentric lines of growth and low ridges, and also with faint radiations.

Harper's Hill.

This species, described by Morris, was first figured by J. D. Sowerby in Mitchell's Australia. The indistinct radiate striations are stated by Morris to be well represented in J. D. Sowerby's figure. This figure (his figure 1, pl. 2) represents a much thinner species than the last, and from either of the preceding it is distinguished by its radiations and slightly flattened lateral surface, as well as form. Figure 1, plate 8, represents a species allied to this in form, and with faint radiations in the cast and texture of the shell, though not well seen in the exterior. The surface is marked with coarse, low, concentric ridges.

Its length and height is 5 inches; thickness $\frac{6}{100}$ L.; apical angle about 100° . The specimen is from Harper's Hill.

Isocardia? J. D. Sowerby, in Mitchell's Exped. into Australia, vol. i. p. 15, pl. 2, figs. 1, 2.

Eurydesma cordata, J. Morris, in Strzelecki's New South Wales, p. 276, pl. 12, the second and third figures; also the first?

53. *CARDIUM AUSTRALE* (M'Coy) Dana.—Oblong, compressed, dilated, semicircular in front, diminishing much and prolonged behind, strongly carinate from the beak to the infero-anterior margin. Anterior to the carina, the surface a little concave, and finely striate longitudinally; posterior to it, costate, four costæ moderately broad, next nine or ten much narrower, and the following again broader.—Length $1\frac{1}{4}$ inches; height rather less than two-thirds the length.—Plate 8, figure 2, valve, natural size, with the beak imperfect.

Glendon, valley of the Hunter.

Pleurorhynchus australis, M'Coy, Ann. and Mag. Nat. Hist., vol. xx., p. 300, pl. 16, fig. 4—M'Coy mentions Wollongong as a locality; the author did not meet with it there; and from the term "sandy schists" applied to the containing rock, we should suspect Glendon to have been the locality of his specimen.

54. *CARDIUM FEROX* (Dana).—Very large; thick and very strongly costate; the costæ unequal, broad, nearly flat and subangular. Anterior (?) muscular impression suborbicular. Palléal impression excavate, acute and undulate.—Plate 8, fig. 3, view of part of inner surface of the extremities of two valves, and cast of exterior in part; 3 *a, b*, different views of interior cast of the same, showing muscular and palléal impressions.

Wollongong Point, District of Illawarra.

Our specimen of this species is only a portion from one end of the shell, as represented in the figures referred to; of this part, the valves, and an external and internal cast, are preserved. The valves, where stoutest, are over half an inch in thickness. The height of the specimen could not have been less than 5 inches, and the thickness $3\frac{1}{2}$ or 4 inches. The costæ are very irregular, often subdividing, and are from an eighth to a quarter of an inch, or more, in width; they are more or less longitudinally striated. The muscular impression is nearly an inch in its horizontal diameter; and is indistinct in its markings. The palléal impression in the cast is a neatly acute raised line, with short undulations, (about four to half an inch). The end of the shell is a long, nearly erect curve, indicating that the animal was higher than its thickness.

We have referred this species to the genus *Cardium*; but we still cannot understand how in a *Cardium* there should be a strong marginal costa, and the other costæ nearly parallel with it, in a continuous series. In the species of *Cardium* the costæ usually terminate on the margin; and this is a general truth with respect to bivalves.

GENUS CYPRICARDIA.—Several of the following species have the form of *Mytilus* or *Avicula*, and one that of *Gervillia*. But they are also similar in form to species of *Cypricardia*; and besides, they approach that genus in the very strong anterior muscular impression, situated far forward, near the anterior margin. The structure of the shell in three species, (the *C. arcodes*, *C. imbricata*, and *C. acutifrons*,) is very beautifully fibrous; the other specimens are external casts. This character removes them from *Mytilus*, while it does not oppose their union with the *Cypricardiæ*. Moreover, the species occur with deep-water molluscs, and this was evidently their natural habitat. The character of

the muscles evidently separates them from *Avicula*, to which they are allied in their fibrous shells. The posterior muscular impression is very faint, but in some instances may be distinguished; and we therefore remove them from the genus *Modiolopsis* (*Hall*), which is based on the existence of but a single muscle.

55. *CYPRICARDIA ACUTIFRONS* (*Dana*).—Thick and much elongate, very oblique, (*Gervillia*-like,) prolonged and broad behind, with the posterior margin orbiculate; in front very short, acuminate. Surface smooth, with a few concentric undulations. Cardinal margin straight, about half the length of the shell. Lateral surface convex, and not carinate posteriorly, excavate from the beaks downward. Inferior margin concave near front, and again more broadly so below the beak. Anterior muscular impression strong, situated near the front; posterior indistinct.—Length $3\frac{3}{4}$ inches; height of posterior part of shell $1\frac{3}{4}$ inches; angle between the cardinal margin and the line of elongation of the shell, about 32° .—Plate 8, fig. 4 *a*, *b*, different views, natural size.

District of Illawarra.

The specimen is partly an exterior cast, with portions of the shell remaining. The fibrous texture is distinct.

Modiolopsis acutifrons, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 159.

56. *CYPRICARDIA IMBRICATA* (*Dana*).—Rather thin; oblong; sub-alate above, sub-orbiculate behind; short and obtuse in front and half lower than behind; cardinal margin straight and nearly as long as the shell; surface neatly marked with small concentric ridges; otherwise smooth; sides compressed below the beaks, not carinate posteriorly. Inner surface of valves towards beaks finely marked with radiate striæ.—Length $2\frac{1}{8}$ inches; greatest height about half the length.—Plate 8, figure 5, a compressed and broken specimen, enlarged one-sixth.

Harper's Hill.

The valve is half a line thick, and throughout is very distinctly fibrous, the fibres being easily separable. A line extends from the back of the beak backward, diverging a little from the cardinal margin, and thus giving an alate upper border to the shell, upon which the faint ridges of the surface are in part nearly vertical.

Figures 6 and 7, plate 8, represent two specimens, which may belong to the species just described. Yet the surface of the cast towards the beak is smooth, and not finely radiato-striate; the alate portion is separated by a more distinct suture, and has its surface more finely striate. Figure 6 represents a cast, the anterior and posterior parts of which are broken; figure 7 is another imperfect specimen, with a portion of the shell remaining. The sides are much convex. The beak of the cast is thin, and has almost a trenchant summit; its sides are flattened. The cardinal margin was very long, as in the *imbricata*.

Modiolopsis imbricata, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 159.

57. *CYPRICARDIA ARCODES* (*Dana*).—Thick, subventricose, oblong; sub-alate above; extremities orbiculate, a little narrower in front; cardinal margin much shorter than the shell. Surface nearly as in the *imbricata*. Sides very convex. Slightly compressed anteriorly. Anterior muscular impression vertical, much elongate upward, and forming

a projection in front of the beaks. Posterior muscular impression faint.—Length $1\frac{3}{4}$ inches, height much less than half the length.—Plate 8, fig. 8 *a, b*, views of a cast, natural size.

Harper's Hill.

The texture of the valves is fibrous as in the *imbricata*, and the form of the species is in general similar, though thicker and less oblong, with the cardinal margin much shorter. It resembles in shape an *Arca*. The large muscular impression stands up, nearly as in Bronn's genus *Myophoria*, (*Lethæa* Geogn. pl. 11, fig. 6.)

The surface of the cast shows some faint traces of radiations towards its anterior portion. The height of the shell was probably about two-thirds its length.

Modiolopsis arcodes, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 159.

NOTE.—Fig. 9, plate 8, represents a part of a cast of an allied species, probably a young individual.

58. *CYPRICARDIA PRÆRUPTA* (*Dana*).—Moderately thick; elongate; broader behind and orbiculate; in front abruptly truncate, with a vertical fold quite near the front margin, and another excavate area obliquely downward from the beak. Surface smooth, with some fine striæ of growth, and very faint radiations; convex posteriorly, without a carina. Cardinal margin straight, and gradually rounding into the posterior margin; inferior margin excavate posterior to middle. Anterior muscular impression strong, nearly circular, situated close to the front margin; posterior indistinct.—Length $1\frac{4}{10}$ inches; greatest height $\frac{5}{10}$ L.; apical angle 100° .—Plate 8, figure 10, natural size.

District of Illawarra.

This species closely resembles the *Modiolopsis faba* of Hall (New York Palæont., pl. 35, fig. 6), which is a lower Silurian species. The breadth in front is about three-fourths the greatest breadth.

Modiolopsis prærupta, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 159.

59. *CYPRICARDIA SILIQUA* (*Dana*).—Rather thin, oblong, broader posteriorly, and margin orbiculate; front a little projecting, and rounded below. Cardinal and inferior margins straight, and rounding into the posterior. Sides convex, not carinate behind, compressed below the beak. Anterior muscular impression distinct, situated near the front margin. Surface concentrically subplicate.—Length $1\frac{1}{4}$ inches; greatest height $\frac{5}{10}$ L.; apical angle about 130° .—Plate 9, figures 1 *a, b*, different views, natural size.

District of Illawarra.

This small species resembles the *Mytilus (Modiola) Teplofi* of Verneuil (Russia, pl. 19, fig. 17); but it is somewhat higher proportionally, has the front a little more projecting, and the posterior margin is more nearly semicircular. Still it is possible that they are identical. Verneuil's species is from the *coal mines* of Lissitchia in Russia.

Modiolopsis siliqua, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 159.

60. *CYPRICARDIA SIMPLEX* (*Dana*).—Moderately thick; elongate; oblong sub-elliptical, (length more than twice the height,) rather broader posteriorly, and elliptically rounded behind. Front margin obliquely truncate and rounded below. Cardinal margin scarcely arcuate, rounding into the posterior. Inferior margin regularly arcuate. Late-

ral surface throughout evenly convex. Surface smooth, faintly subplicate concentrically. Anterior muscular impression a little excavate, short sub-elliptical, marginal. Length $1\frac{1}{2}$ inches; height $\frac{4.4}{10.6}$ L.; apical angle about 132° .—Plate 9, fig. 2, natural size.

Modiolopsis simplex, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 158.

61. *CYPRICARDIA* (*AVICULA* ?) *VENERIS* (*Dana*).—Thin; much elongate, narrower anteriorly, elliptic posteriorly, with a long cardinal margin. Sides somewhat excavate beneath the beaks, and inferior margin correspondingly excavate. Surface somewhat convex, and not carinate posteriorly, long radiate; costate over the middle and posterior surface, the lower costæ a line or more apart at the margin, the upper nearer; also faint concentric lines of growth, and faint undulations.—Length $2\frac{1}{10}$ inches; greatest height about $\frac{4.0}{10.6}$ L.; below the beak, height somewhat more than half the greatest height. Plate 9, figs. 3 *a*, *b*, an external cast, imperfect, natural size.

Glendon, valley of the Hunter.

62. *AVICULA VOLGENSIS*? (*Verneuil*).—Plate 9, fig. 4. An imperfect specimen, natural size, from Wollongong, Illawarra. The specimen does not give the complete form of the species. The costæ are fine, and appear to differ from those of the *volgensis*, (Russia, 473, pl. 41, fig. 13,) in frequently subdividing, or being less regular, and as close and fine at the lower margin as above.

63. *PTERINEA MACROPTERA* (*J. Morris*).—Our specimen is an imperfect one, and we venture no remarks upon it. It is from Illawarra.

Pterinea macroptera, J. Morris, in Strzelecki's New South Wales, p. 276, pl. 13, figs. 2, 3.

64. *PECTEN COMPTUS* (*Dana*).—Orbicular, 20–22 larger costæ, obtusely triangular, with the sulci broadly concave, and occupied with a medial costa, and 1 to 3 smaller; costæ naked, without markings or transverse striæ. Ears large, longitudinally marked with fine diverging costæ. Length and height $2\frac{1}{3}$ inches; distance, at the lower margin, between the middle of two larger costæ, $\frac{1}{3}$ to nearly $\frac{1}{4}$ inch.—Plate 9, fig. 5, natural size.

Harper's Hill.

The specimen is a single convex valve. The shell is white and well preserved, and is less than a third of a line thick.

Pecten comptus, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 160.

Pecten sub-5-lineatus (?) M'Coy, Ann. & Mag. Nat. Hist., vol. xx., p. 298, pl. 17, fig. 1. M'Coy's specimen (from Harper's Hill) was a little larger than ours, and this may account for the occurrence, in some instances, of five intermediate costæ.

65. *PECTEN LENIUSCULUS* (*Dana*).—Large, plano-convex, orbicular. Surface concentrically sub-undulate, nearly smooth, minutely costate or fine striate, costæ without cross striæ or markings, rather more distant, and somewhat larger on the convex valve. Ears large, subequal, transversely undulate and longitudinally striate.—Length and height $4\frac{1}{2}$ inches; thickness $1\frac{1}{2}$ inches; apical angle, excluding the ears, 100° .—Plate 9, figs. 6 *a*, 6 *b*, different sides, natural size.

District of Illawarra.

The costæ of this comparatively smooth species are about seven or eight to a breadth of a fourth of an inch near the middle of the flat valve, and four or five near the lower margin. In one specimen, the convex valve near the lower margin has but three costæ in a fourth of an inch. The flat valve is somewhat convex in its upper part, and a little concave below. The cardinal margin is straight.

Pecten leniusculus, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 160.

66. *PECTEN TENUICOLLIS* (*Dana*).—Sub-orbicular, 24-costate, costæ very slender, subacute, smooth. Sulci shallow, nearly flat at bottom, and having an intermediate smaller costa. Ears moderately large. Cardinal margin straight.—Length $1\frac{1}{8}$ inches; height $1\frac{1}{2}$ ($1\frac{1}{8}$?) inches; distance of larger costæ at lower margin of valve, about $\frac{4}{5}$ line. Apical angle, ears excluded, slightly exceeding a right angle.—Plate 9, fig. 7, natural size; 7 *a*, section of surface.

Harper's Hill.

The specimen is a single convex valve, somewhat broken, and the surface of the shell is a little shining.

Pecten tenuicollis, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 160.

67. *PECTEN MITIS* (*Dana*).—Plate 9, figs. 8 *a*, *b*, Glendon. Like other specimens from Glendon, this *Pecten* is much broken and distorted. It appears to have been a little oblong and oblique, with unequal ears; surface with minute smooth costæ, the larger with two, more minute, intermediate; distance between larger costæ at lower margin, about four-fifths of a line. Length $1\frac{3}{4}$ inches, height probably a fourth less. Apical angle, excluding ears, much exceeding a right angle.

68. *PECTEN ILLAWARRENSIS* (*J. Morris*).—Plate 9, figure 9, shell, natural size; 9 *a*, section of surface. Harper's Hill. Morris gives Illawarra as the locality, the correctness of which we somewhat doubt. The species is a little higher than long. Both valves are convex, and 18 to 20-costate. Costæ large, smooth and rounded, and separated by concave interstices a little broader than the costæ. Apical angle, excluding ears, 80° to 90° . Height $4\frac{1}{4}$ inches; length $3\frac{3}{4}$ inches. Ears large. Distance between the middle of the costæ, at the lower margin, averages three-eighths of an inch.

Pecten illawarrensis, J. Morris, loc. cit., p. 277, pl. 14, fig. 3.

69. *PECTEN SQUAMULIFERUS* [?] *Morris*.—An imperfect specimen of *Pecten*, in our collections from Harper's Hill, has the costæ of the size in Morris's *squamuliferus*, and minutely undulate above, corresponding with the appearance in Morris's figure. The costæ are very nearly equal, rounded, and about half a line broad an inch from the beak.

Pecten squamuliferus, J. Morris, loc. cit., p. 278, pl. 14, fig. 1.—Specimen from Van Diemen's Land.

——, M'Coy, loc. cit., vol. xx., p. 298.—Locality cited, Wollongong, [query, olive-coloured rock of Harper's Hill ?]

70. —? Plate 9, figure 10, represents a portion of what appears to be a bivalve shell, which we do not venture to refer to a genus. It is bilobate, and appears as if it

might have some relation to an alate Avicula. The surface is distinctly marked with broad flat costæ, as represented in the figure. The specimen is from Illawarra.

c. *Mollusca Gasteropoda.*

71. *PILEOPSIS TENELLA* (*Dana*).—Short conical, oblong, acuminate at apex, and very slightly recurved. Apex anterior to centre, but situated over the base; aperture ovate-elliptical, entire, half narrower anteriorly. Surface smooth. Length of aperture $\frac{5}{8}$ inch; breadth $\frac{3}{8}$ inch; height of cone same as breadth.—Plate 9, figs. 13 *a, b*, different views, natural size.

Harper's Hill.

Patella tenella, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. p. 151.

72. *PILEOPSIS ALTA* (*Dana*).—High, compressed, conical; (height fully as great as length,) acuminate above, and apex much recurved forward, and projecting beyond the base. Base narrow elliptical, its length more than twice the breadth.—Plate 9, fig. 14, *a*, natural size; *b*, under view of same.

Harper's Hill.

The specimen here described belongs to the collections of Rev. Mr. Wilton of Newcastle. The description has been drawn up from a figure of it, made by his permission.

73. *PLEUROTOMARIA MORRISIANA*.—Conical, a little oblong, angle of spire about 35° , whorls about 4, convex, carinate, carina subacute, an upper carina obsolescent, a lower distinct. Aperture orbiculate.—Length 8 lines; breadth below, 5 lines.—Plate 9, fig. 15, specimen from Illawarra, natural size; 15 *a*, portion enlarged; fig. 16, specimen from Harper's Hill, natural size.

Black Head, District of Illawarra, and also Harper's Hill.

The specimens from Harper's Hill are mostly larger than those from Illawarra, the latter seldom exceeding a length of 6 lines. In the enlarged figure, it is observed that there are two concave lines encircling the spire; and, as usual, the direction of the lines in each, show the direction of the lines of growth.

I have adopted M'Coy's specific name, in preference to my own of earlier date, as the honour is well due to Mr. Morris, the author of the chapter on Fossil Australian Mollusca in Strzelecki's valuable work.

Pleurotomaria trifilata, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 151.

Pleurotomaria Morrisiana, M'Coy, loc. cit. vol. xx. 306, pl. 17, fig. 5. M'Coy observes that the species occurs in the sandstone of Muree, N. S. W., as well as of Wollongong.

74. *PLEUROTOMARIA NUDA* (*Dana*).—Short conical, angle of spire about 115° , whorls 4 or 5, rounded, separated by a suture, smooth, slightly carinated, with another obsolete carina either side.—Length half an inch; breadth about $\frac{3}{4}$ inch.—Plate 9, fig. 17 *a, b, c*, different views, natural size.

Harper's Hill.

Pleurotomaria nuda, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 151.

75. *PLEUROTOMARIA STRZELECKIANA* (*Morris*).—This large species was found abundantly in the Illawarra sandstone, but no Glendon or Harper's Hill specimens were met with by the writer.

Pleurotomaria Strzeleckiana, J. Morris, loc. cit. 287, pl. 18, fig. 5.

76. *PLATYSCHISMA OCLUS* (*Morris*).—This species is somewhat rounded conical, the larger spire a little depressed, and the angle of the spire about 90° . Our specimens are from Harper's Hill. The greatest diameter of any specimen observed was $3\frac{1}{8}$ inches.—Plate 10, fig. 1, represents a depressed specimen, believed to be of this species; it was probably distorted by pressure.

Platyschisma oculus, J. Morris, loc. cit., 286, pl. 18, fig. 1.

77. *PLATYSCHISMA ROTUNDATUM* (*Morris*).—Not uncommon in the sandstone of middle and southern Illawarra.

Platyschisma rotundatum, Morris, 286, pl. 18, fig. 2.

78. *PLATYSCHISMA DEPRESSUM* (*Dana*).—Large, suborbicular, very much depressed, almost disk-form, angle of spire about 140° . Whorls 3 or 4, each much flattened, separated by a suture; the back of the outer whorl, half an inch wide and round-truncate. Surface unevenly and coarsely marked with striæ of growth.—Diameter $4\frac{1}{2}$ inches.—Plate 10, figs. 2 *a*, *b*, different views, natural size.

Harper's Hill.

This species differs widely from the *oculus* in its very depressed form, and flattened whorls, the outer of which has the back subtruncate.

