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ART. XXVIII.—*A dissected volcanic Mountain ; some of its revelations ;* by JAMES D. DANA.

THE island of Tahiti—the largest of the Society Islands—affords excellent illustrations of two widely different subjects :

I. Erosion by running waters ; and

II. The inner structure of a great volcanic mountain.

I have described the features of the island in my Geological Report of the Wilkes Exploring Expedition,* from observations made in 1839, and have pointed out the bearings of the facts on the two subjects, but I give there no map of the topography, or views of the peaks ; and I now return to the subject to add these illustrations with some further remarks.

The island has nearly the shape, as regards outline, of a letter 8, and was once a twin of volcanoes. Only the northern and larger of the two peninsulas is often visited, and of that I speak. It was originally a gently sloping cone of the type represented by the Hawaiian volcanoes ; for its beds of lavas, as seen in the sides of the valleys, slope at a small angle toward the shores ; mostly 3° to 10° —varying in some parts to 15° —on the north and west sides, where my examinations were made. Supposing the mean slope to be 8° the height above the sea-level of the original cone—the diameter of the island being twenty miles—would have been nearly 7500 feet. But

* Pages 283 and 386 of the quarto volume (of 756 pp. with a folio Atlas) published in 1849. See also Abstract of part of the results, this Journ., II, ix, 50, 1850.

the slopes above may have been steeper and the height much greater. The greatest height at the present time according to an imperfect measurement made by Lieut. W. M. Walker, U. S. N. (who took as a base a line measured on the coral reef near Matavai) is about 7000 feet.

The old cone is now a dissected mountain. Valleys cut profoundly into its sides, and lay bare the center to a depth of from 2000 to nearly 4000 feet (by estimate) below the existing summit; and the deep valleys so crowd on one another that the dissection is complete.

The topographic features of the island are shown on the accompanying map. This map is a copy in the main of that in Captain Wilkes's Narrative of the expedition. "In the main," I say, because I have made changes, removing some of the imperfections introduced by the art of the map-maker or engraver and his want of knowledge of the region. I should not have taken this liberty were it not that part of the map was originally from a sketch of my own, communicated to the Hydrographic department of the Expedition. My sketch comprised the northern third of the island, from the center outward, between the Papenoo and Punaavia valleys,* and was prepared from personal observations in the valleys of the region, and on an ascent of Mt. Aorai, one of the two highest peaks. Being the only person of the Expedition that made the ascent, no other one had the opportunity for so comprehensive a view of the ridges and valleys of that part of the island.* Of the central peaks, the highest, at *a* on the map, made 7000 feet in height by Lieut. Walker's measurement, is called *Orohena*; the next highest, about 500 feet lower, at *b*, is the one called *Aorai*.†

I. Erosion.

As the map shows, the island in its present condition is an admirable model of a deeply denuded or water-sculptured mountain cone. To appreciate the precise conditions under which the denudation went forward it has to be borne in mind that the waters from the rains and clouds are most abundant about the summits and higher portion of the island, and are there perpetually at work. In these upper parts, therefore, or above 1500 feet, forests and shrubbery cover the ridges and valleys wherever there is a foothold; but toward the coast, or

* On the ascent and at the summit I took some bearings, but I made no attempt at a trigonometrical survey, and the map is still unsatisfactory in its minor details; but it well illustrates the points in view.

On the excursion I had with me only two Tahitians. The ascent was made after Captain Wilkes had left Tahiti with his vessel, the *Vincennes*, and hence the mistaken statement in his Narrative that I was accompanied by others of the expedition.

† These words are pronounced O-rò-he-nàh and Ow-ry.

below a level of 1000 to 1500 feet, the slopes, down to the grove-clad border-plain of the island, are grass-covered and look bare in the distant view.

1.

Map of Tahiti, the coral reefs excluded; the lower side is the northern, or that toward the equator: PP, village of Papenö; M, of Matavai; P, of Papaua; T, of Toanoa; P', of Papieti, the largest; P'', of Punaavia. The valleys are named from the villages on the coast at their termination.

The following are the features due to the erosion :

- (1.) The ridges and valleys are arranged nearly radially.
- (2.) The highest peaks are about the center.
- (3.) The valleys terminate for the most part near the sea-level instead of extending deeply beneath it, as shown by the

fact that the outline of the island is nearly even, instead of being indented with deep bays.

(4.) The larger of these valleys abut at their heads against the central peaks in lofty precipices—precipices of two to nearly four thousand feet. Some of the larger valleys are widest at the center of the island and terminated under the peaks in vast amphitheatres.