Platyschisma depressum, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 151.

79. *NATICA* — ? Plate 10, fig. 3, natural size. From Illawarra. Our specimens are too imperfect to be satisfactorily characterized.

80. *BELLEROPHON UNDULATUS* (*Dana*).—Scarcely compressed, back of whorls rounded, surface smooth, having a series of distant plications crossing the back parallel with the lines of growth, (nearly V-shape, the lower angle being rounded;) plicæ most abrupt on the posterior side, and becoming obsolete laterally. Aperture deltoideo-lunate, a little dilated either side.—Diameter $\frac{3}{4}$ inch; thickness through the centre $\frac{2}{3}$ inch.—Plate 10, fig. 4, *a*, *b*.

Harper's Hill.

There are about four plications on the back in a distance of half an inch.

Bellerophon undulatus, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 151.

81. *BELLEROPHON STRICTUS* (*Dana*).—Discoid, much compressed, smooth; back of whorls rounded. Aperture very narrow, compressed lunate, not laterally dilated.—Diameter $\frac{3}{4}$ inch; thickness at middle half the diameter.—Plate 10, figure 5, *a*, *b*, different views, natural size.

Wollongong, District of Illawarra.

Resembles a compressed Goniatite, but has no septa. The part of the aperture either side of the included body of the shell is narrow linear.

Bellerophon strictus, Exped. Foss., Amer. Jour. Sci., ii. Ser., iv. 151.

82. *BELLEROPHON MICROMPHALUS* (*Morris*).—Plate 10, figs. 6 *a*, *b*, different views, natural size.—Illawarra.

This species, like the preceding, has the aspect of a Goniatite. It differs from the *strictus* in being proportionally much thicker.

Bellerophon micromphalus, J. Morris, loc. cit., 288, pl. 18, fig. 7.

————— M'Coy, loc. cit., vol. xx. 308. Locality cited, Muree, N. S. W.

d. *Mollusca Cephalopoda*.

83. *THECA LANCEOLATA* (*Morris*).—Plate 10, fig. 7 *a*, lower extremity; *b*, upper extremity; *c*, section; *d*, specimen restored.

From Black Head, District of Illawarra.

The tapering form (resembling a straight horn), and the somewhat triangular shape of a transverse section, are correctly stated by Morris. The length is sometimes at least $2\frac{1}{2}$ inches, with the longest diameter at base over half an inch. The aperture, when unbroken, is a little flaring, and on the flattened side of the shell the margin is produced a little, and has an arcuate outline, which is therefore parallel with the arcuate striæ below,—showing that these faint uneven striæ are striæ of growth. The shell is very thin; and like some others of the locality has a dark olive-green fracture and chloritic texture. The inner surface is quite smooth, without striæ.

The Thecæ have been arranged with the Pteropoda, on account of a resemblance in form to the shells of some species of that group. The resemblance is quite as great to the osselet in some Cephalopoda, if we suppose the blade part wanting; and from the large size and structure of the Thecæ, they probably belong to that order. In the *Ommastrephes* of Blainville, the bone has a hollow conical termination, analogous apparently to the shell of the Thecæ, the latter differing only in being without the thin blade-like elongation above. The striæ of growth, and the form of the aperture support this conclusion.

Theca lanceolata, J. Morris, loc. cit., p. 289, pl. 18, fig. 8.

GENUS CONULARIA.—The Conulariæ have been arranged provisionally by d'Archiac and de Verneuil* with the Pteropoda,† and this reference of them has since been very generally adopted by Palæontologists. Still there are some reasons for doubting its correctness.

The shells of the Pteropoda are external, and unjointed in character. The long four-sided conical Conulariæ, on the contrary, are distinctly articulated (or at least admit of motion) between the sides. The same species, as it occurs in the rocks, is of various shapes, dependent on this jointed structure, and sometimes the sides are pressed quite

* Mem. Foss. Older Deposits of the Rhenish Provinces, p. 325.

† This view has been apparently favoured by finding transitions to the Thecæ, those holding it, supposing the latter to be Pteropods.

together. The character of the articulation is represented in fig. 9 *a*, plate 10. From this structure and the fragility of the shells, we are led to infer that they were probably internal instead of external; and the articulation enabled the animal to accommodate the shell, by means of muscular action, to the motions of the body, or of its internal parts.

These observations are rendered more certain by the discovery by Mr. James Hall, of Conulariæ in the New York rocks which have transverse septa in the smaller extremity of the shell.* This fact has led him to arrange them with the Cephalopoda, where we believe they properly belong. The thin delicate shell in the Cephalopod genus, *Conoteuthis*, (Blainville,) has analogous septa within the alveolar extremity; and, moreover, it was evidently internal, (as in the Ommastrephes,) and therefore corresponds with the view taken of the Conularia. The shell of the Conularia is peculiar in being jointed; but this structure adapts it the better for internal functions. The transitions to the unjointed Thecæ corroborate the opinion here expressed.

In the Conulariæ the plates are transversely plicate, and the parallel ridges form an obtuse angle at middle, which is pointed away from the apex of the shell. They are consequently often broken longitudinally along the medial line. These minute ridges are sometimes quite smooth, and in other cases are dotted, or crenulate, or otherwise marked.

The characters distinguishing species are best derived from the nearness of the plications and their markings; the comparative breadth of adjoining plates; and the angle of divergence of the pyramid. The form varies much, as we have stated. The angle of divergence often differs also in different parts of an individual, it being less towards the base than towards the summit.

This genus has been recently made the subject of study by Hr. Dr. Guido Sandberger, of Wiesbaden.† He adopts the generic character drawn up by Koninck:‡ “Testa recta, elongata, pyramidata, tenuissima, quadrilatera, transversim plicata; angulis longitudinaliter sulcatis.” The real character of the angles is not here brought out, and the following is offered as more correct in this point:—*Testa (interna) elongatè tetragono-pyramidata, tenuissima: lateribus inter sese articulatis (aut subarticulatis) transversim tenuiter plicatis.*

84. CONULARIA INORNATA (*Dana*).—Large, adjoining sides very unequal, smaller $\frac{3}{4}$ the breadth of larger. Plicæ remote, (ten to half an inch,) naked, smooth [?]; angle of convergence 12° . Plate 10, fig. 8, natural size.

Glendon.

This fine species in its inornate plications, size and proportional dimensions of the sides, approaches most nearly the *C. irregularis* of de Koninck, (Carb. Foss. Belg., p. 496, pl. 45, fig. 2.) But the plications are still more distant, although they are more remote than usual in that species; there are in the Glendon specimen ten plications in the same space that contains twelve in the *irregularis*. The specimen, which is but a portion of a perfect individual, is very nearly 3 inches long, and has the breadth of the sides at the smaller extremity $\frac{3}{4}$ and $\frac{9}{10}$ of an inch; at the larger extremity $\frac{9}{10}$ and $1\frac{2}{10}$ of an inch. It has the rusted appearance that belongs to the Glendon specimens, and it is impossible

* Palæontology of New York, i. 222, pl. 59, fig. 4 *c*, *d*, *e*.

† Leonhard und Bronn's Neues Jahrbuch, 1847, p. 8.

‡ Anim. Foss. Belg., 1842, p. 494.

to determine whether the surface of the ridges were quite smooth or granulated; though it is apparent that they could not have been regularly crenulate.

85. *CONULARIA LEVIGATA* (*Morris*).—Plate 10, fig. 9, specimen compressed together, natural size; 9 *a*, enlarged view of articulation.

Harper's Hill, where it is abundant.

The form of this species in the specimen before us is but slightly convergent, except at the summit. The adjoining sides are subequal; in one individual, the larger side is $\frac{6}{10}$ of an inch; and the smaller $\frac{5.6}{100}$. There are 14 to 16 plications in half an inch; and the plicæ are smooth, without markings of any kind. No *Conulariæ* were observed in Illawarra, to which region this species is accredited by Strzelecki.

Conularia levigata, *Morris*, loc. cit., p. 290, pl. 18, figs. 9 *a*, *b*.

86. *CONULARIA TENUSTRIATA* [?] (*M'Coy*).—A fragment from Harper's Hill contains 25 to 27 striations in half an inch, and appears to belong to this species.

C. tenuistriata, *M'Coy*, loc. cit., p. 307, pl. 17, figs. 7, 8. Muree, New South Wales, is given as the locality. *M'Coy* describes also another species of *Conularia* from Muree, (*C. torta*), having, as he states, but two longitudinal furrows (articulating sutures).

3. RADIATA.

87. *FENESTELLA INTERNATA* (*Lonsdale*).—Plate 10, fig. 13, part of frond, natural size; 13 *a*, cast of upper side of same, enlarged; *b*, branchlet enlarged, seen from below after the removal of the exterior coat.

Glendon.

Lonsdale, in *Darwin's Volcanic Islands*, p. 165; in *Strzelecki's New South Wales*, p. 269, pl. 9, figs. 2, 2 *a*, 2 *b*.

88. *FENESTELLA MEDIA* (*Dana*).—Near *internata*, but spaces less rectangular, more oval and unequal; nearly half a line long. Under surface finely striate, and bearing a small tubercle at intervals.—Plate 10, fig. 14, part of a frond, natural size; 14 *a*, under surface enlarged. Fig. 15, cast of a frond; (is this last the *internata*?)

Glendon.

89. *FENESTELLA AMPLA* (*Lonsdale*).—Plate 11, fig. 1, part of frond, natural size; 1 *a*, inner inferior surface enlarged. Figure 2, 2 *a*, represents a cast of the frond of what appears to be another species, with much longer and more rectangular interstices, and at the same time more slender branchlets.

Glendon.

Lonsdale, in *Darwin's Volcanic Islands*, p. 163; in *Strzelecki's New South Wales*, p. 261, pl. 9, figs. 3 to 3 *d*.

90. *FENESTELLA FOSSULA* (*Lonsdale*).—Plate 11, fig. 3, part of frond, natural size; 3 *a*, cast of upper surface, enlarged; *b*, internal inferior surface, enlarged.

Glendon.

This very delicate species is quite common at Glendon, and forms fronds several inches in extent.

Lonsdale, in Darwin's Volcanic Islands, p. 166; in Strzelecki's New South Wales, p. 269, pl. 9, figs. 1, 1 *a*.

91. *FENESTELLA GRACILIS* (*Dana*).—*Lax*, branchlets extremely slender, dichotomous with arcuate axils; reticulation somewhat irregular; spaces large, and usually not rectangular, three or four times as wide as the branchlets. Under surface of branchlets smooth or slightly striate.—Plate 11, fig. 4, part of frond, natural size.

Glendon.

This species is near the *F. formosa* of M'Coy, (Carb. Foss. Ireland, pl. 29, fig. 2,) but the spaces are larger.

NOTE.—Plate 11, figs. 5, 5 *a*, represent another *Fenestella*; but we forbear describing from our imperfect specimen. The spaces and branchlets are minute as in the *F. fossula*, but the under surface is marked irregularly by a few undulating lines, and the branchlets diverge more frequently through the intercalation of new branchlets.

92. *CHETETES CRINITA* (*Lonsdale*) *Dana*.—Plate 11, fig. 6, much reduced, showing the form and direction of the columns; 6 *a*, size and closeness of columns; *b*, outer surface, natural size; *c*, outline of cells of same enlarged.

Wollongong Point, District of Illawarra.

The specimens of this species from Illawarra are occasionally six inches in diameter, and have a spheroidal form. They usually occur as the interior of spherical concretions, like most of the fossils of Wollongong Point. The size of the columns is about a fourth of a line; or, as they lie in the specimen, there are 30 in the breadth of half an inch; they separate rather easily, and are singularly regular in form, with few constrictions from irregular growth, and these commonly very slight and in concentric lines, which sometimes give a specimen the appearance of being made of successive tiers of columns.

Stenopora crinita, *Lonsdale*, in Strzelecki's New South Wales, p. 265, pl. 8, fig. 5.

93. *CHETETES TASMANIENSIS* (*Lonsdale*) *Dana*.—Plate 11, fig. 7, natural size; 7 *a*, surface enlarged. Fig. 8, a flattened specimen; 8 *a*, surface of same enlarged.

Harper's Hill.

Lonsdale's specimens are cited as from Mount Wellington, Mount Dromedary, Norfolk Plains, Van Diemen's Land. Those of Harper's Hill have a pearly white exterior, and are imbedded in the dark greenish argillaceous sandstone of that place. The branches are few, about half an inch in diameter. The columns are of uneven diameter, and are very slender, there being 35 or 38 to a breadth of half an inch. The apertures of the cells are oval; the interstices are either broad, or are quite narrow; the granules of the surface are irregularly placed, and often wanting between some of the cells. One specimen, (fig. 8,) is much flattened out by compression, as was the case with one mentioned by *Lonsdale*.

Stenopora tasmaniensis, *Lonsdale*, in Darwin's Volc. Islands, p. 161; in Strzelecki's New South Wales, p. 262, pl. 8, fig. 2.

94. *CHETETES OVATA* (*Lonsdale*) *Dana*.—Plate 11, fig. 9, natural size ; 9 *a*, *b*, enlarged views of columns.

Harper's Hill.

The columns are rather irregular in outline, and number about 30 in a breadth of half an inch. The branches in our specimens are half an inch in diameter, and have rounded terminations. The mode of divergence and interpolation mentioned by Lonsdale as characterizing this and other species, belongs to all corals growing, like these, from a budding cluster, and is well seen in the *Pocilloporæ*, many *Porites*, and in other genera. Lonsdale's specimens are quoted from the same localities as the *tasmaniensis*. The figure in Strzelecki represents well the character of our specimens, except that the constrictions of the columns are not quite as numerous.

Stenopora ovata, Lonsdale, Darwin's Volc. Islands, p. 163 ; Strzelecki's New South Wales, p. 263, pl. 8, fig. 3.

95. *CHETETES GRACILIS* (*Dana*).—Ramosé, branches slender, $1\frac{1}{2}$ to 3 lines thick ; cells subelliptical, and having the border a little prominent. Columns of the size in the *ovata*, (about 6 to a line in breadth,) even, with few constrictions.—Plate 11, fig. 10, natural size ; 10 *a*, columns enlarged ; *b*, *c*, surface of different parts enlarged.

Wollongong Point and Black Head, Illawarra.

Fig. 15, plate 10, represents another small coral ; but the specimen is so imperfect that we refer it very doubtfully to the genus *Hemitrypa*.

96. ENCRINITAL REMAINS. Fragments of one or more species of Encrinital remains occur in the Glendon rock, with the *Fenestellæ* and other species of that locality. But no good specimens have been seen by the writer.—Plate 11, figures 12 *a*, *b*, represent portions of one from that place.

Plate 11, figures 13, 14, represent portions of Encrinital remains in limestone, probably from the limestone region towards Yass Plains. Figure 15 is a fragment from the sandstone of Wollongong.

97. GENUS PENTADIA.—This genus is formed for three singular fossils, or portions of fossils, from Illawarra. Two of them have been seen only as casts, presenting finely the minute markings of the surface. The other is solid calcareous, and has been recrystallized since fossilization, so as to have an oblique transverse cleavage. There is evidence that they must have been hard, and not mere animal tissue, in their solid structure and the perfect symmetry of form which is retained by the specimens, for they are not at all distorted by pressure. That they were not each an Echinoderm is also apparent from their being quite solid calcareous throughout, whence it is obvious that they must have been calcareous or subcalcareous plates, when in their original condition. They must either be an internal secretion of some animal, or portions of an external shell or coverings. Mr. James Hall, to whom I submitted the specimens, pronounces them portions of a Crinoid, and offers reasons that seem to place it beyond doubt. The symmetrical radiate form of one specimen, precludes the idea of its having come from the interior of any mollusc, while, at the same time, it corresponds in this respect with the Radiata.

On this ground, and moreover, an actual resemblance to the plates of certain encrinites, particularly the echino-encrinites and some others, he feels assured that they are crinoidal. The three specimens observed, although so unlike in form, may therefore have belonged to a single species, as the dissimilarity is not greater than is common. The markings of the three are identical in character, and the specimens were all found at the same locality. The only objection I know to their being parts of a single species is the fact that the triangular specimen is much thicker than either of the other two. The following are the characters of each. We retain the generic name proposed in the American Journal of Science, and call the species to which the pentagonal plate, and one or both of the others belonged,

PENTADIA CORONA.—Plate 10, Figure 10, 10 *a*, *b*, *c*.

Figure 10, plate 10.—Discoid, five-sided, (or approaching ten-sided,) angles and edges rounded. Upper and under surfaces correspondingly radiato-undulate, consisting of five triangular areas and five intermediate concave depressions. Above, delicately marked concentrically with fine crenulate ridges, constituting a series of concentric pentagons (about thirty in all), the ridges of the inner seven or eight, coarser than the following. Diameter 2 inches; thickness $1\frac{1}{2}$ lines.—Figure 10 is a view of the sculptured surface, and 10 *a*, a section across from *a* to *b*, showing the thickness; 10 *a*, opposite surface; *b*, enlarged view of inner ridges.

The angles of the concentric pentagons are situated in the medial line of each pentagonal area, and in four of the intermediate depressions there is at middle a re-entering angle (Λ -like) to each pentagon. One of the depressions, in which there are not these re-entering angles, differs from the others in being broader and less abrupt, the triangular areas either side almost sloping into it and thus forming it. The outer two-thirds of the upper surface have the delicate ridges crossed at right angles by very fine parallel lines, and this produces the appearance of crenulation.

Figure 11, plate 10.—Reniform, thin, arcuately flexed; resembling a single segment of the preceding, enlarged by a wing-like dilatation of one side, the projection nearly as large as the segment, and thus producing the reniform shape. Breadth $1\frac{1}{8}$ inches; length $\frac{3}{4}$ of an inch; thickness at middle 1 line, much less so at the margin.

The minute ridges meet in an angle (that of a pentagon) along the middle of one lobe, and on either side of this lobe are flexed Λ -shape, though not regularly so except towards the posterior margin. The other lobe (the wing-like enlargement alluded to) has the same parallel ridges on the surface, but they do not meet in an angle.

Figure 12, plate 10.—Trigonal, rather thick, margin rounded, not alate. Breadth 1 inch; thickness $\frac{1}{4}$ inch.

The surface, like that of the last, is marked with two sets of lines meeting in the angle of a pentagon, as in one segment of the pentagonal specimen. The line in which the angles lie is to one side of the middle of the triangle, so that the surface on one side is twice as broad as that on the other; and on each side the parallel ridges have each a re-entering angle (Λ -shape).

Pentadia.—Amer. Jour. Sci., ii. Ser., iv. 152.

4. FOSSIL PLANTS.

CONIFERÆ.—The large stumps and trunks of trees in the coal deposits of New Holland, (pages 484, 491.) were long since examined by Mr. William Nicoll,* and shown to belong to Coniferæ.

In addition to these remains of wood, little is found of the rest of the coniferous plants. This absence of leaves and fruit has been explained in our remarks on the origin of the Australian coal beds. Alluvial depositions do not contain large deposits of leaves, since these lighter parts are borne away and scattered far and wide by rapid currents. The trunks of pines occur above and below the coal seams, rather than within these seams; and while the latter bear every evidence of the gentlest depositions, the former prove as clearly that there had been a change to a condition of less quiet waters.

Fruit scales.—There are a few remains of fruit scales which appear to belong to this tribe of plants, and some of them approach those of the genus *Taxodium*.

1. Plate 12, fig. 1.—Ovate; 11 lines long, and 7 broad; much convex, apex rounded. Surface smooth with indistinct veinings, and no trace of a midrib. Concave at base where it was attached.

2. Plate 12, fig. 2.—Obovate, somewhat convex; a little elevated along the centre; surface smooth. About $\frac{3}{4}$ of an inch long, and nearly half as broad.

3. Plate 12, fig. 3.—Broad suborbicular, very convex, most so towards the borders; quite thin, and having a delicately veined structure. Base, for attachment, slightly convex. Length 9 lines, breadth 11 lines. Margin of attachment $5\frac{3}{4}$ lines.

4. Plate 12, fig. 4.—Ovate, acuminate and acute at apex, convex, smooth, not distinctly veined. Length $\frac{1}{2}$ inch, and breadth half the length.

5. Plate 12, fig. 5 *a.*—An oblong scale, probably like fig. 2.

6. Plate 12, fig. 5 *b.*—Very short ovate, with a truncate base and obtuse apex. Surface smooth, somewhat convex. Length 3 lines; breadth $2\frac{1}{2}$ lines.

7. Plate 12, fig. 6.—Very broad triangulato-ovate (rather broader than long); base truncate, apex acute. Surface smooth. Length nearly half an inch.

8. Plate 12, fig. 7.—A scale nearly like the last, but proportionally a little longer; connected at base with a cluster of granules or an irregular, uneven surface, apparently from the fruit to which the scale was attached.

9. Plate 12, fig. 8 *a.*—A cluster or uneven surface like that just mentioned, with imperfectly preserved scales attached, somewhat like that in fig. 7. The drawing represents the appearance and colour of the spot, as it is seen on the light clay.

10. Plate 12, fig. 8 *b.*—A scale, nearly like fig. 6, very broad triangulato-ovate; base truncate and nearly as broad as the scale; apex obtusish; no midrib; somewhat convex. On either side an oblong piece, apparently detached or torn from the scale by pressure.

11. Plate 12, fig. 8 *c.*—Small ovate, $1\frac{1}{2}$ lines long; obtuse at apex, base truncate and nearly as broad as the scale.

12. Plate 12, fig. 8 *d.*—This may be a torn fragment from some leaf or scale; yet it appears to be complete.

* Edinb. New. Phil. Jour., Sept., Jan., 1832–1833, p. 155. Mr. Nicoll's specimens were received from Rev. C. P. N. Wilton, of Newcastle, who collected them from different localities, Newcastle, Macquarie Lake and other places.

GENUS NOEGGERATHIA.—We here refer certain spatulate leaves, having the following characters: *Sessile; no midrib; veins straight, close, slightly divergent, and occasionally connected transversely.* They evidently belong to Noeggerathia, as this genus is laid down by Goeppert in Tchihatcheff's *L'Altai Oriental*, p. 384, whose species are nearly identical with those of Australia. The leaves differ only in not being pinnate. They usually occur singly and are nowhere abundant. In one specimen there are a number of them proceeding from a common base, as if a cluster of leaves growing together, and perhaps at the extremity of a branch. In general appearance they resemble the leaves of the broad-leaved pine, *Damara australis*. Goeppert considers the species to be allied most nearly to *Cyclopteris*.

A species of this genus is referred by Morris to the genus *Zeugophyllites* of Brongniart. But it is obvious from our specimens that the leaves are not petiolate, neither is it probable that such a cluster could have belonged to a plant of the palm kind.

NOEGGERATHIA SPATULATA (*Dana*).—Leaves rather short spatulate, obtuse, triangular at apex, and subacute; narrow at base, and gradually widening; venation very fine, rather indistinct, 4 or 5 veins in a breadth of a line.—Plate 12, fig. 9, a cluster of leaves, radiating from a common base, each nearly $2\frac{1}{2}$ inches long.

District of Illawarra.

In this cluster, which is evidently a natural group, the leaves are of different ages. The younger are quite narrow oblanceolate, (length five times the greatest breadth,) and have a tapering apex. The older are nearly an inch broader towards the apex; the base of the largest is but little over $1\frac{1}{2}$ lines; and from this base they widen till within half an inch of the apex. The centre from which the leaves radiate, has a shining coaly aspect, as if a soft bud, or vegetable base of some thickness had been pressed down and carbonized. The same specimen contains a portion of another similar group.

NOEGGERATHIA MEDIA (*Dana*).—Elongate lanceolate, tapering towards the base, and broadest within an inch of the apex. Extremity subtriangular and apex rounded. Veins a little divergent, about 15 to half an inch. One leaf 5 inches long, about an inch wide within an inch of apex, and a fourth of an inch at base; another shorter.—Plate 12, fig. 10, natural size. May this be the *N. aequalis* of Goeppert, loc. cit., plate 27, fig. 7?

Newcastle, mouth of Hunter River.

NOEGGERATHIA ELONGATA (*J. Morris*) *Dana*.—In this species, found at Newcastle, the venations are more distant than in the preceding. In Morris's figure, they are nearly half a line apart; and in one specimen in our collections they are $\frac{1}{2}$ to $\frac{2}{3}$ of a line apart. The form is represented by Morris as widest towards the base. But the cluster of the *spatulata*, figure 9, shows that the form varies much according to age. The length is 6 inches or more. The species may be identical with the *Noeggerathia distans* of Goeppert, loc. cit., plate 28, figure 8.

Zeugophyllites elongatus, J. Morris, in Strzelecki's *New South Wales*, p. 250, pl. 6, figs. 5, 5 a.

NOTE.—In a fragment of a leaf of uncertain character, the venations are straight, as in the above, very distinct, and nearly a line apart. Plate 12, fig. 11. This is near a species referred to *Calamites* by Goeppert, loc. cit., plate 26, figure 3.

SPHENOPTERIS LOBIFOLIA (*Morris*).—Plate 12, fig. 12. Natural size.
Newcastle.

The leaflets are obtuse ovate, mostly with 3 rounded lobes on either side; length of a leaflet 4 lines, breadth a little over 2 lines. The branchlets in our specimen are from $\frac{1}{2}$ to $\frac{2}{3}$ of an inch apart.

Sphenopteris lobifolia, J. Morris, loc. cit., p. 246, pl. 7, fig. 3; loc. Newcastle.

————— M'Coy, Ann. & Mag. Nat. Hist., xx. 149; loc. Mulubimba, from which place four other species, also, are described by M'Coy.

GLOSSOPTERIS BROWNIANA (*Brongniart*).—Plate 12, fig. 13, different fronds, natural size; 13 *a*, part of a frond, magnified two diameters, showing venation; *b*, cast of under (?) surface of a smaller part, magnified six diameters; *c*, a clump of fronds, as they grew together.

Newcastle and Illawarra, very abundant.

From the description of the *Browniana* by Brongniart, a species instituted from Australian specimens, it appears that this common fern of the Australian coal fields was referred to by him. It is very abundant, constituting more than nine-tenths, and perhaps ninety-nine hundredths, of all the fossil leaves of these regions; and much of the clay at Newcastle and in Illawarra owes its thin foliation to the close packing of its leaves. But although our species is, in all probability, the *Browniana*, we should hardly recognise it from Brongniart's figures, (Veg. Foss., pl. 62, fig. 1,) as the venation in our specimens is quite unlike that represented by him. We speak with some confidence on this point, as the specimens collected by the writer have been very numerous. On account of this difference, we have suspected that the figures were made from a different species, although the size and form seem to correspond well with the common fern of the coal beds. The spaces in the reticulation in two of the fronds, in Brongniart's figure 1, average more than half a line in breadth, or 10–12 to half an inch. The enlarged view, in fig. 1 A, approximates more nearly to our specimen, as it indicates (allowing it to be magnified 3 diameters), that there were 18 spaces (in breadth) in the reticulation, to half an inch. In the specimens obtained by the writer, the venation is very close, and except in specimens partly worn, it requires close attention clearly to distinguish it. The number of spaces in breadth in half an inch is 20 to 24. We have fronds of all sizes, from a length of $1\frac{3}{4}$ inches and width of 5 lines, to a length of 6 and width of $1\frac{1}{2}$ inches, the largest from Australia figured by Brongniart; and in all, the venation is about equally close, showing that there is little variation with age. In the smallest specimen, on figure 13 *c*, the number is 5–6 in a line and a half (20 to 24 in half an inch;) and in the largest frond of this figure, the number is the same. The cross-lines in the reticulation are few and distant, the spaces being long linear, in many cases even half an inch, although but a quarter of a line broad. At the margin, the closeness is not greater than elsewhere, and the anastomosing are scarcely less numerous than towards the midrib.

Figure 13 *c* is one of great interest, as it exhibits the mode of growth of the plant, showing that the fronds formed a clump, as is common now with numerous ferns, especially those of warmer climates. The footstalk into which the frond tapers is very long, quite equalling, in the young individual, the length of the frond, and probably not much shorter in the older frond. The base of one in view in the specimen is 3 inches long, and another is nearly $3\frac{1}{2}$ inches. At least 20 fronds were clustered together in the clump, and probably others, which now lie concealed between the unexposed layers of the shale.

The form of the frond is spatulate at all ages, it being widest about a third or a fourth of its length from the extremity, and attenuate below into the petiole; and it is generally a little arcuate to one side, instead of being quite straight. The extremity is rounded or obtusely subtriangular. The midrib seldom exceeds a line in breadth below, and the petiole, a line and a half. The veins pass off at an angle of 30° , and curve outward, so as to make an angle of 50° with the midrib in specimens of medium size, and 65° or 70° in the largest specimens. The course of the veins is seen along the midrib in faint striations, as observed in a natural cast in the enclosing clay. In a cast of a frond, the veins of one (the upper) surface are represented by raised lines; and those of the opposite (under) surface by linear depressions, having a slender raised line along the middle, as shown in figure 13 *b*. The spaces in the former are smooth; in the latter there is a minute transverse rugosity, which we have endeavoured to represent in the figure just referred to.

Fig. 14, plate 12, may be a very young specimen of the above species.

Glossopteris Browniana, M. Ad. Brongniart, Hist. Veg. Foss., p. 223, pl. 62, fig. 1; also fig. 2?

————— J. Morris, in Strzelecki's New South Wales, p. 247, pl. 6, fig. 1.

————— M'Coy, Ann. & Mag. Nat. Hist., xx. 150. Mentions Jessy Plains, and Mulubimba, New South Wales, as localities.

GLOSSOPTERIS AMPLA (*Dana*).—Frond very large and broad ovate, entire, undulate, apex obtuse. Midrib very stout and broad, $\frac{3}{4}$ to 1 inch at base, and slender towards apex. Venation close, narrow, reticulate. Near the margin for nearly an inch, veins very much subdivided; more closely crowded, and scarcely reticulate. Spaces average $\frac{4}{10}$ of an inch in length, and 16 to 18 of them in breadth occupy half an inch. Near the margin there are 24 or more to a half inch.—Plate 13, fig. 1 *a*, basal portion, natural size; 1 *b*, apical portion.

Newcastle and Illawarra.

The full size of this species we cannot ascertain from our specimens, as the frond was evidently quite thin and tender, and is much broken. The breadth could not have been less than six inches, and the length probably exceeded considerably a foot. The fronds are often more or less in folds, and the folds pressed together. The veins pass off from the midrib with a curve, nearly as in the preceding species, but rather more abruptly.

From the remarks already made on the changes which the *Browniana* undergoes from age, it is obvious that this species is quite distinct.

GLOSSOPTERIS RETICULUM (*Dana*).—Large, oblong elliptical, breadth not over a third (a fourth?) of the length, gradually attenuate towards apex. Veins neatly and rather coarsely reticulate, the reticulations continuing almost or quite to the margin; spaces averaging one-third of an inch in length, and a sixteenth of an inch in breadth (or about $\frac{1}{2}$ an inch), angle of divergence from midrib about 65° .—Plate 13, fig. 2, part of a frond.

Newcastle.

This species has some resemblance to Brongniart's second figure of the *Browniana* (fig. 2, pl. 62), in the coarseness and character of its reticulation; but the veins do not so completely lose their reticulating character, and become parallel lines for a breadth of over half an inch along the margin, as in his Indian specimen. The specimen is $2\frac{1}{2}$ inches broad $3\frac{3}{4}$ inches from the summit of the frond (which is probably not far from

half its length). The figure represents an emargination at apex, which exists in the specimen, but is supposed to be accidental.

NOTE.—Figure 3, plate 13, represents the basal portion of a frond, having some resemblance in its venation to the above; yet from the angle of divergence from the midrib, and the actually narrower spaces, it may be a different species. This angle of divergence is about 30° , and the venation in this basal part of the frond is parallel with the margin. The spaces average 4 or $4\frac{1}{2}$ lines in length, and half a line in breadth (12 to half an inch). The frond must have been a large one. The midrib is moderately stout, ($1\frac{1}{2}$ lines broad below,) and very distinct in outline. About $1\frac{1}{2}$ inches of the petiole remain on the specimen.

GLOSSOPTERIS ELONGATA (*Dana*).—Narrow elongate, lanceolate (?), attenuate below. Midrib rather stout, very distinct, veins make an angle of 60° or more with the midrib, elegantly reticulate, spaces short, average length $\frac{1}{7}$ inch, and 9 or 10 in breadth to half an inch.—Plate 13, fig. 4, natural size.

Newcastle.

The specimen is but a part (the basal) of a frond. This portion is an inch broad 3 inches from the base. The reticulation is wholly different from that of the *reticulum*, the spaces being very short. From figure 3, described above, it also differs widely in the angle of convergence in the frond below, and in having the venation retain at base its large angle with the midrib, instead of running parallel to the sides as the veins diverge from the petiole.

GLOSSOPTERIS ? CORDATA (*Dana*).—Strongly cordate at base, with the lobes rounded. Midrib stout. Veins near base of frond reversed, diverging at a very large angle from the midrib, neatly reticulate, less so near margin and lines parallel; spaces narrow, oblong, nearly 4 to a line in breadth.—Plate 13, fig. 5, natural size.

District of Illawarra.

The cordate base of this species was at first suspected, on account of its peculiarity, to be a result of fracture, but the direction of the venation proved this to be incorrect. The reticulation resembles that of the *ampla*. The midrib is a sixth of an inch broad. The fragment of the frond, constituting our specimen, is only the basal portion, and we cannot therefore give the length; the frond was probably quite broad for its length.

GLOSSOPTERIS LINEARIS (*M'Coy*).—A specimen apparently of this species was obtained in the Illawarra coal beds.

Glossopteris linearis, M'Coy, loc. cit., vol. xx., p. 151, pl. 9, figs. 5, 5 a.

PHYLLOTHECA AUSTRALIS.—Plate 13, fig. 6, representing parts of six plants, on a single slab, natural size; fig. 1, plate 14, a circle of leaflets of same species. The specimen is in the collection of the Rev. C. P. N. Wilton of Newcastle, whose many kindnesses I have occasion to remember with gratitude.

Newcastle.

The general characters of this simple species are well shown in these figures.

1. Its jointed structure.
2. The sheaths encircling the stem at each node, and not properly a continuation of the node below, as in true *Equiseta*.

3. The linear leaflets proceeding from the edge of the sheath, and corresponding each to one of its delicate ridges or interstriations.

4. The tubular character of the plant (as in *Equisetum*).

In No. I. there is an abrupt bend at *a*, one of the articulations, showing where the sheaths are attached, and exhibiting by its torn character, the relation of the leaflets to the sheath. In No. V., and less perfectly in I. and III., we have the upper extremity of the plant, exhibiting the successively decreasing joints, and the shorter and less divergent whorls of leaflets. The tubular character of the plant is evident from the thinness of the fossil and the manner in which it is in some cases broken by pressure into fibres, corresponding to the striæ of the surface. The compressed sheaths exceed considerably in diameter the part of the plant they encircle, as if not applied when living quite close to the plant; below, they cover about half the length of a joint of the stem. Some of the leaflets are more than two inches long; their breadth is less than half a line. The lower leaflets are much spread, or even somewhat drooping, while the upper are nearly erect.

These plants are considered by Brongniart as resembling somewhat the *Equisetacea*, but as more closely related to the *Asterophyllites*. M'Coy has suggested that they belong near the *Casuarinæ*, on account of the manner in which another species, observed by him, branches—that is, directly above the nodes, instead of below them, like the *Equiseta*. That so thin tubular plants can be very closely allied to the woody *Casuarinæ*, seems to us somewhat doubtful.

Phyllothea australis, Ad. Brongn., Prodrome.

—————, Lindley and Hutton, Fossil Flora.

—————, Unger, *Chloris Protogæa*.

—————, J. Morris, in Strzelecki's New South Wales, p. 250.

—————, M'Coy, *Ann. and Mag. Nat. Hist.*, vol. xx. pp. 152, 156.

NOTE.—Fig. 2, plate 14, represents two naked stems, pertaining apparently to the genus *Phyllothea*. One is an inch broad, $6\frac{1}{2}$ inches long; and the others are about half an inch broad, and 4 to 6 inches long. They all have a striated surface, as the figures show, and consist of joints $1\frac{1}{8}$ inches long. They were evidently thin tubular plants like the preceding, as the fossil has no greater thickness than a leaf of a *Glossopteris*. Whether they are the *P. australis* of more advanced age with the sheaths fallen off, or different species, I have not the means of determining. M'Coy's figures of his two new species, *P. ramosa* and *P. Hookeri*, (*loc. cit.* p. 156, pl. 11,) appear to show that the plants belong in the same genus with the preceding.

CLASTERIA (nov. gen.)—CLASTERIA AUSTRALIS, Dana.—This name is here proposed for some singular plants or portions of plants, presenting the characters shown by figures 3, 4, on plate 14, of natural size, and the enlarged drawing, figure 5. We do not pretend to understand their nature, or explain by any hypothesis their structure. They are broad linear, $\frac{2}{3}$ of an inch to $\frac{7}{8}$ wide, with the sides parallel; and from the appearance of the fossil, it is apparent that they must have been hollow, as remains of both an upper and under integument can be distinguished. They consist of two unsymmetrical longitudinal halves. In figure 3, I, each half has a transverse elevation at distant intervals, and between the elevations, a transverse depression, as shown more clearly in figure 5. The elevations and depressions are unlike in their length of interval in the two halves, as represented. In II and III, the same structure is seen. In figure 4, IV, the structure is different, the stem appears to be broken across either one or both halves, at intervals of half

to one inch; and on close examination it is found that a carbonaceous film here intersects the stem (or one half of it) extending into the clay beneath, and causes the appearance of fracture. Besides, the stem is angularly depressed at intervals, along the centre. In figure V the stem looks as if crumpled into a series of large angular depressions. The name *Clasteria* (from *κλαστος*, broken) alludes to this broken appearance.

It is especially remarkable that the stem which has the form in figure 3 at one extremity, gradually changes to V and then IV, figure 4, showing that although so different, all these forms are parts of one and the same individual. The impressions are very thin, as in the *Phillotheca*. The idea of their having some connexion with seed-bearing vessels or pods is suggested by the form, but no analogy can be appealed to by the writer to sustain it.

ANARTHROCANNA AUSTRALIS (*Dana*).—On plate 14, figure 13, there is represented a linear leaf, (6 inches long,) half an inch broad, having a faintly striated surface. It appears to pertain to the genus *Anarthrocanna* of Goeppert, as published in Tchihatcheff's *L'Altai Oriental*, p. 379, Appendix.

Figure 6 *a*, plate 14, represents a plant from the Illawarra coal beds, which is of uncertain relations. It is represented with the same indistinctness and want of details that appear in the specimen. It has a coaly aspect without any regular texture apparent to the naked eye, and seems to have been a thick membranous or woody plant, with opposite branches at intervals of about four inches.

CYSTOSEIRITES?—At *b*, on the same figure, there is a Fucoid plant of singular character. It has some resemblance to a fragment from the fossil called *Cystoseirites nutans*, by Sternberg, (*Flora der Vorwelt*, v. and vi. tf. 18, figs. 1–3; Bronn's *Lethæa Geognostica*, p. 223, pl. 14, fig. 8.)

AUSTRELLA RIGIDA (*Dana*).—Plate 14, figures 7, 8. A plant having the stems rigid, evenly narrow linear, and branching at intervals, with the angle at the axil 60° to 70° , and the branches like the main stem in characters and size. The specimen in figure 8 is only $\frac{1}{4}$ of a line broad, and shows no appearance of a midrib. Figure 7 *b*, appears to be the same plant a line broad. From Newcastle.

CONFERVITES? TENELLA (*Dana*).—Plate 14, figure 9, represents another doubtful plant. It is in long linear threads of varying breadth, and flexed irregularly arising from its flexible character. It is occasionally branched. The breadth is about $\frac{1}{4}$ of a line. Common at Newcastle. It is an extremely thin fossil.

II. FOSSILS FROM TIERRA DEL FUEGO AND PERU.

1. Fossils from *Tierra del Fuego*.

The following fossil is the only one obtained during the few hours ashore in the vicinity of Nassau Bay, *Tierra del Fuego*. It is allied to the *Belemnite*, but from certain peculiarities constitutes properly a new genus.