(5.) The ridges toward the borders of the island are somewhat broad-backed, but, over the interior, very narrow. Above an elevation of 3000 feet or so (as I found in my ascent), the top edge of the ridges for much of the way is but three or four feet wide—too thin to be represented on a map of so small scale as the above; and in some spots it diminishes to a foot, and even, at times, to a thin edge of bare rock; and from the crest the declivities either side pitch off steeply 1000 to 2000 feet.*

(6.) Within a mile or two of the central peaks erosion has reduced the height of some of the narrow ridges a thousand feet or more, or still further lowered and thinned them until dwindled to a mere pinnaced wall at the base of the peaks.

2.

The "Crown" at the head of the Papiete Valley.

A view of a portion of one of these thinned-down ridges, called, on the island, the Crown, I here introduce from my note-book.† The ascent of one of the highest peaks is possible only along a ridge that has kept unbroken its connection with the summit, and an experienced guide is needed to make sure of the right and safe way.

My own ascent of Aorai was made by the ridge that forms the west side of Matavai Valley (the valley which terminates

* The chief error in the map as published in the Narrative arises from the covering of the ridges with the conventional hachures for vegetation—these giving them a width of a fourth to half a mile instead of a yard or two. The top edge is covered with shrubbery, and it serves the mountaineer a good turn by shutting from view the steep slopes alongside.

† The "Crown" is at the head of the Papiete Valley, between it and the Puna-avia Valley.

at M on the map); and my return was by the west side of the Papaua Valley, that next west of the Matavai Valley. The top of Aorai was found to be "not six feet broad; beyond it, the mountain ridge continued for a short distance, with the same sharp, knife-edged character, and then was broken off by the Punaavia valley," while "at its western foot appeared 'The Crown.'" Across a valley, 3000 to 4000 feet deep, stood Orohena, only two miles distant, with nearly erect sides and equally sharp crest; and similar features characterized the other ridges in the panorama.

I refer the reader to my Expedition report for the details, and for a discussion on valley-making about volcanic mountains and elsewhere, including the formation of the amphitheatres and a detailed description of the steps in the progressing erosion changing the finished volcanic cone into a Tahiti, illustrated by facts from Hawaii and elsewhere. "Mount Loa, alone, contains within itself the material from which an island like Tahiti might be modeled that should have nearly twice its height and four times the geographical extent." (Rep., p. 392).*

II. *The inner Structure of a great Volcanic Mountain.*

The above facts with regard to the dissected island have their chief interest as an introduction to the second subject of my paper—*The inner structure of a great volcanic mountain.* The profound dissection has laid open the island to its very core, and to a depth below the *original* summit of certainly more than 4000 feet. If, as we may suppose probable, the old cone had, like Mt. Loa or the Maui volcano, a great pit-crater at top, the interior must be open to view for at least 3000 feet below the bottom of the crater.

Although my time at the island did not allow of a thorough exploration of the central region, one point of fundamental significance was made out, and put beyond question: that the mass of Orohena was not composed of beds of lava. There were no horizontal (or nearly horizontal) lines or divisions. Instead, there were vertical lines indicating vertical joints or an imperfect columnar structure, in the unstratified mass; and this was true for the mass to the very top.

* Descriptions of the results of erosion are given in my Report, in connection with the special accounts of several of the islands visited, and of Australia, and in chapters on the origin of valleys, on pages 379 to 392 and 526 to 533. A brief statement of the general results is made in my Manual of Geology, p. 642.

A similar history of the process with similar descriptions of "knife-edged ridges," amphitheatres, etc., is contained in Capt. Dutton's Report on the Hawaiian volcanoes, published two years since by the U. S. Geological Survey. As he makes no mention of my volume, or even of its title or its author, in his work, I may add that his readers can at least supplement their knowledge on the subjects treated by consulting my report of thirty-seven years since.

This remarkable feature has been little appreciated notwithstanding my report on the facts. I was recently gratified to find that I could fortify my descriptions by means of outline sketches of Orohena from my note-book of 1839, which have

3.

4.

Sketches of Orohena as seen on the ascent of Aorai. Orohena, the highest summit; the other peak, to the left, Pitohiti.

till now remained unpublished. The views were taken from points toward the top of Aorai when on my ascent. They are closely alike, but differ enough (because taken from points of different elevation) to corroborate one another. They show no horizontal lines and place the fact of their absence beyond question. In that region of luxurious tropical growth, had there been distinct bedding in the face of Orohena, unequal erosion would have made recesses and projecting shelves, and occasioned corresponding lines of shrubbery; and even if the faintest horizontal divisional planes existed, the oozing out of waters would have produced bands of green from the growth of mosses and other vegetation. But there were no shelves, or bands. The surface in view was nearly bare of vegetation.