GENUS HELICERUS (*Dana*).—Near *Belemnites*. Ossicle calcareous, thick sub-cylindrical, containing internally a slender tubular cavity, (a continuation probably of an alveolus above,) which terminates below in a fusiform chamber helicoidly divided.

HELICERUS FUEGIENSIS.—Plate 15, fig. 1 *a*, section of part of ossicle exposing the

internal tube; *b*, same with the fusiform helicoid cavity below (the ossicle is here inverted); *c*, outline of lower part of ossicle.

The tube appears to enclose a rolled membrane or dissepiment, which connects and corresponds in its turns with the spire below. The spiral character of the fusiform chamber is well retained in the material which now fills it, which has this structure, and peels off very regularly in a spiral coat, as seen in the figure. The ossicle tapers below, and is obtuse at its extremity. It is about half an inch in diameter; and the fusiform chamber about one half. The tube is $\frac{1}{8}$ this diameter. On one side of the cylinder there is a shallow longitudinal groove. The calcareous substance of the fossil has the usual radiately fibrous structure of the Belemnite.

2. Fossils from San Lorenzo, Peru.

TRIGONIA LORENTII (*Dana*).—Transversely subtriangular, lower margin arcuate. Sides compressed; flank flattened, carinate, nearly smooth. Anterior to carinate surface marked with two series of parallel ridges meeting at an acute angle (68° , nearly); ridges of posterior series short, broader than the others, and about one-third as numerous; ridges of anterior series elongate, regular, all obtuse, naked, about 25 in number.—Length $2\frac{1}{2}$ inches; height $\frac{7.4}{100}$ L.; flank nearly $\frac{1}{2}$ inch wide; apical angle about 120° .—Plate 15, fig. 2, shell, natural size; 2 *a*, vertical section; *b*, *c*, hinge, imperfectly preserved.

TURBO ———. Plate 15, fig. 3 *a*, *b*. Natural size. The length of this imperfect specimen is $2\frac{3}{8}$ inches; aperture nearly semicircular, and $1\frac{5}{8}$ inches across; last whorl rotund, carinate below, with very low tubercles, or none.

NAUTILUS TENUI-PLANATUS (*Dana*).—Very large. Shell thin and broad discoid. Exterior without (!) markings. Septa straight, rather crowded; $1\frac{1}{2}$ to 2 lines apart. Siphuncle a short distance inside of centre.—Breadth 7 inches.—Plate 15, fig. 4.

3. Fossil Ammonite from the Andes.

AMMONITES PICKERINGI (*Dana*).—Large, thick discoid, whorls ventricose; sides costate; costæ large, rounded, naked, simple, equal and separated by equal rounded intervals.—5 inches or more in diameter; last whorl at least $1\frac{3}{4}$ inches through, in the direction of the diameter of the shell; the next on the same diameter hardly half this breadth. Costæ of outer whorl a fourth of an inch broad.—Plate 15, fig. 5, exterior cast, natural size.

This specimen was obtained by my friend and associate in the Expedition, Dr. C. Pickering, at an elevation of 16,000 feet, on the route to Sierra de Pasco. As we have a cast of only one side, the character of the back of the whorls is not ascertained.

NOTE.—Plate 15, figure 6, represents an Ammonite from a rolled fragment obtained at Truxillo, examined in a collection of fossils at Lima, and drawn by permission. It is near the *A. communis*, but the whorls in a cross section (6 *a*) are more nearly rotund, and have a slight depression along the back. The costæ are equal, acute, naked, bifid along the back, and separated by concave sulci. Diameter $2\frac{1}{2}$ inches. Last whorl about $\frac{5}{8}$ inch across, costæ about $1\frac{1}{2}$ lines apart.

Fig. 7, plate 15, represents an *Ostræa* from Truxillo, observed in the same collection at Lima. It is supposed to be tertiary. As we are not fully informed as to its mode of occurrence, we pass it by with this bare mention.

III. FOSSILS FROM NORTHWESTERN AMERICA.

1. CETACEAN.

Vertebræ and fragments of other cetacean bones are occasionally found in the argillaceous sandstone of Astoria, (south side of the Columbia, about thirteen miles above its mouth,) and may be picked up along the shores of the river. Plate 16, fig. 1, represents one of the vertebræ, of its natural size.

2. FISHES.

In the same region, just alluded to, we obtained the remains of four species of fossil fish.

Figure 2, plate 16, represents a species allied to *Trigla*. It was found (as figured) in a concretion of limestone in the argillaceous rock. The surface of the mass having been worn on the river's banks, the skeleton is exposed to view in the manner here shown. A large part of the vertebral column remains, and portions of the bones of the head, with parts of the pectoral fin, and many of the scales. The bones and scales have the colour, translucency and hardness of tortoise shell. The scales have the surface strongly striated below the central line, and a pectinate lower margin; they are also concentrically and neatly marked with delicate lines of growth. The striated character is owing to thin trenchant ridges, which have a serrulate edge. The form is suborbicular, the larger approaching quadrate, and the smaller somewhat hexagonal; the lower margin is strongly arcuate. The vertebræ are longer than their breadth.

Figure 3, plate 16, is another species, of which we have only a cast in a fragment of argillaceous slate. The genus we have not made out.

Figures 1, 2 *a*, 2 *b*, plate 17, of natural size, represent large vertebræ from the same locality. Those of the latter two figures pertain, as we suppose, from the very open texture and fine calcareous plates, to a species of shark. The first is also very open in its texture, and owes its apparent solidity to the limestone with which it is mineralized. In the specimen, edges of vertical plates are seen occasionally on the sides, (as on the left side of the figure, and also on the back top edge towards the right,) and on the broken surface, (front of figure,) there are a few irregular oblique plates either side of the centre, as represented; all indicating a very coarsely cellular structure.

3. CRUSTACEA.

CALLIANASSA OREGONENSIS (*Dana*).—Remains of a single species of crustacea are found in the calcareous concretions of the argillaceous rock near Astoria, (see plate 17, fig. 3.) It is related to *Callianassa*, a genus whose species live mostly in holes on muddy shores. The compressed form and nearly equal length and breadth of the hand and carpus, are characteristic of this family of Crustacea.

The joints of the leg figured have a smooth surface. The under margin of the hand and thumb is straight, and denticulate. The inner margin of the thumb and finger is slightly crenulate. The finger is narrow, slightly arcuate, subacute, and shuts rather closely upon the thumb. The length of the hand is nearly $\frac{3}{4}$ of an inch, and its breadth $\frac{3}{8}$ inch; the carpus has the same length, and is little broader; its upper and lower margins are entire; the next joint preceding is but $\frac{1}{3}$ of an inch broad, and apparently somewhat shorter than the carpus.

BALANUS.—In the soft argillaceous shale, remains of a barnacle are found, but in too imperfect a state to be characterized. A figure is given on plate 17, fig. 4.

4. MOLLUSCA.

The fossil shells of Astoria have been described for this place by Mr. T. A. CONRAD, whose labours in conchology in general, and especially in the department of tertiary species, are well known. We insert his descriptions in his own words, adding a few measurements from the specimens.

1. *MYA ABRUPTA* (Conrad).—Subelliptical, slightly ventricose, widely gaping posteriorly. Surface marked with concentric undulations. Beaks separated, nearly medial, slightly prominent. Anterior margin acute, orbiculate; posterior margin abrupt, arcuate, somewhat reflexed; basal (inferior) margin arcuate; dorsal margin short, straight, nearly parallel with the base.—Plate 17, figure 5, 5 *a*.

Astoria, Oregon.

[Length $2\frac{3}{4}$ inches; height $\frac{5.7}{100}$ L.; thickness (and breadth of gaping behind) $\frac{3.2}{100}$ L., or $\frac{5.6}{100}$ H. Apical angle 162° .]

2. *THRACIA TRAPEZOIDES* (Conrad).—Trapezoidal; ventricose; flank flattened, carinate, side anteriorly compressed. Surface faintly concentric undulate, and neatly but unequally marked with concentric striæ. Beaks prominent, medial. Posterior margin truncated, basal margin tumid at middle.—Plate 17, figs. 6 *a*, 6 *b*, natural size.

Astoria, Oregon.

[Length $1\frac{4}{10}$ inches; height $\frac{7.7}{100}$ L.; thickness $\frac{4.5}{100}$ L., or $\frac{5.8}{100}$ H.; apical angle 140° . Cast having the surface faintly concentric undulate. Muscular impressions rather indistinct, the posterior quite small, pallear sinus large.]

SOLEMYA VENTRICOSA (Conrad).—Oblong; ventricose; dorsal and basal margins straight and parallel. Anterior side narrowed, the margin orbiculate. Posterior margin scalloped, the inferior half truncated obliquely inwards. Beaks distant from the anterior extremity.—Plate 17, figs. 7, 8, natural size.

Astoria, Oregon.

[Length $3\frac{3}{4}$ inches; breadth $1\frac{1}{2}$ inches. Lateral surface smooth, radiated with narrow bands.]

DONAX ? PROTERTA (Conrad).—Much elongate, ventricose; anterior margin orbiculate, posterior side produced; basal margin straight; ligament margin straight and oblique. Beaks little prominent. Sides somewhat flattened inferiorly, contracted slightly

from beak to base; cavity most capacious between the umbones.—Plate 17, fig. 9, natural size.

Astoria, Oregon.

[Length about $1\frac{1}{3}$ inches; height $\frac{1}{2}$ inch; beak $\frac{1}{3}$ inch back of the front; apical angle 140° .]

VENUS BISECTA (Conrad).—Oblique, subrhomboidal, ventricose, with robust lines of growth. Anterior side very short, truncate, angulate below, having a submarginal vertical furrow, and the inferior margin at its termination slightly excavate. Posterior surface strongly excavate from the upper side of the beak to the posterior margin, and subcarinate below the excavation; ligament and supero-posterior margin forming together a regular curve. Basal margin arcuate, a little tumid behind the middle.—Plate 17, figures 10, 10 *a*, natural size.

Astoria, Oregon.

[Length 2 inches; height $\frac{8.5}{100}$ L.; thickness $\frac{5.4}{100}$ L. or $\frac{6.3}{100}$ H.; distance anterior to beak $\frac{1}{3}$ inch; apical angle 120° . Valves quite thin.]

VENUS ANGUSTIFRONS (Conrad).—Obliquely cordate, ventricose. Anterior side narrow, rounded. Posterior extremity somewhat truncated, arcuate; ligament margin elevated, arcuate; basal margins arcuate. Exterior surface everywhere convex, marked with fine lines of growth.—Plate 17, fig. 11, natural size.

Astoria, Oregon.

[Length $1\frac{3}{4}$ inches; height $\frac{7.0}{100}$ L., or $1\frac{1}{4}$ inches; part anterior to beak 5 lines; apical angle 134° ; valves quite thin.]

VENUS LAMELLIFERA (Conrad).—Subtrigonal, ventricose, ligament margin very oblique and slightly curved, long, posterior margin direct, truncate; basal arcuate. Lateral surface everywhere convex, and having thin concentric elevated lamellæ.—Plate 17, fig. 12, 12 *a*, natural size.

Astoria, Oregon.

[Length 2 inches; height $\frac{8.3}{100}$ L.; valve very stout; cast excavate just below palleal impression.]

VENUS BREVILINEATA (Conrad).—Subtrigonal, ventricose. Anterior extremity truncate; ligament margin elevated, curved; posterior margin subtruncate; basal margin strongly arcuate. The specimen is a cast, and it is remarkable for a series of irregular vertical impressed lines or sulci, towards the base, which must correspond with prominent lines on the interior of the valve.—Plate 17, fig. 13.

[Length of cast 2 inches; height $\frac{8.0}{100}$ L.; thickness $\frac{5.3}{100}$ L. The irregular sulci on the lower half of the cast are nearly half an inch long, and extend upward from the palleal impression. The sinus in the palleal impression is acute triangular. The surface of the cast is faintly concentric undulate.]

[NOTE.—Figures 1, 1 *a*, plate 18, represent still another Venus, with a very thick valve, and smooth cast, having the sides evenly convex. It resembles the *angustifrons*, but is hardly as ventricose, and the valve in that is very thin. Length of cast $2\frac{1}{2}$ inches; height 1.6 inches; thickness 1 inch.]

LUCINA ACUTILINEATA (Conrad).—Suborbicular; ligament margin short, straight and a little oblique; posterior margin somewhat truncate widely, nearly direct; supero-anterior margin truncate. Surface with concentric lamelliform striæ and intermediate fine lines; anteriorly with a slightly prominent fold. Basal margin orbiculate. This species is very nearly related to *L. contracta*, (Say,) a recent shell of the Atlantic coast, and fossil in the miocene of Virginia. It differs from Say's species in being proportionally more elevated, and in having a much shorter ligament margin.—Plate 18, figs. 2, 2 *a*, *b*, natural size.

Astoria, Oregon.

[Length $1\frac{1}{2}$ inches; height slightly less than length; thickness $\frac{4.5}{100}$ L.; the more prominent ridges of the surface nearly a line apart.]

TELLINA ARCTATA (Conrad).—Oblong subelliptical, compressed; front very obliquely truncate and a little sinuous, below reflected; basal margin arcuate; ligament margin declining, arcuate; posterior extremity rounded. Beak nearest the anterior extremity. Plate 18, fig. 3, 3 *a*.

Astoria, Oregon,

[Length 2 inches; height $\frac{6.6}{100}$ L.; thickness $\frac{2.6}{100}$ L. or $\frac{4.0}{100}$ H.; apical angle 124° . Valves very thin.]

TELLINA EMACERATA (Conrad).—Elliptical, much compressed; anterior extremity obliquely truncate, straight from the apex, front reflected; dorsal margin posteriorly declining; posterior margin rounded; inferior margin arcuate. Lateral surface marked with fine, regular, closely-arranged, concentric, impressed lines.—Plate 18, fig. 4, natural size.

Astoria, Oregon.

[Length $1\frac{1}{2}$ lines; height half the length; apical angle about 140° .]

TELLINA ALBARIA (Conrad).—Thin, smooth, subtriangular; beaks medial; anterior extremity obtuse; posterior margin regularly rounded; basal margin straight at middle.—Plate 18, fig. 5.

Astoria, Oregon.

TELLINA NASUTA (Conrad).—Subtriangular, convex, anterior side with a slight prominent fold, angulated anteriorly; anterior margin curved above, truncated at the extremity; posterior margin rounded. Beaks medial. Anterior basal margin arcuated; basal margin tumid near the middle.

Astoria, Oregon.

TELLINA BITRUNCATA (Conrad).—Elliptical, compressed; anterior side reflected; extremity truncated; posterior margin obliquely truncated. Ligament margin short, straight, parallel with the anterior basal margin; basal margin slightly contracted in the middle; posterior extremity acutely rounded.

Astoria, Oregon.

NUCULA DIVARICATA (Conrad).—Subovate, convex, with divaricating striæ. Extre-

mities rounded; ligament margin very oblique, slightly arcuate; basal margin arcuate. Beaks near the anterior extremity.—Plate 18, figs. 6, 6 *a*.

Astoria, Oregon.

NUCULA IMPRESSA (Conrad).—Oblong ovate, convex, with regular concentric impressed lines. Anterior extremity rostrate, slightly recurved, extremity truncated; ligament margin arcuate, slightly declining; rounded behind. Beaks submedial. Basal margin arcuate, slightly contracted near the anterior extremity.—Plate 18, fig. 7 *a, b, c, d, e*.

Astoria, Oregon.

[Length 1 inch; breadth very nearly half an inch. Apical angle 155° to 160°. The fine lines of the surface are neat, but closely crowded.]

PECTUNCULUS PATULUS (Conrad).—Suborbicular, convex, with radiating lines. Hinge margin elongate. Extremities rounded; anterior margin curved inwards; posterior margin, nearly direct.—Plate 18, fig. 8, 8 *a*, natural size.

Astoria, Oregon.

[Length $1\frac{3}{8}$ inches; height about $1\frac{2}{3}$ inches.]

PECTUNCULUS NITENS (Conrad).—Suborbicular, oblique, smooth and polished, with fine obsolete radiating lines, extremely neat. Hinge margin quite short, rectilinear; posterior margin slightly arcuate.—Plate 18, fig. 9, *a, b*, natural size.

Astoria, Oregon.

[Length $\frac{1}{3}$ inch; height $\frac{36}{100}$ L.]

ARCA DEVINCTA (Conrad).—Rhomboidal. Ribs narrow, flattened, and little prominent anteriorly; on the posterior side wider, slightly convex, and longitudinally striated. Beaks distant.—Plate 18, figs. 10, 10 *a*.

Astoria, Oregon.

ARCA ———. A cast having a rhomboidal outline, with prominent distant beaks. Plate 18, fig. 11 *a, b*.

CARDITA SUBTENTA (Conrad).—Not longer than high, broad obovate, ventricose, with about twenty-two rounded, not very prominent radiate costæ, and with strong concentric wrinkled lines. Posterior extremity somewhat truncate.—Plate 18, figs. 12, 12 *a*.

Astoria, Oregon.

[Length and height $\frac{5}{8}$ inch; thickness $\frac{2}{8}$ inch; apical angle 105°.]

PECTEN PROPATULUS (Conrad).—Large, subequivalve, suborbicular, compressed; costæ about 17, rounded, narrow, interstices much wider than the ribs; ears unequal. Plate 18, fig. 13, 13 *a*.

Astoria, Oregon.

[Length and height 4 inches.]

TEREBRATULA NITENS (Conrad).—Ovate, smooth and glossy. Superior valve convex; inferior valve flattened towards the base; basal margin sinuous; beak prominent,

curved. Valves very thin. This shell is remarkable for having the peculiar lustre and consistence of many species of *Anomia*. The shell is partially removed, and the surface exhibits obsolete radiating lines.—Plate 19, fig. 1, 1 *a*.

——? Plate 19, fig. 2. A broken shell from the argillaceous shale below Astoria.

DOLIUM PETROSUM (*Conrad*).—Ovate globose with revolving ribs about on the body whorl; shoulder angulate, tuberculate, below the angle having a slightly concave space, with a revolving prominent line. Spire scalariform, and rather elevated; volutions 5.—Plate 19, fig. 3 *a*, *b*, 4 *a*, *b*, 5 *a*, *b*, natural size.

Astoria, Oregon.

There are three specimens of this species, all of which are casts. In the smallest the tubercles are very prominent, and less so in the others; and there is a row of small tubercles below the flattened space on the upper part of the body whorl.

SIGARETUS SCOPULOSUS (*Conrad*).—Obliquely oval, somewhat ventricose, flattened on the upper half of the body whorl. Disks with numerous revolving lines.—Plate 19, figures 6, 6 *a*, *b*, *c*, *d*, natural size.

Astoria, Oregon.

NATICA SAXEA (*Conrad*).—Subglobose. Whorls five, convex, with distinct lines of growth; a broad brown band at base of the shell, and a lighter-coloured brown band revolves on the upper part of the whorls, contiguous to the suture; a narrow darker band margins the suture. Umbilicus large, partially covered by a callus.—Plate 19, fig. 7 *a*, *b*. Natural size.

Astoria, Oregon.

This species closely resembles *N. heros* (Say) in contour and in the umbilicus; but the brown band at the base is, I believe, wanting in the *heros*.

BULLA PETROSA (*Conrad*).—Cylindrical, narrow, sides gently curved.—Plate 19, figure 8, natural size.

Astoria, Oregon.

CREPIDULA PRÆRUPTA (*Conrad*).—Oblique, oblong, somewhat elliptical and ventricose, with simple lines of growth. Sides flattened. Beak narrowed and laterally curved; the side towards which the apex is directed, slightly contracted, and having a somewhat sinuous margin.—Plate 19, figs. 9, 9 *a*, natural size; 10 *a*, *b*, views of a cast, probably of this species.

Astoria, Oregon.

CREPIDULA ——? This species, of which there is only a cast in the collections, is very much depressed, with the summit narrow and nearly straight, subacuminate, broadest across the beak, the sides there being somewhat dilated.—Plate 19, figs. 11 *a*, *b*, natural size.

Astoria, Oregon.

ROSTELLARIA INDURATA (*Conrad*).—Subfusiform, with oblique, curved, rounded ribs,

whorls contracted or narrow towards the suture. The specimens are fragments of casts. The lip does not appear to have been greatly expanded.—Plate 19, fig. 12, natural size.
Astoria, Oregon.

CERITHIUM MEDIALE (*Conrad*).—Turreted, with fine acute revolving lines; whorls angulated in the middle, and having a row of tubercles on the angle; suture impressed; whorls contracted beneath the suture.—Plate 20, fig. 1, natural size; 1 *a*, cast.
Astoria, Oregon.

BUCCINUM? DEVINCTUM (*Conrad*).—Elevated, with numerous wrinkled revolving lines; whorls flattened and sloping above. Middle of revolutions of the spire nodulous. Margin of the labrum profoundly arcuate.—Plate 20, figs. 2, 2 *a*, natural size.
Astoria, Oregon.

FUSUS GENICULUS (*Conrad*).—Fusiform, with closely arranged revolving lines, alternate in size. Whorls of the spire angulated below the middle, and with longitudinal ribs on the inferior half. Body whorl with short ribs on the angle, and beneath, the revolving lines are larger and more prominent than above.—Plate 20, fig. 3.

FUSUS CORPULENTUS (*Conrad*).—Fusiform. Body whorl ventricose, suddenly contracted at base, flattened and sloping towards the suture; whorls of the spire angulated and nodulous in the middle; flat and sloping above.—Plate 20, fig. 4, cast, natural size.

NAUTILUS ANGUSTATUS (*Conrad*).—Compressed. Septa sinuous and profoundly angulated towards the periphery; from the angle the outer margin of the septa is parallel with the periphery, and anteriorly suddenly becomes transverse across the margin or periphery.—Plate 20, figs. 5, 6, natural size.
Astoria, Oregon.

[The largest specimen of this species in the collections is 9 inches in diameter.]

TEREDO SUBSTRIATA.—Nearly straight and evenly cylindrical, very slightly tapering. Surface minutely and very neatly striate longitudinally.—Plate 20, figs. 7, 7 *a*, *b*, natural size.
Astoria, Oregon.

NOTE.—The figures from 8 to 13 inclusive, on Plate 20, representing species from Astoria, are given of natural size, without names.

Figure 8 is an external cast; and fig. 8 *a*, an internal cast.

Figure 9, is an external cast.

Figures 10, 11 are external casts; 10 *a*, 11 *a*, are internal casts.

Figures 12, 13, species of *Turritella*, natural size.

Figure 1, plate 21, an imperfect cast.

FORAMINIFERA.—Figures 2 to 4, inclusive, plate 21, represent three species of Foraminifera found rather abundantly, but poorly preserved in the soft argillaceous shale on the shores below Astoria.

5. RADIATA.

GALERITES OREGONENSIS (*Dana*).—Figures 5, 6, 6 *a*, represent a species of the Echinidæ, occurring only in broken fragments and scattered spines in the Astoria argillaceous shale, associated with minute Foraminifera. Specimens are so imperfect that we refer it with hesitation to the genus Galerites. The spines are half an inch long, very slender, delicately striate, with the striæ punctate or subrenulate.

NOTE.—Fig. 7, plate 21, represents what appears to be a fossil, but it shows no regular characters beyond what is observed in the figure. The texture is soft, with the colour brownish-black, differing decidedly from the rock in which it is imbedded. The texture would suggest the idea of the ink-bag of a sepia, but other characters do not seem to sustain this view.

Figure 203 is another doubtful fossil. It appears at first sight to be a coral extending through the limestone in convoluted or intersecting plates, $1\frac{1}{2}$ to 2 lines thick, consisting of hexagonal cells. But the cells are very unlike those of any coral within the knowledge of the writer. The interstices are extremely thin, and the cells are destitute of rays or septa of any kind. Their diameter is nearly $\frac{1}{2}$ a line, and the length $1\frac{1}{2}$ to 2 lines; and they are transverse in position, being oblong across the plates, like horizontal columns or cells of a honeycomb. They differ widely in form and position from the cells of the Bryozoa and Hydroidea; and seem rather to pertain to the spawn of some species of mollusc. This is only a suggestion offered with much hesitation.

6. PLANTS.

ABIES? ROBUSTA (*Dana*).—Only one species of fossil plant with distinct leaves was observed by the writer in the Astoria deposits. This, like most of the specimens, occurs in a limestone nodule. It is represented in fig. 9, plate 21. It is one of the Coniferæ, and appears to be a species of Abies. The leaves are attached to a stem, and apparently were placed somewhat irregularly around it. They are very stiff and rigid, 4-sided, with sharp angles and flat surfaces, the section being rhomboidal; the width is a line, and the transverse diameter about one-third the width.

Near the mouth of Fraser's River, a dark blue slate was observed by a party from the Vincennes, and specimens obtained, one of which is represented in fig. 10, plate 21. It is supposed to pertain to the tertiary formation of the coast, and to be of the same age with that of Astoria. The leaves are all beautifully preserved, as shown in the figure.

No. 1 may be a *Lycopodium*, or possibly a *Juniperus*.

Nos. 2, 3, 4, 5, 6, 7, 8, 9, are leaves of one or more species of *Taxodium*.

No. 10 appears to be a leaf of a *Smilax*.

Nos. 11, 12, 13, 14, 15, of uncertain species. 11 and 12 are opposite sides, probably, of similar leaves; and 13, 14, 15, are like No. 11.

The same specimen contains, at *a*, a round piece of fossil resin, probably from some of the coniferous plants whose leaves are here imbedded.

Fig. 11, plate 21, represents a very thin calcareous leaf-like expansion, occurring in the argillaceous shale near Astoria. It is too imperfect to be fully characterized. The specimen is apparently one of the calcareous Algæ. The frond is very thin, and deeply lobed; the lobes longitudinally undulate; the surface very smooth, and without markings of any kind. It is extremely tender, and its thickness does not exceed that of common writing paper.

A P P E N D I X I I.

Exposure of Living Corals to Sun and Air.—(p. 94.)

MR. BEETE JUKES, in his account of the voyage of the "Fly," recently published, mentions that he observed about the Australian reefs, living *Astræas*, the tops of which at low tide were 18 inches above the water; and he adds, that he believes an exposure to the sun and air for two or three hours will not kill many polyps.

On Dolomisation.—(p. 153.)

The experiments of von Morlot, alluded to on page 153, are properly a confirmation of a view previously presented by Haidinger. As early as 1827, this author, in an article on pseudomorphism, described certain dolomitic pseudomorphs, and stated that in their formation "part of the carbonate of lime was replaced by carbonate of magnesia, so as to form in the new species a compound of one atom of each," (Trans. Roy. Soc. Edinb., March 19, 1827.) Elie de Beaumont, in 1837, suggested the same view, and thus accounted for the occurrence of open spaces in the dolomite, often amounting to twelve per cent. of the mass. Haidinger, observing the frequent occurrence of gypsum and dolomite in the same beds, concluded that the sulphate of magnesia was the agent by which the change was produced, in the manner stated on page 154, and confirmed by von Morlot. Some heat is required, according to these authors, for this result.

The theory of dolomisation, to be complete, must meet the cases presented by the coral rocks, in which the calcareous material is subjected to the ocean, whose waters contain for the most part a magnesian *chlorid* instead of *sulphate*; and farther, *no heat* can be supposed to have been concerned. The limestones of the western of the United States, are nearly true dolomites in composition, since they contain, according to Mr. D. D. Owen, from thirty to forty-five per cent. of carbonate of magnesia. Yet they are compact rocks, that present no evidence of the action of heat during their formation or since. We may believe that the result is due to a simple reaction of the carbonate of lime and certain oceanic salts present; but the process needs illustration by actual experiment.

Chalk of Oahu.—(p. 150.)

This chalk consists simply of the comminuted corals and shells of the reef. It has been examined microscopically by Prof. J. W. Bailey, at the request of the writer, and found to be destitute of the minute organisms abounding in the chalk of England.

Rocks of the Pacific.—(p. 372.)

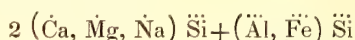
The feldspathic material of the rocks of the Pacific appears to vary in composition, and to belong to several different mineral species. On page 230, one of these species, resembling anorthite externally, is described under the name *Maulite*, the island of Maui being one of its localities. It contains soda for its alkali and not potash, a general fact with regard to the lavas of the Hawaiian Islands as far as chemically examined. Prof. B. Silliman, Jr., has also analyzed a similar mineral from a cellular, porphyritic basalt on Upolu, one of the Samoan or Navigator Islands. The following are the steps in the process of analysis, and his results.

The fusion was made with hydrated baryta, and the silica determined in the usual way. From the hydrochloric solution after the separation of the silica, the iron, alumina, lime, and baryta were thrown down by carbonate of ammonia, leaving in solution with the alkalies, the magnesia, there having been sufficient ammoniacal salt formed to prevent its precipitation. The precipitate of iron, alumina, &c., was redissolved in hydrochloric acid, and the baryta precipitated by sulphuric acid; this course being taken in order that the alkalies might be determined as chlorids. The alumina and iron were now again precipitated by ammonia, and, subsequently, the lime by oxalate of ammonia. The magnesia was separated from the alkalies, and determined by the mercury process.

The mineral is not decomposed by boiling in the concentrated acids. *Composition* :—

	In 1.703 grammes.	Per cent.
Silica - - - -	- .916	53.79
Alumina - - - -	- .320	18.79
Peroxyd of iron - - - -	- .072	4.23
Lime - - - -	- .168	9.86
Magnesia - - - -	- .151	8.87
Soda - - - -	- .053	3.11
Hygrometric moisture and loss	- .023	1.35
	<hr/> 1.703	<hr/> 100.00

From this may be deduced the formula



Prof. Silliman, Jr., suggests for the species, which is apparently new, the name *Samoite*, alluding to the group of islands where it occurs.

Samoite constitutes thin and broad tables, colourless and of a glassy lustre, thickly disseminated through a dark-coloured, basaltic base. The specific gravity, according to Prof. Silliman, Jr., is between 2.8 and 2.85, and hardness 5.5 to 6. Cleavage oblique, probably indicating triclinic crystallization like anorthite. The tables are usually twins, although not over half a line in thickness.

Before the blowpipe alone, fusible with difficulty on the thinnest edges. With borax, dissolves forming a colourless bead. With salt of phosphorus, leaves a siliceous skeleton.

Specific Gravities.—On page 200, the specific gravity is mentioned of two lavas of

Kilauea, one compact stony, of a dark gray colour (2·93), and another greenish-black and vitreous (2·91). The following are a few determinations of other rocks.

Compact gray basaltic rock from Kauai. Specific gravity = 2·962. Fuses on thin edges before the blowpipe.

Compact brown basalt, approaching a clinkstone, from Cockscomb Hill, Tutuila, (p. 310.) Specific gravity = 2·728. Fuses with difficulty on thin edges, before the blowpipe.

Grayish clinkstone from Lahaina, Island of Maui (p. 231). Specific gravity = 2·66. At a high heat fuses on thin edges before the blowpipe.

Clinkstone porphyry, a compact rock, speckled with flesh-coloured points, from Waianae Plains, Oahu, (p. 250.) Specific gravity = 2·3315.

Syenite from Tahiti, (p. 294.) Specific gravity = 2·73.

Chert or baked clay of Nobby, New South Wales, (p. 511.) Specific gravity = 2·496. Infusible before the blowpipe.

Rocks of the Bay of Islands, New Zealand, p. 439.

In the Antarctic Voyage of Captain Ross, volume ii., Appendix iii., R. M'Cormick, Surgeon of H. M. Ship Erebus, observes that the clay of the Bay of Islands, and elsewhere in New Zealand, rests on a volcanic substratum of trapean rocks. The character of the work in which the statement is made leads us to remark here, that this is wholly at variance with our observations, as well as those of Dieffenbach and others who have visited these regions.

Australia.—(p. 449.)

The continent of Australia has an area of about 3,000,000 square miles. Europe exceeds this extent by only *one-twelfth*; and the United States, before its recent Californian acquisitions, were more than *one-fourth* less in area, or with these, about *one-tenth* less.

The principal settlements are on the *east*, in New South Wales, commenced as a convict colony in 1788, and augmented by free settlers first in 1794;—on the *west*, at Swan River, commenced in 1829; on the *south*, in South Australia, at Adelaide and other places, commenced in 1834; and on the *north*, at Port Essington, commenced in 1838. Port Philip, on the south, north of Van Diemen's Land, belongs to New South Wales.

Age of the Coal of Australia.—(p. 495.)

On page 495, we have alluded to the resemblance of certain Siberian coal plants to those of Australia, and have cited the opinions of Tchihatcheff on the age of the former. The following paragraph on this subject from *L'Altai Oriental*, page 378, is the one

alluded to in the text. Speaking of the extensive deposits of sandstones and shales containing the fossil plants mentioned, and of the coal beds they overlie, he says:—

“ J’ai cru, en réunissant les uns et les autres dans un seul groupe géologique, ne plus devoir considérer celui-ci simplement comme un membre intercalé dans le terrain houiller, mais bien comme un système indépendant de celui-ci, et lui succédant immédiatement ; il représenterait conséquemment la dernière phase de la création paléozoïque de l’Altai, et y correspondrait peut-être au *todtliegende* des Allemands, c’est-à-dire à notre grès rouge. Cette formation se trouve particulièrement développée sur l’espace compris entre la chaîne de l’Alataou et les rivières Tchoumysch, Kondoma, Mrassa et Oussa.” This region he calls the “basin of Kouznetzck,” from the name of one of its villages.

Pronunciation of Polynesian Words.

The names of places in Polynesia may be pronounced with correctness, by attention to a few particulars.

The vowels have the same sounds as in the Italian ; that is,

A	is like	<i>a</i>	in	father,	or like	the	syllable	<i>ah.</i>
E	“	“	“	cane,	“	“	“	<i>ay.</i>
I	“	<i>ee</i>	“	seen,	“	“	“	<i>ee.</i>
U	“	<i>oo</i>	“	moon,	“	“	“	<i>oo.</i>

AI is nearly like the English *i*, (or *eye*,) being made up of the sounds *ah*, *ee*, (the letters *a*, *i*,) spoken together.

AU, is nearly like the English *ow*, being made up of the sounds *ah*, *oo*, (the letters *a*, *u*,) spoken together.

Thus Kauai	is pronounced	-	-	-	-	Kow-eye.
“ Maui	“	-	-	-	-	Mow-ee.
“ Tahiti	“	-	-	-	-	Tah-hee-tee.
“ Samoa	“	-	-	-	-	Sah-mo-ah.
“ Upolu	“	-	-	-	-	Oo-po-loo.
“ Tutuila	“	-	-	-	-	Too-too-e-lah.
“ Kealakekua	“	-	-	-	-	Kay-ahlah-kay-kooah.
“ Oahu	“	-	-	-	-	O-ah-hoo.

The only other point requiring attention is, that there are as many syllables as there are vowels, every syllable ending in a vowel.

I N D E X .

- Aconcagua Peak, 557.
 Actiniæ, 82, 102.
 Agate in Oregon, 620.
 in Australia, 461.
 Ahii, or Peacock's Island, 63, 72.
 Aitutaki, 405.
 Amargura, eruptions of, 25.
 Ammoniac, Sal, in New Zealand, 446.
 at Kilauea, 181, 201.
 Ammonites from the Andes, 721.
 Amphitheatre in the Punaavia Valley of
 Tahiti, 301, 381.
 of Eimeo, 302, 305.
 Amygdaloid of Nassau Bay, 605.
 Albite of Oregon, 630.
 Albitic rocks of Chili, 565.
 Aleutian Archipelago, curved range of,
 419.
 Allen, on the growth of corals on the east
 coast of Madagascar, 101.
 Allorisma audax, 688.
 curvatum, 688.
 Alluvial delta of Feejee rivers, 340.
 plains and terraces of Oregon and
 California, 619, 659.
 Alum of Kilauea, 181, 201.
 of New Zealand, 446.
 Aluminous depositions from the New Zea-
 land hot springs, 448.
 stalactites in cavern on Upolu, 323.
 of Mount Loa, 207, 208.
 Analysis of aluminous stalactites of Mount
 Loa, 207.
 ibid. of Upolu, 324.
- Analysis of capillary glass and lavas of
 Kilauea, 199, 200.
 of coal from Australia, 476.
 of corals, 151, 152.
 of coral chalk from Oahu, 150.
 of coral rock from Matea, 153.
 of coral sand, 153.
 of limestone concretions, 657.
 of Mauilite, 230.
 of sal ammoniac, 202.
 of Samoite, 732.
 of sulphate of copper, 202.
 Anarthrocanna australis, 720.
 Andes of Chili, 557, 560.
 Peak of Santiago, 582.
 of Peru, 587.
 ammonite from, 721.
 Apamama, 51, 410.
 Apatite derived from coral, 152.
 found in coral rock on Mauki, 152.
 Apia Island, 52, 409.
 harbour, Upolu, 115.
 Apolima, 333.
 Aratica (Carlshoff), 54, 61, 75.
 water in, 76.
 Arca devincta, 726.
 Asiatic coast, curved ranges of islands near,
 419.
 Assumption Island, 354.
 Astarte gemma, 688.
 Astartila, 688.
 corpulenta, 691.
 cyclas, 690.
 cyprina, 689.

- Astartila cytherea, 689.
 intrepida, 689.
 polita, 690.
 transversa, 690.
 Atiu, caverns in, 68.
 level of, 404.
 Atoll, origin of the term, 33.
 see beyond, *Coral island*.
 Augite on Tahiti, 298.
 in Feejees, 350.
 Australia, effects of the continent, in determining the courses of island ranges adjacent to, 433.
 extent of, 733.
 trends of bays and mountains in, 424.
 N. S. Wales, see *New South Wales*.
 Aurora, island of, 67.
 Avicula veneris, 704.

 Balanus fossil, from Oregon, 723.
 Banabe, subsidence at, 400.
 Basalt, masses of, on Rose Island, 309.
 Basaltic conglomerate in Illawarra, 502.
 of Oregon, 653.
 Basaltic dikes, New South Wales, 505.
 baking of the rocks of Nobby, by heat of, 511.
 changes in adjoining rocks, from heat of, 504.
 Basaltic eruptions, influence of, in New South Wales, on animal life, 518.
 Basaltic or high islands, of the Pacific, extent of, 25.
 origin of the mineral constitution of, 372.
 Basaltic rocks of Australia, 495, 513.
 of Chili, 579.
 of Illawarra, 496.
 of Oregon, 640, 645, 669.
 decomposition of, 648.
 Barrier reefs, 33.
 origin of channels within, 123.
 Bay of Islands, New Zealand, 439, 733.
 Bay-indentations, an evidence of subsidence, 393, 675.
 Beaches, elevated, in Oregon, 659.
 in Australia, 534.

 Beach formations from coral sands, 43, 64, 148.
 ibid. on Oahu, 45, 253.
 ibid. on Kauai, 275, 277.
 Beaumont, Elie de, theory of mountain chains, not confirmed, 424.
 Beechey, elevation of Elizabeth Island, 403.
 elevation of Osnaburgh Island, 403.
 height of Ducie's Island, 403.
 remark on the Gambier Group, 130.
 soundings near coral islands, 55.
 Belemnite in rocks of Nassau Bay, 604, 720.
 Beveridge Reef, 407.
 Birgi, on coral islands, 69.
 Birnie's Island, 69, 407.
 Bischof, G., views of, on volcanic action, objected to, 369.
 Bishop, A., on Kilauea in 1825, 185.
 Blow-holes of Koloa, Kauai, 272.
 of Kiama, New South Wales, 496.
 Boiling springs, Feejees, 343.
 Bolabola, notice of, 304.
 reef of, 37.
 Boulders at Wallawalla, Oregon, 674.
 Bowditch Island, 53, 72.
 Buch, L. von, theories of, noticed, 369, 370, 371.
 trachyte of Teneriffe, 373.

 California, northern, 613.
 rocks of, 630, 638.
 terraces in, 663.
 Callianassa oregonensis, 722.
 Callao, on the vicinity of, 587.
 recent deposits along the coast, 588.
 Canaries, observation on the valleys of, 390.
 Capillary glass, Kilauea, 178, 199, 200.
 Cardinia costata, 692.
 cuneata, 692.
 exilis, 692.
 recta, 691.
 Cardita subtenta, 726.
 Cardium australe, 701.
 ferox, 701.
 Carlshoff, 54, 61, 75.
 Caroline Islands, 410.