Such features are in striking contrast with those observed in

the lower or outer part of the mountain. Toward the coast stratified lavas are seen along the valleys, and the layers are usually but twenty feet thick or less. The vesicular lavas, the larger part a chrysolitic basalt, alternate with layers of tufas and conglomerate. But five or six miles up one of the valleys (the Papenoö), the layers of lava were much thicker, and, as my Report states, some bluffs a thousand feet in height constitute apparently a single bed, and are more or less columnar throughout. This greater thickness of the beds on approaching the center appears to show that the eruptions were far more copious early in the history of the volcano than they were later. But this is not an explanation of the massive structure of Orohena. The uniform massiveness through so great height at the volcano's center has plainly come, as I long since stated, from the cooling of continuously liquid lava at the center, or in the region of the great central conduit of the cone.

We appear to have an explanation of the facts, or a suggestion toward an explanation, in the condition of Mount Loa, on Hawaii. At the beginning of one of its great eruptions the central mass of liquid lavas stands at a height of more than 12,000 feet above the sea-level; and the breadth of the liquid mass at top, if of the size of the crater (as it sometimes has been), is over 8,000 feet. To appreciate the conditions it is to be considered that the summit-crater of this great volcano has been in eruption on a grand scale *eight* times since 1843,—the last time in 1880–81; or, on an average, once in five years; and that the fires at some of these times of activity have continued active, at heights of 10,000 to 12,000 feet, for 10 to 18 months. A mass of liquid rock at the mountain's center 10,000 to 12,000 feet high above the sea level and at least 5,000 feet in breadth near the top is not an exceptional condition in the volcano; it may be often true.* If 5,000 feet broad at top, the breadth would be greater below as it descended toward the deep region of continuous or wide-spread liquidity. Suppose such a mountain to have its last eruption and then to cool off, and become extinct. The central liquid mass, in such a case might perhaps retreat downward as a consequence of escape, either outside or subterranean, and a great cavity be left. But if pressure from below and resistance to fracture should hold the lavas to their place, as it did in the case of the ejections making the laccoliths of the Gilbert Mountains described by Professor Gilbert, they would cool there, and the liquid central mass would become the solid central mass.

* On the size of the crater (called Mokuaweoweo) and the height of the mountain, see page 235 of this volume; and on the area of sinking, and therefore of liquid lavas, in Kilauea at one of its eruptions, see the last volume. p. 398.

It can hence hardly be doubted that a massive central structure, like that revealed in the dissection of Tahiti, is a common feature of the *greater* volcanic mountains that have become extinct.

The slow cooling, extremely slow, on account of the magnitude of the mass, and under great pressure moreover, would have caused the lava to solidify into a *compact* crystalline rock, and often into a *coarsely crystalline* rock.

I found evidence of the massive condition and slow cooling of the rocks of the interior of the island in one of the valleys leading to the center. Up the Papenoö Valley six to eight miles from the coast, along the stream, I found many worn masses of a whitish granite-like dioryte.* It had evidently been brought down the valley from one of the central peaks at its head, either Orohena or an associate; and the conclusion seemed to be unavoidable that the difference between it and the lavas below in compactness and grade of crystallization was due to difference in pressure and rate of cooling; and I say (Report, p. 377) that although the liquid rock of volcanic outflows generally cools without distinctly visible crystallization, or with only crystals of feldspar, or of augite, in a compact 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," and I add further: "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." In this way I explain the formation of the dioryte, a hornblende rock. I thence remark (p. 378): "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."†

This conclusion had not a full basis of facts; for I had not collected specimens from the bases of those central peaks. But it was right, as I have believed ever since the visit to Tahiti and

*The rock is called syenite in my Report; but I describe the feldspar as near albite, recognizing thus its triclinic character. I give the specific gravity as 2.73. My excursion up the valley was cut short by a circumstance beyond my control and hence the specimens were not traced to their source. The specimens I left in 1844 in Washington, where they were deposited under Government orders.

† The same chapter in my Report (p. 375) contains a suggestion as to the increase in the feldspathic character of the lavas in the central conduit of a volcano through a prolonged liquation-process, which has not been sustained by facts.

Hawaii in 1839 and 1840. The idea is now no longer a half-studied conclusion, but, thanks to the elaborate investigations of Messrs. Hague and Iddings, and of Allport, Judd and others, it is an *established* fact in the science of igneous rocks.*