- Caroline Islands, evidences of subsidence among, 400, 401.
- Cascade range of mountains, in Oregon, 614.
- Caverns in Australia, 536.
 in elevated coral islands, 67.
 on Hawaii, 160, 161, 175.
 on Kauai, 271.
 on Oahu, 239, 253.
 on Upolu, 323.
- Cementation of coral sand, 44, 153.
 of pebbles, on Oahu, 44, 254.
- Chagos Bank, 67, 133.
- Chalcedony, formed from the geysers of New Zealand, 447.
 at Nassau Bay, 604.
 origin of, 606.
 in Australia, 461, 513.
 in Oregon, 620.
- Chalk, of coral origin, Oahu, 150, 252, 732.
- Chalybeate spring, in the Shasty Mountains, 643.
- Chamisso, depth of water at the Marshall Islands, 63.
- Charlotte's Island, 409.
- Chase and Parker, on Kilauea, in 1838, 187.
- Chevalier, E., height of Mount Loa, 156.
- Chert or baked clay of Nobby, 511, 733.
- Chili, observations on, 557.
 basaltic and porphyritic rocks of, 579.
 coal of, 585.
 copper mines of, 584.
 granitic rocks of, 561.
 ibid, veins in, 565.
 silicified wood in, 584.
 stratified rocks in, 583.
- China, absence of corals from coast of, 144.
- Chloritic rock, in Northern California, 633.
- Chondrodite, elements of, in coral rocks, 152.
- Christmas Island, 56, 405.
- Chrysolite, observations on the origin of, 377.
 in the lavas of Nanawale, 192.
 on Madeira, 550.
 on Kauai, 268.
 on Oahu, 244, 246.
 on Tahiti, 298.
- Cinder cones, characters of, 354.
- Cinder eruptions, absent from Kilauea, 193.
 origin of, 358.
- Clarke, W. B., fossils of Australia, 483, 494.
 account of Lafu, 140.
- Clasteria australis, 719.
- Cleobis, 695, 698.
- Clermont Tonnerre, elevation of, 403.
- Climate of New South Wales, observation on the cause of the dryness of, 455.
 of windward and leeward shores, in the Pacific, 27, 166, 227, 338.
- Clinker fields of Hawaii, 162, 165.
 formation of, 187.
- Clinkstone of Maui, 231, 733.
 of Mount Loa, 208.
 of Mount Kea, 214.
 of Oahu, 238, 250, 733.
- Coal formation, in Australia, 469.
 origin and history of, 518.
 age of, 493, 733.
 rocks of Nobby, baked by heat of a dike, 511.
- Coal of Oregon, 658.
 of Australia, analysis of, 476.
 of Chili, 585.
 on Luzon, 544.
 on New Zealand, 439.
- Coan, T., eruption of Kilauea in 1840, 188, 189.
 Kilauea since 1840, 193.
 on an elevated rim formed around the great lake of Kilauea, 178.
 eruption of Mount Loa, at summit, in 1843, 209.
 floods in Hawaiian streams, 389.
- Cocoanut, uses of, on coral islands, 76.
- Columnar rocks, Feejees, 348.
 near Hilo, Hawaii, 215.
 on Illawarra, 496.
 on Kauai, 268, 272.
 on Oahu, 239.
 on Tahiti, 297.
 on Tutuila, 311.
 on Upolu, 316.
 curved, in New South Wales, 508.
- Columnar structure of basalt, facts respecting the origin of, 509.

- Columnar structure of basalt, induced in tufa
on Madeira, by heat, 552.
of tufa, Oahu, 240.
- Columbia River, 613, 616, 624.
River, Grande Coulée, 624, 674.
submerged forest of, 674.
islands and prairies of, 666.
deposits at mouth of, 667.
actions of sea on bar of, 524.
- Concentric structure in basalt, Kauai, 269.
New South Wales, 507.
Upolu, 316.
in coal formation, New South
Wales, 480.
in granite, Chili, 563.
in sandstone below the coal, Aus-
tralia, 486.
in Sydney sandstone, 465.
- Concretions, calcareous, from Glendon,
New South Wales, 481.
of limestone in the tertiary shale of
Oregon, 654.
ibid., containing coarse crystallizations
of carbonate of lime, 656.
twig-like in recent deposits, near Cal-
lao, 589.
- Confervites tenella, 720.
- Conglomerates in the Feejees, 346, 349.
of Kauai, 268.
of Mount Kea, 214.
of West Maui, 231.
of Oahu, 239, 250.
of Nassau Bay, 602.
ancient, of Oregon and California, 638.
of Tahiti, 295.
of Tutuila, 311.
coral, 38, 44, 329.
- Conrad, T. A., description of Oregon fos-
sils, 723.
- Continents, origin of, 429, 436.
- Contraction of the globe, effects of, 428,
430, 432, 435.
a cause of the earth's features, 428, 435.
- Cook, Captain, height of Atiu, 404.
height of Mount Loa, 156.
- Cooling, slow, in volcanic centres, 365, 368.
- Copper, sulphate of, Kilauea, 181, 201, 202.
- Coral, growing, light, temperature, and
other causes influencing, 93,
94, 95, 97, 731.
depth of, 97, 98.
rate of, 101.
secretion of, 80, 84.
influence of waves in breaking, 105.
texture and composition of, 89.
- Coral animals, structure and growth of, 80.
- Coral formations, now above the sea, on
Kauai, 275.
ibid. on Molokai, 233, 408.
ibid. on Maui, 231, 408.
ibid. on Oahu, 45, 234, 248, 251,
408.
ibid. on Luzon, 544.
not on Tahiti, 299, 404.
in tufa craters, 244, 328.
- Coral chalk, 150, 252, 732.
- Coral conglomerate, 38, 44.
consisting partly of basaltic peb-
bles, Upolu, 329.
- Coral debris, formation of, 105.
whether distributed over sea bot-
tom between coral islands, 154.
- Coral field, character of, 104.
- Coral islands, general remarks on, 33, 48.
description of the condition of,
when most complete, 75.
distribution of, in the Pacific, and
proofs from, of subsidence, 394.
effects of subsidence on, 130, 133,
395, 396.
area of several, 54.
basalt on, 78, 309.
crater theory of, objected to, 123.
beaches of, 59.
description of several, 51.
elevations of, 402.
elevated, Metia and others, 67, 403.
emerged land of, 60.
fissures in reefs of, 59.
lagoons of, 48, 63, 65.
mud in, 63.
ship entrance to, 54, 120.
shores of, 62.
soundings in, 63.

- Coral islands, lagoons, origin of, 123, 130.
 logs floated to, 77.
 loose or attached coral blocks on, 61.
 plants of, 78.
 shore platform, 59, 60, 65, 109.
 sandhills on, 64.
 soundings around, 55.
 stones carried to, on logs, 77.
 structure of, 57.
 water on, 76.
- Coral reefs, general features of, 33, 35, 36.
 distribution of, how limited, 134, 136.
 effect of rivers on, in Feejees, 341, 342.
 or islands, evidences from, of elevation, 248, 251, 351, 402.
 evidences from, of subsidence, 393, 394.
 mode of formation of, 103, 108.
 rate of growth of, 121.
 barrier and fringing, 33.
 of north shore of Tahiti, 41.
 fringing, not necessary evidence of no subsidence, 394.
 inner, 38.
 outer, characters of, 36.
 nullipore accumulations on, 37.
 channels within barriers, 40.
 ibid., origin of, 123.
 causes of passages through, 114.
 thickness of, 46.
 harbours of, 114.
 windward highest, 113.
 geographical distribution of, 134.
 of Pacific Ocean, 137.
 of African coast, 145.
 of East Indies, 142.
 Feejee Group, 34.
 of Indian Ocean, 145.
- Coral reef seas, limits of, 135, 146.
 Coral mud, 107, 149.
 Coral rock or limestone, 37, 39, 57, 67, 147, 322.
 Coral rock or limestone of beach origin, 39, 43, 45, 64, 149, 253, 277.
 of Matea, analysis of, 153.
 often destitute of fossils, 38, 46, 149.
 affording mineral fluorids, and phosphates, 152.
 in tufa craters, 244, 328.
- Coral sand, cementation of, 44, 153.
 Cotopaxi, character of summit of, 356.
 Couthouy, J. P., elevation of Clermont Tonnerre, 403.
 isthmus on Tahiti, 294.
 on corals on the declivities of Tahiti, 300.
 soundings of Lanu To'o, 321.
- Craters, kinds of, on Hawaii, 223.
 kinds of, in Pacific, 353.
 of eruption, 370.
 of elevation, 370.
 pit, of Mount Loa, 211, 224.
 tufa, origin of, 260.
 containing lakes, 213, 245, 320, 326.
 of large size, at the Canaries, 362.
- Crater of Kilauea, see *Kilauea*.
 see farther, *Volcano*.
- Crystallization in volcanic centres, 377, 378.
 Cunningham, W. C., on Rarotonga, 364.
 lava on Tutuila, 310.
- Curvatures in ranges of islands, 418.
 Curved ranges off the Asiatic coast, 419.
 of New Guinea chain, 421.
- Curved columnar structure, Tahiti, 297.
 basaltic columns, N. S. Wales, 508.
 on Kauai, 269.
- Cypricardia acutifrons, 702.
 arcodes, 702.
 imbricata, 702.
 prærupta, 703.
 rugulosa, 696.
 siliqua, 703.
 simplex, 703.
 veneris, 704.
- Dangerous Archipelago, see *Paumotus*.
 Dalyell, J. G., on the rate of growth of zoophytes, 102.
 Darwin, C., calcareous incrustations noticed by, 45.

- Darwin, C., thickness of reefs, 47.
 soundings near coral islands, 55.
 depth of water at Keeling Island, and
 on coral mud of, 63.
 on the Maldives, 66, 133.
 depth of growing corals, 98.
 on the origin of coral mud, 108.
 theory of coral islands, 125.
 observation on the summit of Cotopaxi,
 356.
 rarity of dislocations in volcanic dis-
 tricts, 361.
 on the cause of feldspathic centres of
 volcanic mountains, 374.
 arrangement of the Galapagos Islands,
 418.
 origin of valleys of Australia, 527.
 views of, on elevation of San Lorenzo,
 591.
 on the Patagonian tertiary, 609.
- Dean's Island, 48, 54.
 elevation of, 402.
- Deception Island, remarks on, 547.
- Declivity, see *Slope*.
- Decomposition of basaltic rocks, in Austra-
 lia, 513.
 producing a material like
 mica slate, 515.
 on Tahiti, 298.
 of rocks of Nassau Bay, 606.
 of rocks of New Zealand, 441.
 of granite, Chili, 578.
 of Wollongong sandstone, 400.
- Degradation from the action of the sea, 111,
 381.
 from running waters, 384, 386.
 evidence of the length of time since
 volcanic eruptions ceased, 283, 391.
- Degradation in Feejees, 350.
 of rocks, New South Wales, 526.
 in Oregon, 670.
- Delta of Feejee rivers, 340.
- Depeyster's Island, 407.
- Depths of growing corals, 98.
- Descloiseaux, A., temperature of geysers,
 203.
- Deserts, cause of, 455.
- Dibble, J., an early eruption of Kilauea, 183.
- Dieffenbach, on New Zealand, 437, 447.
- Dikes, effects of, on forms of volcanic cones,
 360, 361.
 regularity of, in volcanic regions, 361.
 of Chili, 582.
 of Kauai, 269.
 of Madeira, 552.
 of Nassau Bay, 605.
 of basalt, New South Wales, 505.
 at Punch-bowl, Oahu, 243.
 near Kaala, Oahu, 251.
 of Tahiti, 297.
 of Upolu, 317.
 of sandstone, in Oregon, 654.
- Dislocations, a result of contraction, 430.
 rare, in volcanic districts, 361, 436.
- Distribution, geographical, of coral reefs,
 134.
- Dolomite, origin of, 153, 731.
- Donax? protexta, 723.
- Douglas, height of Mounts Loa and Kea,
 156, 157.
 on Kilauea, in 1834, 187.
 ascent of Mount Loa, 208.
- Drift sand-rock of coral material, 45, 64, 277.
- Drummond Island, 409.
- Ducie's Island, elevation of, 403.
- Duke of York's Island, 72, 407.
- Duke of Clarence, 54, 407.
- Duchassaing, on the rate of growth of a
 Madrepore at Guadaloupe, 102.
- Earth, origin of general features of, 424.
 structure of crust of, 421, 435.
- Earth's crust, thickness of, according to W.
 Hopkins, 427.
- Earthquakes, a cause of, 432, 436.
 none at an eruption of Kilauea, 188.
 ibid. of Mount Loa at summit, 210.
 of Valdivia, in 1837, causing waves
 on Pacific Islands, 27, 335.
 rotation by, in Lima, Peru, 599.
- East Indies, curved ranges in, 419.
 coral reefs of, 142.
 Philippine and Sooloo Islands, 539.
- Eimeo, 285, 302.

- Elevated coral reefs or islands, 67, 402.
- Elevations of modern eras in the Pacific, 402.
 of Christmas Island, 405.
 among the Feejee Islands and others north, 407.
 in the Hervey Group, 404.
 of Jarvis and neighbouring islands, 405.
 among the Kingsmill Group, 409.
 among the Ladrões, 410.
 among islands north of Samoa, 407.
 among the Sandwich Islands, 233, 251, 408.
 of Tahiti, no evidence of, in coral rock on summits, 299.
 among the Tonga Islands, 406.
 of Washington Island, 405.
 in the Pacific, deductions concerning, 412.
- Elevation theory of von Buch, noticed, 369, 370.
- Elizabeth Island, elevation of, 403.
- Ellice's Island, 407.
- Ellis, eruptions near Kapapala, Hawaii, in 1823, 165, 184.
- Emmons, G. F., Caryophyllia obtained by, 99.
 account of lake on Tahiti, 293.
- Enderby's Island, 63, 65, 70, 407.
- Epidote in basaltic and porphyritic rocks of Chili, 580, 581.
 at Nassau Bay, 605.
 veins of, in Chili, 565.
- Epochs in geological history, origin of, 436.
- Equisetacea of Australia, 719.
- Eruptions through fissures, 196.
- Eruptions, see *Volcanic*.
- Eua, island of, 406.
- Eurydesma cordata, 700.
 elliptica, 700.
 globosa, 700.
 sacculus, 700.
- Fakaafo, 53, 54, 72, 407.
- Falls, in New South Wales, 451.
 of the Hanapepe, 264.
 of the Wailuku, near Hilo, 167.
- Fanning's Island, 405.
- Faults in the coal formation of New South Wales, 476.
 in San Lorenzo, 594, 597.
- Feejee Islands, general features of, 337.
 boiling springs of, 343.
 elevations among, 351, 407, 412, 414.
 geological structure of, 343.
 view of the island Aiva, 127.
 Whippley Harbour, in Viti Lebu, 118.
 rivers in, 27, 340, 342.
 reefs of Vanua Lebu and other islands, 34, 35, 39, 41, 337.
 thickness of reefs of, 48.
- Feis, island of, 410.
- Feldspathic centres of volcanic mountains, 204, 364, 368, 372.
 ibid., C. Darwin on, 374.
 ibid., von Buch on, 373.
 rocks of Maui, 231, 733.
 of Mount Kea, 214.
 of Mount Loa, 207.
 of Oahu, 238, 250, 733.
 of Tahiti, 294, 296.
 graduating into basaltic, New South Wales, 498.
 of Borabora, 304.
- Fiords of Northwest America, 675.
 evidence from, of subsidence, 676.
- Fish, fossil, from Australia, 482, 681.
 from Oregon, 722.
- Fissures, origin of, 195, 196, 217, 224, 436.
 general laws respecting, 416.
 general characters of, 281, 415.
 in the coal formation, New South Wales, 77, 480.
 in the Sydney sandstone, 467, 525.
 in the Wollongong rocks, 487, 489.
 in stratified rocks of San Lorenzo, 595.
- Fissure eruptions, Mount Loa, 196.
- Fitton, trends in Australia, 424.
- Fitzroy, temperature of the sea near the Galapagos, 135.
- Flames during volcanic action, 184.
- Floating vegetation of certain lakes, 521, 522, 541.

- Floods of Australia, 520.
of Hawaiian streams, 389.
- Fluidity of lavas, influence of, on the characters of cones, 358.
- Foraminifera, from Oregon, 729.
- Forbes, E., explorations in the Ægean, 100.
- Fossils of Australia, 468, 482, 491, 681.
at Nassau Bay, Tierra del Fuego, 604, 720.
of Oregon, tertiary, 657, 722.
of Rio Negro, 609.
of San Lorenzo, 597, 721.
rare in many reef rocks, 38, 57, 67, 149.
absence of, from some beach formations, 46, 149.
- Fountains on shores of Upolu, 314.
- Fremont, J. C., on the Rocky Mountains, 612.
- Galapagos, cause of absence of corals from, 135, 137, 418.
- Galerites oregonensis, 729.
- Gambier Islands, view of, 130.
thickness of reefs, 47.
evidences of subsidence at, 397.
- Gardner's Island, 407.
- Geographical distribution of coral reefs and islands, 134.
. *ibid.*, of Pacific islands, 11, 414.
- Geysers, temperature at depths in, 203.
of New Zealand, 447.
- Glauber salt of Kailua, Hawaii, 215.
- Glossopteris ampla, 717.
Browniana, 716.
cordata, 718.
elongata, 718.
linearis, 718.
reticulum, 717.
- Goeppert, on the genus Noeggerathia, 715.
- Goodrich, J., eruption of Mount Loa at summit, in 1832, 208.
- Gran Canary, feldspathic rocks of, 373.
- Grande Coulée, 624, 674.
- Granitic rocks of Chili, 561.
of Oregon, 630.
decomposition of, 578, 637.
series of rocks, relations to one another, 635.
- Granitoid rocks on Tahiti, Maurua, and Borabora, 295, 304.
- Greenstone, of Chili, 579.
of Nassau Bay, 604.
- Gold in California, 638.
in the Philippines, 539.
- Gypsum in the Andes, 599.
on San Lorenzo, 598.
crystals of, in buried wood near Callao, Peru, 589.
at Kilauea, 181, 201.
in sea-water, 91.
- Haidinger, W., on dolomisation, 731.
- Hale, H. E., on the Blue Mountains, Australia, 450.
evidence of subsidence at Banabe, 400.
- Hale-a-kala, East Maui, 227.
valleys of, 384.
- Hamilton, W., eruption at Vesuvius, 163.
- Hapaii Islands, 406.
- Harbours formed by coral reefs, 114.
causes of their remaining open, 114.
of Tahiti, 41, 116, 117.
- Harbour of Apia, in Upolu, 115.
of Falifa, Upolu, 117.
Whippey's, of Viti Lebu, 118.
- Hawaiian Islands, 155.
linear arrangement in, 13, 157, 279.
twin and triple character of islands, 280.
changes of level among, 396, 408, 412.
age of the several, 280.
origin of, 279, 368, 415.
height of mountains, 156, 157, 166.
valleys of, 384.
reefs of, 139, 231, 251, 275.
Hawaii, general features of, 158.
Kohala range, 168, 216, 284.
falls of the Wailuku, 167.
Mount Loa, with Kilauea or Lua Pele, 168.
eruptions, 183, 208, 215.
Mount Kea, 214.

- Hawaiian Islands, Hawaii, Hualalai, 215.
 kinds of craters on, 223.
 Kapoho Point craters, 213.
 floods of rivers, 389.
 Maui, 226.
 Kahoolawe, Lanai and Molokai, 231.
 Oahu, 233.
 Kauai, 262.
- Heat from dike, effect of, on coal formation, in Nobby, 511.
 change of colour in rocks, from, 504.
 columnar structure, produced by, 240, 552.
- Height of Mount Loa, 156.
 of Kilauea, or Lua Pele, 166.
 of Mount Kea, 156, 157.
 of Mount Hualalai, 156.
 of Haleakala, 156, 227.
 of Eeka, 156, 227.
 of summits of Oahu, 234.
 of Madeira, 550.
 of Australian mountains, 450.
 of Oregon mountains, 612, 615.
 of San Lorenzo, 593.
- Helicurus fuegiensis, 720.
- Henderson's Island (or Elizabeth), 68, 402.
- Henuake, or Honden, 52, 62, 70, 402.
- Hervey Islands, reefs of, 138.
 elevations among, 404.
 remarks on Rarotonga, 364, 405.
- Homomya audax, 687.
 curvata, 688.
- Honden, Henuake or Dog Island, 52, 62, 70, 402.
- Hopkins, W., on fissures, 426.
 thickness of the earth's crust, 427.
- Hornblendic rocks of Chili, 562.
- Hornblende of Oregon and Northern California, 631.
 in trachyte, at the Sacramento Butte, 651.
- Horne Island, 407.
- Hot springs of Baños, on Luzon, 543.
 of Feejees, 343.
 of New Zealand, 445, 447.
- Hot springs, probable existence of, formerly, in Oahu, 260.
- Huahine, 285, 303.
- Hualalai, observations on, 215, 371.
 height of, 156.
- Hull's Island, 407.
- Humboldt, character of Cotopaxi, 356.
 relation of periods of quiescence in volcanoes, to their size, 367.
- Hypersthene rock, in Northern California, 631.
- Igneous, see *Volcanic*.
- Illawarra, rocks of Wollongong, 485.
 basaltic scenery of, 496.
 evidences of change of level in, 534.
- Illawarra Mountain, 451.
- Islands, Pacific, number of, 9.
 geographical distribution of, 11.
 arrangement of, 12.
 character, area, and number of, 23.
 review of, with reference to coral reefs, 137.
- Island ranges of Pacific, relative positions and curves of, 414, 418.
 curved, off the Asiatic coast, 419.
 cause of curvatures in, 433.
- Island, Deception, 547.
 Madeira, 549.
- Islands, Caroline, 16, 395, 400, 410.
 coral, 29, 33, 48.
 Feejeean, 139, 337.
 Hawaiian, 155.
 Kingsmill or Tarawan, 50, 76, 409, 417.
 Paumotu, 14, 24, 53, 58, 137, 394, 402.
 Samoan, 15, 138, 307, 407.
 Society or Tahitian, 14, 285, 404.
 Sooloo, 539.
 Tongan, or Friendly, 39, 63, 138, 406.
- Jarvis Island, 52, 68, 405.
- Jasper, near San Francisco, California, 632, 636.
 in the Philippines, 540.
 veins of, in Australia, 503.
- Judd, dangerous descent of, in Kilauea, 182.

- Kahoolawe, 232.
- Kailua, warm spring of, 215.
- Kapoho Point, Hawaii, 213.
- Kauai, general features of, 262.
 geological structure and rocks of, 266,
 733.
 craters of Koloa on, 271.
 coral formations, 275.
 general conclusions of, 278.
 relation of the eastern shore ridge, to
 the island, 279, 284.
 elevation of, 408.
- Kawehe Island, 61, 74.
- Keeling's Island, 37.
- Kelley, E. G., on Kilauea in 1838, 187.
- Kilauea, account of, 171.
 map-sketch of, 173.
 section of, 174.
 height of, 166.
 without scoria on its walls, 174, 180,
 224.
 movement to southwest in the large
 lake, 179, 203, 375.
 temperature of, 205.
 not a solfatara, 205.
 steep slopes of lava, on the descent to,
 179.
 liquidity of lavas, 195, 223, 358.
 quiet mode of eruption, 195.
 absence of cinder cones, 193.
 subsidence around, from eruptions, 197.
 eruptions within the crater of, 182.
 not agitated during an eruption at sum-
 mit of Mount Loa, 211, 216.
 eruptions of, 183.
 in 1823, 184.
 in 1832, 184.
 in 1825, C. S. Stewart, 185.
 A. Bishop, 185.
 map of, in 1825, by Lieutenant Mal-
 den, 185.
 in 1829, C. S. Stewart, 186.
 in 1832, after an eruption, J. Good-
 rich, 186.
 in 1834, Douglas, 187.
 in 1838, Chase and Parker, 187.
 Strzelecki, 188.
- Kilauea, in 1839, Shepherd, 188.
 in 1840, 188.
 amount of lavas ejected in 1840, 191.
 ibid., in 1823, 196.
 eruption of, in 1840, took place through
 fissures, 196.
 since 1840, 193.
 frequency of eruptions of, 198.
 isolation of volcanic forces, 198, 218.
 phases of volcanic action in, 222.
 probable origin of, and early condition,
 224.
 sulphur banks of, 180.
 rocks and minerals of, 181, 198.
 siliceous incrustations from decompos-
 ing lavas of, 181, 201.
 compared to Val del Bove, 381.
- King, height of Mount Loa, 156.
- Kingsmill Islands, map and descriptions of,
 50, 51, 76.
 elevations among, 409.
 arrangement of islands, 417.
- Kohala Ridge, Hawaii, 168, 216, 284.
- Kotzebue, height of Mounts Loa and Kea,
 156, 157.
 coral mud at the Marshall Islands, 63.
 water at the Marshall Islands, 77.
 logs floated to the Marshall Islands,
 77.
- Kuria, 52, 56, 410.
- Ladrones, elevations among, 410.
 arrangement of islands, 16, 418, 419.
 evidences of subsidence about, 398.
 reefs of, 139.
 sketch of Assumption Island, 354.
- Lagoons of atolls, 33, 48, 63, 114, 130.
- Lakes, covered with floating vegetation, in
 Luzon and India, 521, 522, 541.
- Lake, called Laguna de Bay, island of
 Luzon, 541.
- Lakes in craters, 213, 320, 326.
- Laminated basalt, Upolu, 316.
 trachyte, 650.
- Lamination, oblique, in Sydney sandstone,
 462.
 ibid., origin of, 523.

- Lamination of micaceous rocks, adjoining veins, in Chili, 577.
 in beach and drift sand-rock, 254, 275, 277.
 of rocks, cause of, illustrated, 256.
- Lanai, 231.
- Lancerote, observation of von Buch on, 371.
- Land lost to the Pacific by subsidence, 400.
- Lava, smooth fields of, on Hawaii, called pahoihoi, 161, 162.
 clinker fields of Hawaii, 162, 165, 187.
 recent fields of, producing potatoes, 166.
 stalactites of, Kilauea, 177, 201.
- Lavas of Kilauea, 175, 176, 179, 198.
 of the eruption of Kilauea in 1840, 190, 192.
 fluidity of, at Kilauea, 178, 195.
 ebullition of, 200.
 cooling of, 187, 191, 204.
 angle of descent of flowing, 210, 356.
 forming steep ridges or slopes around a vent, 178, 179.
 influence of fluidity of, on the character of cones, 358.
 pressure of, in the centre of the volcano of Mount Loa, 217.
 columns of, Kilauea, 177, 178.
 capillary, Kilauea, 179, 199.
 of the summit of Mount Loa, 207.
 of Hale-a-kala, 228.
 of Upolu, 319, 322.
- Lavas, see further, *Rocks*.
- Lava cones, characters of, 355.
- Level, causes of changes in, 431.
 evidences of change of, in the Pacific, 392, 402, 412.
 changes of, in Feejees, 351, 407, 414.
 evidences of change of, in Upolu, 332.
 change of, in Oregon, 670.
 changes of, in New South Wales, 533.
 change of, in Hawaiian Islands, 408.
 see farther, *Subsidence*.
- Lignite in the Jaguel Valley, Chili, 584.
 in Oregon, 658.
- Lime, carbonate of, incrusting pebbles, 44.
 deposited in vesicular rocks, 45.
- Limestone of Madeira, 554.
- Limestone, prismatic, in limestone concretions of Oregon, analysis of, 657.
 coral, see *Coral*.
- Lingula ovata, 685.
- Lisiansky, N., formation of a precipice on Kodiak, 259.
 soundings by, 56.
- Lisiansky, island of, 56.
- Low Archipelago, see *Panama*.
- Loyalty Group, reefs of, 141.
- Lua Pele, see *Kilauea*.
- Lucina acutilineata, 725.
- Luzon, observations on, 540.
 coal of, 544.
 hot springs at Baños, 543.
- Lyell, C., force of waves, 106.
- Mackenzie Island, 410.
- M'Coy, age of coal of Australia, 495.
 fossils of Australia, 683 *et seq.*
- Madagascar, reefs of, 145.
- Madeira, observations on, 549.
 limestone of Caniçal, 554.
 of St. Vincent, 555.
- Mæonia, 694.
- Mæonia axinia, 696.
 carinata, 696.
 elliptica, 697.
 elongata, 695.
 fragilis, 696.
 gigas, 697.
 gracilis, 698.
 myiformis, 697.
 grandis, 697.
 recta, 698.
 valida, 695.
- Magnetic iron sand, on Upolu, 315.
- Maiana, island of, 52.
- Maitea (misspelt, Metia), 285.
- Makin, island of, 52, 113, 410.
- Malden, Lieutenant, map of Kilauea, as seen in 1825, 185.
- Malden, island of, 406.
- Maldivé, origin of the word, 33.
 title of the Sultan of, 32.
- Maldives, soundings about, 56.
 remarks on, 66, 133.

- Mangaia, island of, 404.
 Mangroves of the Feejees, uses of, 342.
 Manhii, or Waterlandt, 54, 74.
 Manilla, on Luzon, 540.
 Manono, island of, 333.
 Manua, island of, 309.
 Manuai, island of, 405.
 Maraki, island of, 52, 71, 410.
 Marchand, height of Mount Loa, 156.
 Margaret Island, 70.
 Marquesas Islands, little coral about, 137.
 evidences of subsidence about, 397.
 Marshall Islands, 15, 410, 417, 421.
 Maui, geological account of, 226.
 on elevation of, 408.
 Mauilite, a new mineral, 230.
 Mauke, island of, 404.
 Mauna Loa, see *Mount Loa*.
 Mauritius, area of crater, 363.
 Maurua, 285, 304.
 Megadesmus antiquatus, 694.
 cuneatus, 693.
 levis, 694.
 globosus, 694.
 Melanesia, limits of, 12.
 active volcanoes of, 25.
 Menchikoff atoll, 54, 133.
 Metamorphic changes, New Zealand, 439, 440, 448.
 rocks in Oregon, 630, 637.
 Metia, an elevated coral island, 67, 126, 403.
 Mica in trachyte, 650.
 Mica schist, material resembling, produced by decomposition of basalt, 515.
 Micronesia, limits of, 12.
 Minerals, in the Feejees, 350.
 of the Hawaiian Islands, 198, 230.
 of Nassau Bay, 604.
 in New South Wales, 468, 513.
 of Oregon, 620, 637, 656, 658.
 of Samoa, 315, 323, 732.
 of San Lorenzo, 598.
 of Tahiti, 298.
 Mineral constitution of basaltic islands of the Pacific, 372.
 Mineral fluorids and phosphates formed from coral rock, 151, 152.
 Mineral spring at Kailua, affording glauber salt, 215.
 in the Shasty Mountains, 643.
 Mitchell, T. L., fertility of New South Wales, 453.
 extent of the Coxe Valley, New South Wales, 527.
 Mitiaro, island of, 404.
 Modiolopsis, see *Cypricardia*.
 Molokai, 232, 233.
 elevation of, 408.
 Morehead, depth of growing corals in the Red Sea, 98.
 Moresby, on the Chagos Bank, 67.
 soundings by, 56.
 Morlot, A. von, on dolomisation, 153, 731.
 Morris, C., age of coal of Australia, 495.
 fossils of Australia, 683 *et seq.*
 Mount Eeka, on Maui, height of, 156, 227.
 Haleakala, on Maui, height of, 156.
 Hood, 615.
 Hualalai, 156; 215.
 Kea, account of, 214.
 height of, 156.
 height of vegetation on, 167.
 early level of, 413.
 valleys of, 384.
 Mount Loa, height of, 156.
 height of vegetation on, 167.
 form of, 168.
 dome, proper limits of upper curve of, near Kilauea, 226.
 map of part of, 169.
 angle of slopes of, 169.
 account of Kilauea, 171.
 summit crater and eruptions of, 206, 208.
 various pit craters and cones of, 211.
 characteristics of, 214, 355.
 a crater of eruption, 370.
 not topped with cinders, 216.
 quietness of eruptions, 216.
 mode of action in, 217.
 slopes of lava in, 357.

- Mount Loa, pressure of lava in central conduit of, 217.
isolation of lines of volcanic forces in, 218.
influence of dikes on, 361.
rapidity of formation of, 365.
subaerial origin of surface rocks, 413.
contains the material of a Tahiti, 392.
- Mount Loa, no deep valleys in, 384.
- Mount St. Helen's, 615.
- Mountains, origin of, 431, 436.
arrangement of, on continents, 414, 422, 430.
remark on maps of, 611.
of Australia, 450.
of Madeira, 550.
of Oregon, 614.
Rocky, general features of, 611.
Andes, Chilian, 557, 560.
Peruvian, 587.
of Tahiti, 286, 289.
- Mountain ranges, causes of curvatures in, 433.
theory of Elie de Beaumont respecting, not supported, 424.
- Mya abrupta, 723.
- Myonia, see *Mæonia*, 694.
- Mud, coral, at different islands, 63.
formation of, 108.
- Nairsa (or Dean's Island), 48, 54, 75.
elevation of, 402.
- Namouti, 51, 54.
- Namuka, 406.
- Nanawale eruption, 189, 192.
- Nanouki, 51, 409.
- Nassau Bay, in Tierra del Fuego, observations on the vicinity of, 601.
- Nautilus tenui-planatus, 721.
- Navigator Islands, see *Samoa*.
- New Caledonia, reefs of, 140.
- New Guinea chain, 421.
cause of curvature in, 433.
- New Hebrides, 140.
- New Holland, reefs of, 140, 141.
- New Holland, trends of bays and mountains in, 424.
see *New South Wales* and *Australia*.
- New South Wales, features of, 449.
Blue Mountains and Australian Alps, 450.
Kangaroo Grounds, 451.
salt water in, 455, 469.
climate of, 455.
rocks of, 456, 495, 733.
silicified wood of, 483, 491.
coal formation in, 469.
Newcastle coal rocks, 470.
Illawarra coal rocks, 470, 477.
calcareous concretions from Glendon, 481.
baked coal rocks of Nobby, 511, 733.
floods of, 454, 520.
description of fossils of, 681.
observations on the origin of the deposits of, 516.
origin of valleys of, 527.
action of sea on coasts of, 109, 532.
evidences of changes of level in, 533.
list of works and memoirs on, 536.
- New Zealand, geological observations on, 437, 733.
volcanic cones and phenomena of, 442.
hot springs of, 445, 447.
sulphur of White Island, 447.
sea-shore platform of, and view of "The Old Hat," 109, 442.
action of sea on shores, 442.
- Newmarket Island, 407.
- Nobby, rocks of, 511, 733.
- Noeggerathia æqualis, 715.
distans, 715.
elongata, 715.
media, 715.
spatulata, 715.

- Notomya, 695.
 Nucula abrupta, 698.
 concinna, 699.
 divaricata, 725.
 glendonensis, 699.
 impressa, 726.
 Nukunono, 407.
 Nullipores on the margins of reefs, 37, 57,
 58, 73, 101.
 Oahu, account of, 233.
 rivers of, 234.
 Pali or precipice, 235, 258.
 view from Kaneohe, of precipice, 236.
 valleys of, 236, 385, 388.
 tufa craters of, 237, 240.
 structure and dip of layers, 238.
 rocks of, 238.
 caverns of, 239, 253.
 columnar forms of rocks, 239.
 Diamond Hill, 240.
 Punchbowl, 242.
 Koko Head craters, 243.
 salt lake region, 245.
 craters of Kaneohe Point, 248.
 Kaala Mountains, 250.
 coral reef rock, elevated, 251.
 coral chalk of, 150, 252, 731.
 coral sand rock, 45, 253.
 general review of geological history of,
 256.
 twin character of, 257.
 eastern mountain latest in eruption,
 260.
 early level of, 412.
 Oatafu, 407.
 Ocean, Pacific, see *Pacific*.
 Oceanic basins, a result of contraction, 428,
 430, 436.
 Ofu, 309.
 Okatutaia, 404.
 Olosenga, 309.
 Oolitic rocks, at Nassau Bay, 604.
 constitute San Lorenzo, 597.
 Oregon, general features of, 611, 613.
 dryness of climate, 621.
 Cascade Range, 614.
 Oregon, Coast Range, 615.
 Swalalahos, a volcanic peak, 615, 643.
 Blue Mountains, 616.
 Grand Rond, 616.
 Grande Coulée, 624, 674.
 geological structure of, 625.
 minerals of, 637.
 fossils from, 657, 722.
 terraces in, 659, 670.
 submerged forest of the Columbia, 674.
 causes of features of, 668.
 Orthonota costata, 692.
 Osnaburgh Island, 285.
 elevation of, 403.
 Otahaa (Tahaa), 285, 304.
 Otaheite, see *Tuhiti*.
 Otuhu, 70.
 Ovalau, one of the Feejee Islands, 342.
 Owhyee, see *Hawaii*.
 Pacific Ocean, extent of, 9.
 subdivisions of, 11.
 general features of, and arrange-
 ment of land, 10, 11, 414.
 geological agencies in, 26.
 tides of, 26.
 coral islands, number and extent
 of, 24.
 see farther, *Coral*.
 distribution of coral reefs and
 islands in, 134, 137, 395.
 review of volcanic action in, 353.
 encircled by ranges of volcanoes,
 430.
 origin of the constitution of the
 basaltic islands of, 372.
 origin of the valleys of islands,
 379.
 origin of general features of, 424.
 on changes of level in, 392, 402,
 412.
 subsidence in, indicated by coral
 reefs, 393, 394.
 extent of, 399.
 period of, 401.
 loss of land to, by subsidence,
 400.

- Pacific Ocean, axis of area of subsidence, 398, 432.
 relation of subsidence of, to changes over the continents, 429.
- Pachydomus antiquatus, 693.
 carinatus, 696.
 cuneatus, 693.
 gigas, 697.
 levis, 694.
 sacculus, 700.
- Pahoihoi, 162, 165.
- Palmyra Island, 405.
- Pampas of Rio Negro, 607.
- Pango-pango, harbour of, 310, 311.
- Patagonia, Rio Negro, in Northern, 607.
 tertiary of, C. Darwin, 609.
- Paumotu Islands, 14, 24, 53, 71, 137.
 changes of level in, 394, 401, 402.
- Peabody, J., analysis of Pele's hair, 199.
- Peale, T. R., cavern in Upolu, 323.
- Pebbles cemented by lime, 44, 329.
- Pecten comptus, 704.
 illawarrensis, 705.
 leniusculus, 704.
 mitis, 705.
 propatulus, 726.
 squamuliferus, 705.
 tenuicollis, 705.
- Pectunculus nitens, 726.
 patulus, 726.
- Pele's hair, 179, 199.
 analysis of, 199, 200.
- Pelews, 410.
- Pentadia corona, 712.
 It is possible that the plates referred on page 712 to Pentadia, may pertain to McCoy's genus *Tribrachyocrinus*. See Ann. and Mag. Nat. Hist. xx. 228, pl. xii., fig. 2, 1847.
- Percival, J. G., character of dikes illustrated in a work by, 416.
- Perry, O. H., soundings near Upolu, 99.
- Peru, observations on the vicinity of Callao, 587.
- Pescadores, 54.
- Petrified wood, in Oregon and California, 658, 669.
 in N. S. Wales, 483, 491, 714.
- Petrified wood, in Chili, 584.
 on Luzon, 542.
- Philippine Islands, geological observations on, 539.
- Pholadomya audax, 687.
 curvata, 688.
 glendonensis, 687.
 undata, 687.
- Phyllothea australis, 718.
- Pickering, C., observations on Kilauea, 181, 182.
 pit craters of Mount Loa, 212.
 observations on Mount Kea, 214.
 tubular concretions of Maui, 231.
 observations at salt lake of Oahu, 248.
- Pico Ruivo, height of, 550.
- Pipestone of Northwest America, 636.
- Pitchstone in Oregon, 644.
- Plants of coral islands, 78.
 fossil, of Australia, 482, 491, 714.
 of Oregon, 729.
- Pleurorhynchus australis, 701.
- Polynesia, limits of, 11.
- Polynesian words, pronunciation of, 734.
- Porphyritic rocks of Chili, 579.
 basalt, 267, 294, 310, 315, 345, 498.
- Porphyry of the Sacramento Bute, 650.
 conglomerate, Chili, 583.
 in Peru, 599.
- Potatoes growing over recent lava fields, 166.
- Powell, soundings by, 56.
- Prairies, upper and lower, of Oregon, 619.
- Prase and prasoid rock, in Northern California, 632.
- Precipices of Upolu, 312, 325, 332.
 of Oahu, 235, 258.
 of Tahiti, 285, 287, 291.
 of Madeira, 549.
- Prevost, C., views on volcanic action, 372.
- Productus brachythærus, 686.
 fragilis, 686.
- Protogine in Northern California, 634.
- Puddingstone of the Shasty Mountains, 639.
 of New South Wales, 461.
 consisting of coral and basaltic pebbles, 329.

- Pumice, formation of, 201.
 in the Feejees, 346.
 floated to coral islands, 77.
- Pumiceous tufa of Madeira, 551.
- Pylstaart's Island, 406.
- Pyramia, 695.
- Quoy and Gaymard, on limits of growing corals, in depth, 98.
- Radack Islands, 15, 410, 417, 421.
- Raiatea, 285, 304.
- Rains, confined to windward slopes, 27, 159, 227.
- Raivavai, island of, 405.
- Ralick Islands, 15, 410, 417, 421.
- Raraka, island of, 48, 54, 73.
- Rarotonga, island of, 405.
 solid centre of, 364.
- Ranges of islands and mountains, laws respecting, 414.
- Redfield, W. C., cause of deserts, 455.
- Reefs, see *Coral*.
- Refrigeration, effects of the earth's, 428, 435.
- Revillagigedo Islands, 137.
- Rigaud, S. P., extent of land in the different zones in the Pacific, 9.
- Rio Negro, Northern Patagonia, remarks on, 607.
- Rivers of Chili, periodical rise and fall in, 561.
 of New South Wales, 454.
 floods of, 520.
 in the Feejees, 340.
 of Oregon, 613, 617.
 flowing from the Rocky Mountains, 613.
 of Pacific islands, often confined mostly to windward side, 27, 159.
 of Upolu, 314.
 effect of, on coral reefs, at Feejees, 341, 342.
- Rocks of Chili, stratified, 583.
 basaltic and porphyritic, 579.
 granitic, 561.
 of the Feejees, 345.
 of Madeira, 550.
- Rocks of New South Wales, 456, 469, 485, 495, 733.
 degradation and decomposition of, 526.
 of New Zealand, 438, 733.
 of Oregon and North California, 625, 630, 632.
 of the Pacific, 372, 732.
 of Samoa, 308.
 of Upolu, 315, 732.
 of Tutuila, 310.
 of Oregon and North California, topographical relations of, 635.
 decomposition of, 637.
 of San Lorenzo, 593.
 of Sandwich Islands, 155.
 Oahu, 238, 250, 733.
 Kauai, 266, 272, 733.
 Maui, 230, 231, 733.
 of Society Islands, 294.
 decomposition of, 298.
 of Tierra del Fuego, Nassau Bay, 602.
 of coral material, 37, 39, 57, 147, 149.
 used for building on Oahu, 39.
 ibid. at Maldives, 64.
 of beach, origin and characters of, 43, 64, 149.
 of drift-sands on shores, 45, 64, 149, 254, 277.
- Rocky Mountains, general features of, 611.
 height of pass in, 612.
 period of rise of, 668.
- Rose Island, 78, 308.
- Rota, island of, 410.
- Rotuma, island of, 407.
- Royle, Dr., on lakes in India, 522.
- Ruptures, see *Fissures*.
- Rurutu, island of, 405.
- Sabine, E., chart of magnetic intensity, 428.
- Sacramento Bute, 649.
- Saint Helena, feldspathic rocks of, 373.
- Sal ammoniac in New Zealand, 446.
 at Kilauea, 181, 201.
- Salines of Australia, 455, 469.

- Salt on San Lorenzo, 598.
 in Oregon, 628.
 salt lake, Oahu, 245.
- Samoa Islands, general remarks on, 307.
 Manua, Ofu, Olosenga, Tutuila, 309.
 Upolu, 312.
 Manono, Apolima, Savaii, 333.
 harbour of Apia, 115.
 harbour of Falifa, 117.
 soundings near, 99.
 on reefs of, 138.
 evidence of subsidence at, 398.
 no evidences of elevation among, 407.
 conclusions respecting, 335.
- Samoite, a new mineral, 732.
- San Francisco, bay of, 613.
- San Lorenzo, secondary rocks of, 593.
 fossils of, 721.
 shells at elevations on, 590.
- Sand of sea-bottom, rippled by waves in deep water, 105.
 to a great extent, of sea-shore formation, 108, 149.
- Sandstone, ancient, of Oregon and California, 638.
 tertiary, of Oregon, 652.
 of New South Wales, 456, 470, 485.
- Sandstone dikes, in Oregon tertiary, 654.
- Santiago, Chili, 558.
- Sandwich Islands, see *Hawaiian*.
- Savage Island, 406.
- Savaii, features of, 308, 333.
- Savu-savu hot springs, 343.
- Schomburgh, R. H., sand-hills of Anegada, 64.
- Scoria of Kilauea, 175, 199, 376.
 not covering walls of Kilauea, or the pit craters of Mount Loa, 224.
- Sea on Columbia bar, 524.
 action of, producing inclined layers of deposition, 523.
 action of, in producing valleys, 381.
 action of, on islands before the existence of reefs, 350, 414.
 action of, on coral islands, 109.
- Sea, action of, on rocks, in Feejees, 350.
 action of, on coasts of New South Wales, 109, 532.
 action of, on New Zealand coasts, 109, 442.
 action of, on bluff, near Rio Negro, 608.
 sands of shores of, 108, 149.
- Sea-beach, at the mouth of Rio Negro, 606.
 coral rocks of, 39, 43, 45, 64, 148, 253.
- Sea-bottom disturbed by waves at great depths, 105.
- Sea-shores, trituration action of sands of, 108, 149, 525.
- Sea-shore platform of coral islands, 109.
 of New South Wales, 109, 532.
 of New Zealand, 109, 442.
- Sea-water, gypsum deposited from, 91, 589.
- Sediment, various characters of, in channels among reefs, 42.
- Seleniferous sulphur, 203.
- Serpentine in Northern California, 634.
 relation of, to other rocks, 630, 636.
- Shale, tertiary, of Oregon, 652.
- Shells, at the top of the Callao cliff, 590.
- Shells, fossil, see *Fossil*.
 worn out by trituration on a beach, and often rare in beach formations, 46, 108, 149, 525.
- Shepherd, on Kilauea in 1839, 188.
- Siau, action of waves on sea-bottom, 105.
- Siliceous concretions in soil, near Paramatta, New South Wales, 516.
 see farther, *Concretions*.
 depositions, New Zealand, 447, 448.
 incrustations, from decomposing lavas, Kilauea, 181, 201.
- Silicified wood, Australia, 484, 491.
 in Oregon and California, 658, 669.
 in Chili, 584.
 on Luzon, 542.
- Silliman, B., Jr., analysis of coral chalk, 150.

- Silliman, B., Jr., analysis of coral rock from Matea, 153.
 analyses of corals, 151, 152.
 analysis of coral sand from the straits of Balabac, 153.
 analyses of capillary glass and lava from Kilauea, 200.
 analysis of sal ammoniac from Kilauea, 202.
 analysis of blue sulphate of copper, 202.
 examination of ferruginous stalactites from Kilauea, 201.
 analyses of aluminous stalactites of Mount Loa, 207.
 analysis of Mautilite, 230.
 analyses of aluminous stalactites of Upolu, 324.
 analyses of Australian coal, 476.
 analysis of limestone concretions of Oregon, 657.
 analysis of a feldspathic mineral from Upolu, 732.
- Siphonotreta curta, 685.
- Slope of Andes, 612.
 of Chimborazo, 170.
 of Etna, 170.
 of Kahoolawe, Lanai, and Molokai, 232.
 of Maui, 227.
 of Mount Loa, 169.
 of Teneriffe, 170.
 of Rocky Mountains, 612.
 of flowing lava, 356, 357.
 of volcanic cones, 354, 355, 356.
- Society Islands, 285.
 Eimeo, 285, 302.
 Tahiti, 286.
 Tahaa, 285, 304.
 Raiatea, 285, 304.
 Huahine, 285, 303.
 Borabora, 285, 304.
 Maurua, 285, 304.
 general character of, 304.
 reefs and harbours of Tahiti, 41, 116, 117, 138.
 evidence of change of level at, 397, 404.
- Soil, red, from basaltic decomposition, 266, 274, 299.
- Solemya ventricosa, 723.
- Solecurtus ellipticus, 686.
- Solecurtus planulatus, 686.
- Solen ellipticus, 686.
- Solfatara, Kilauea not, 205.
- Sooloo Islands, notice of, 539, 544.
 reefs of, 142.
 curved range of, 419.
- Soundings near coral islands, 55, 56.
- Specific gravities of rocks in the Pacific, 732.
- Spirifer antarcticus, 685.
 avicula, 685.
 Darwinii, 684.
 duodecicostatus, 684.
 glaber, 683.
 Hawkinsii, 684.
 oblatum, 684.
 paucicostatus, 684.
 phalæna, 685.
 subradiatum, 684.
 vespertilio, 685.
- Sphenopteris lobifolia, 751.
- Spout-holes, see *Blow-holes*.
- Spring, chalybeate, in the Shasty Mountains, 643.
 hot, of Feejees, 343.
 of Luzon, 543.
 of New Zealand, 445, 447.
- Stalactites, aluminous, of the summit of Mount Loa, 207.
 in cavern on Upolu, 323.
 ferruginous, volcanic, 201.
 calcareous, coral islands, 67.
- Steatite in Northern California, 633.
- Steel, J., section of coal strata, Newcastle, 474.
 faults in the coal beds of Newcastle, N. S. W., 477.
 fossil fish, discovered by, 482.
- Stevenson, T., force of waves, in transporting rocks, 106, 112.
- Stewart, C. S., columns of lava at Kilauea, 178.
 on Kilauea in 1825, 185.

- Stewart, C. S., on Kilauea in 1829, 186.
- Stilbite, at Nassau Bay, 605.
- Stratified structure of Madeira, 296.
of the walls of Kilauea, 174.
- Structure of earth's crust, 426.
columnar, see *Columnar*.
concentric, see *Concentric*.
lamellar, see *Laminated*.
- Strzelecki, P. E. de, Kilauea in 1838, 187, 188.
height of Kilauea, 166.
heights of the mountains of New South Wales, 450.
- Stutchbury, S., depth of growing corals, 98.
observations on the rate of growth of zoophytes, 102.
height of Rurutu, 405.
- Subsidence, coral reefs, evidence of, 125, 393.
bay indentations, evidence of, 393, 397, 675.
along Hawaiian and other Pacific ranges, 396, 397, 398.
at island of Banabe, 400.
in Pacific, axis of area of, 398, 432.
extent of, 399.
effects of, 399.
loss of land in consequence of, 129.
about Kilauea, from eruptions, 197.
action of, in causing the forms of reefs and coral islands, 125, 133.
- Sulphur and minerals of Kilauea, 180, 198.
in New Zealand, 446, 447.
seleniferous, 203.
- Swain's Island, 52, 69, 407.
- Swalalahos, an extinct volcano, in Oregon, 643.
- Sydney Island, 72, 407.
- Sydney sandstone, 456.
oblique layers of deposition in, 462.
- Syenite of Chili, 562.
of Tahiti, 295, 364, 733.
of Oregon, 631.
of volcanic centres, origin of, 377.
- Tafoa, active volcano, 25.
- Tahaa, 285, 304.
- Tahiti, general features of, 286.
coral reefs of, 41, 47, 293.
rocks of, 294.
syenite of, 294, 733.
twin character of, 302.
compact non-stratified centre, 296.
no coral on summits of, 299.
ideal sketch of valley of, 388.
evidence of subsidence at, 397.
- Taiara or King's Island, 52, 71.
- Talcosc rocks of Oregon and Northern California, 632.
of the Philippines, 540.
- Tapuaemanu, island of, 285.
- Taputeouea, 51, 54, 64, 409.
population of, 76.
- Tarawan Islands, map and descriptions of, 50.
water in, 76.
- Tari-tari, 52, 76, 113.
- Tchihatcheff, fossil plants of Siberia and age of rocks, 495, 715, 733.
- Teku, or Four Crowns, 70.
- Tellina albaria, 725.
arctata, 725.
bitruncata, 725.
emacerata, 725.
nasuta, 725.
- Temperature of geysers, 203.
of ocean in coral regions, 95, 134.
- Teneriffe, von Buch on, 371.
trachytic centre of, 373.
- Terebratula amygdala, 682.
elongata, 682.
nitens, 726.
- Terraces in Oregon and California, 659, 670.
- Terraces, origin of, 671.
- Tertiary or recent deposits of Rio Negro, 608.
of Callao, 587.
- Tertiary of Oregon, 651, 669.
- Tertiary fossils of Oregon, 722.
- Tetuaroa, 285.
- Thracia trapezoides, 723.

- Tierra del Fuego, observations on the vicinity of Nassau Bay, 601.
fossil belemnite of, 604, 720.
- Tinakoro, an active volcanic island, 25.
- Tonga Islands, 138, 406.
Tongatabu reefs, 39, 406.
coral mud of, 63.
- Trachyte and pumice, Feejees, 346.
- Trachyte of the Sacramento Bute, 650.
- Trachytic rocks, Nassau Bay, 604.
of Teneriffe, 373.
- Trends of Pacific islands, 414.
of ranges of islands along the Asiatic coast, 419.
in the Atlantic and on the continents, 422.
- Trigonia Lorentii, 721.
- Tubuai, 285, 405.
- Tufa of Feejees, 346.
of Hawaiian Islands, 239, 260, 268.
of Madeira, 551.
of Manilla, 541.
of Oregon, 652.
of Tahiti, 295, 302.
of Upolu, 316.
- Tufa craters of Hawaiian Islands, 237, 240, 260, 271.
of Samoan Islands, 325, 333.
of Tahiti, 302.
general characters of, 355.
chalky coating on layers of, 241.
containing coral, 244, 327.
- Tutuila, 309, 733.
- Tyerman and Bennet, mountains of Tahiti, 288, 289.
a slide in the Matavai Valley, 293.
on Rurutu, 405.
- Umpqua district, 622.
- Upolu, general features of, 312.
volcanic cones of, 313.
fountains on shores of, 314.
rocks of, 315.
dikes in, 317.
extinct craters of, 317.
caverns in, 323.
era of eruptions, 330.
- Upolu, changes of level, 332.
reefs, thickness of, 47.
harbour of Apia, 115.
harbour of Falifa, 117.
- Urosthene australis, 681.
- Valleys of the Pacific islands, origin of, 79.
due to running water of the land, 384.
action of the sea in producing, 381.
deeper on the older islands, 384, 391.
of Madeira, 549.
of New South Wales, 450, 526.
of Oahu and Hanapepe, 236, 263, 385.
of Tahiti, 287.
of tufa cones of Oahu, 240, 388.
- Val-del-Bove, exemplified in Kilauea and Hale-a-kala, 363.
- Valparaiso, 558.
- Vancouver, Cowlitz and Nisqually districts, 621.
- Vegetation, height of, on Mount Loa, 167.
height of, on Mount Kea, 167.
- Vanikoro Group, reefs of, 140.
- Vanua Lebu, 341.
- Vavau, 406.
- Veins, in granitic rocks of Chili, 562, 565.
of hornblendic schist, 578.
- Venus angustifrons, 724.
bisecta, 724.
brevilineata, 724.
lamellifera, 724.
- Vincennes Island, 61, 74.
- Viti, see *Feejee*.
- Viti Lebu, 339.
- Volcanic action and eruption of Mount Loa, mode of, 216.
and boiling process at Kilauea, 171, 173, 176, 193, 203, 223.
phases of, 222.
promoted by fresh waters, 221, 368.
seldom promoted by pulsations in the central igneous fluids of the globe, 369.
flames during, 184.
views of G. Bischof on, objected to, 369.

- Volcanic action, C. Prevost on, 372.
 source and mode of, 366, 367.
 cinders, not forming cones at Kilauea, 193, 194, 358.
 source of, and height of ejections of, at some volcanoes, 194.
 not forming the summit of Mount Loa, 216.
 conduits possibly closed below, 220.
 cones, of cinders, characters of, 354.
 of tufa, characters of, 355.
 of lava, characters of, 356.
 formation of, 222, 260, 366, 367.
 slopes of, 169, 354, 355, 356.
 angle of descent of flowing lavas of, 210.
 effects of fluidity of lavas on forms of, 358.
 other causes of forms of, 360, 367.
 not always centres of eruption, 214.
 elevation theory of von Buch, considered, 369, 370.
 on solid feldspathic centres of, 203, 204, 364, 368, 373.
- Volcanic eruptions of the summit of Mount Loa, 208.
 quietness of, 195, 210, 216.
 of Kilauea, see *Kilauea*.
 of Hualalai, 215.
- Volcanic forces, isolation of lines of, 198, 218, 368.
 a cause of valleys, 380.
- Volcanic glass, capillary, of Kilauea, analysis of, 199, 200.
 regions, dislocations in, rare, 361.
 rocks, see *Rocks*.
 sand-hills, Nanawale, 190.
 salts, Kilauea, 201.
 scoria, absence of, from fissure eruptions, 200.
 origin of pumice, 201.
 ferruginous stalactites, 201.
 theory of lagoon islands, 123, 124.
- Volcanoes, general considerations on, 193, 216, 353.
- Volcanoes, ebullition in craters of, producing a distribution of material, 203, 375.
 not safety-valves, 221.
 closing without leaving a crater, 215.
 cause and length of periods of quiescence, 198, 367.
 cause of nearness to the sea, 429.
 in the Pacific, number of active, 25.
- Volcano, of the Sacramento, extinct, 649.
 of Deception Island, 547.
 of Savaii, 333.
 of Mount Loa, 168, 206.
 of Kilauea, see *Kilauea*.
- Volcanoes of New Zealand, 438, 442, 447.
 of Australia, 453.
 of Oregon, 640.
 of the Philippines, 539, 541.
 of the Sooloo Group, 544.
 extinct, of Upolu, 313, 317, 325.
 of Maui, 227.
 of Koloa, Kauai, 271.
- Wallis's Island, 128.
- Warm spring, at Kailua, Hawaii, 215.
 in Feejees, on Vanua Lebu, 343.
 on Luzon, 543.
 in New Zealand, 445, 447.
- Washington Island, 56, 70, 405.
- Wateoo, 404.
- Water, degradation from running, 384, 386.
 force of, 386, 388.
 agency of, in forming valleys in Australia, 528.
- Water, fresh, on coral islands, 76.
- Waterland, 61.
- Waves, action of, on sea-bottom, 105.
 action of, on coasts, 109, 110, 442, 532.
 force of, on coasts, 106, 112.
- Whittle, J. S., on Deception Island, 547.
- Whytuhu, 71.
- Willammet district, 619.
- Williams, elevation of Mangaia, 404.

Entered

- Wilton, C. P. N., siliceous stumps in Australia, 484.
- Woahoo, see *Oahu*.
- Wolchonsky, island of, 54.
- Wollongong Rocks, 485.
- Wood, silicified, in Oregon and California, 658, 669.
 in Australia, 483, 491.
 in Chili, 584.
 in Luzon, 542.
- Zeugophyllites elongatus, 715.
- Zoophytes, growth and structure of, 80, 85.
 secretion of coral by, 80, 84.
 budding of, 83.
 forms of, 84.
 Alcyonacea, 87.
 Hydroidea, 88.
 Bryozoa, 88.
 causes influencing growth, 93.
 depths of growing, 97.
 rate of growth of, 101.
 distribution of, 95, 134.

THE END.

SMITHSONIAN INSTITUTION LIBRARIES



3 9088 00559 4148