THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. X.—*Points in the Geological History of the islands* MAUI *and* OAHU; by JAMES D. DANA. With Plates III and IV.

THE subjects prominently illustrated by the islands Maui and Oahu are: the conditions of extinct volcanoes in different stages of degradation; the origin of long lines of precipice cutting deeply through the mountains; the extent and condition of one of the largest of craters at the period of extinction; and the relation of cinder and tufa cones to the parent volcano. The other islands of the group present facts bearing on these subjects, but the writer's knowledge of them is too imperfect for review in this place.

I. ISLAND OF MAUI.

The accompanying map, Plate 3, reduced from the recent large government map,* shows the general features of the island of Maui:

(1) The volcanic mountain of East Maui, Haleakala, 10,032 feet in height, having at summit, a crater 2500 feet in greatest depth and twenty-three miles in circuit.

* On this Plate, as on that of Hawaii in the last volume of this Journal, most of the lettering of the original map is omitted, with necessarily also minor details as to erosion and topography.

(2) The abrupt depression of Kipahulu, to the southeast of the summit, surveyed but not geologically studied, which looks as if it were the site of another great crater.

(3) The slopes of eastern Maui, little gullied by erosion, but most so on the side facing northeast—the windward side; and here the longest valleys scarcely reaching to the summit.

(4) The mountain of west Maui, a volcano in ruins, being profoundly cut up by valleys, and the original height reduced to 5788 feet as the maximum.

(5) The low intermont area of Maui, made of the united bases of the two volcanoes, but covered for the most part by the lava-flows of Haleakala, whose fires continued in action long after the western volcano was turned over, dead, to the dissecting elements; the width from north to south at the narrowest part, near the line reached by the lavas of Haleakala, about six miles, and the height at the survey station near its middle, 156 feet.

From my use of the maps of the Hawaiian government survey through the preceding memoir, and my frequent reference to them for facts about the volcanoes, craters and lava-flows, as well as the topography of the island, it has been apparent that they have been a very prominent basis for the conclusions presented. The government map of Maui has still greater geological importance; for Prof. Alexander, the surveyor-general, has made it, by his accurate work and his appreciation of the importance of details, a contribution to science of the highest value and interest. What I have to say of the extent, depth, form and discharge-ways of the great crater, of the heights and positions of cinder cones, and of the erosion of the mountains, should be put mainly to the credit of the map, which was Prof. Alexander's work not only in superintendence and geodetic measurement, but largely also in the details of the survey. The survey of the island, which is still in progress, reflects great credit on the Hawaiian people, and we trust it may be continued until in all parts complete. Every cone, or precipice, or fissure, terrace-level, or lava-stream located is a contribution to the history of the island and to physical and geological science.*

* I am, moreover, personally indebted to Prof. Alexander's kind providings, guidance and instructions for the success of my trip in 1887 (August 4 to 6) up Haleakala and into the crater, where a night was spent—an exceptionally brilliant night after a day of clear views from the slopes and the summit; and also for my excursion up Wailuku valley on western Maui.

I owed much also, while on the island, to the hospitality of Mr. Henry Baldwin of Haiku, Mr. Edward M. Walsh and Rev. Thomas Gulick of Paia, and Mr. Bailey and Rev. Mr. Bissell of Wailuku.

An excellent model of the island of Maui has been made by Prof. C. H. Hitchcock, who devoted much time to it during his recent visit to the Hawaiian Islands. The government map was the chief source of data for the details. The verti-

1. *East Maui.*

I. *The Mountain.*—The crater of Haleakala has been many times described, but first with a detailed map in illustration by Captain Wilkes. Captain Wilkes states that he is indebted for the map to his artist, Mr. Joseph Drayton;* and considering that it was from an artist's survey, not that of a surveying party with instruments, it is a remarkable piece of work. The expedition owes much to Mr. Drayton, not only for his excellent labors as draftsman in all departments at sea, but also, after his return, for his management of engravers, printers, etc., during the publication of the various Reports.

The mountain is usually ascended from Paia, a village on the north coast. The path (see map) passes Olinda and reaches the edge of the crater where the nearly vertical western wall bounding it is not less than 2500 feet in height. Thence it follows the summit southwestward to the southwest angle passing Pendulum Peak† on the borders of the crater just before reaching it. Here are three cinder cones, and the top of one is the culminating point of the mountain, 10,032 feet above tide. They stand at the head of a long line of cinder cones extending southwestward down the mountain to the sea; and near the sea at the foot of this line are three or four comparatively recent lava-streams, enough to illustrate the process of seashore extension by such sea-border outflows. From the southwest angle of the crater and the base of one of the three cinder cones, a cinder-made slope of rather easy grade descends into the crater, making a convenient place of descent; and thence the path continues eastward to the usual place of encampment, 4½ miles from the top.

2. *The two great discharge-ways of the crater.*—Besides its lofty walls and great area, the most remarkable features of the crater are the two openings, a northern and a southern, a mile to a mile and a half wide between precipitous walls of rock—the walls of the northern 2,000 feet and over, of the southern, 1,000 to 2,000 feet—through which poured the lava of probably the last of the great eruptions. The Kaupo lava-stream, the southern, has much the smoother surface, as if more recent; but the broader Koolau stream descended the *wind-*

cal height is increased four times, and the craters and valleys are thus strongly brought out. All such exaggerated relief maps, whether of a mountain or sea-basin, need a note of warning attached to prevent wrong conclusions as to slopes and heights; for the ratio of 4 to 1 instead of 1 to 1 changes a slope of 14° to one of 45°, a low to an acute cone. The light shading used on the map of Hawaii in the last volume of this Journal and here on that of Maui, is intended to bring out the idea as nearly as may be of a mean slope of 7 to 10 degrees.

* Wilkes's Narrative, vol. iv, p. 255. In the Exploring Expedition I had no chance to visit Maui, and saw it only from ship-board when passing it.

† The Pendulum station of Mr. E. D. Preston, of the Coast Survey, in 1887 This Journal, last volume, page 305.

ward slope, and the consequent erosion may have made all the difference.

3. *The Cinder-cones and Lavas at the bottom of the crater.* —Another striking feature of the crater is the group of red and gray cinder-cones which stand over the bottom, sixteen in number; the highest 900 feet above its base and all over 400, and yet looking small in the view from the summit of the great area. The sight to the northward, when half way to the bottom, comprising the northern discharge-way in the distance, the highest of the cinder-cones in the foreground, and beyond these and two other cones the broad stream of lava of the crater-floor as level apparently as a river, stretching away between precipices of more than 2,000 feet and then terminating in an even line at the limit of vision as if there began the plunge to the sea, is wonderfully like the real river of lava on its downward way.

The cinder-cones of the bottom were evidently the last work of the fires. The ashy surface of the cones is without a trace of erosion and thus bears no distinct marks of age. The slopes are mostly 25° to 30° and less, and hence they may have had the pitch diminished somewhat by the winds and rains and earth-shocks, but there are no channelings by descending waters. The material is scoria in coarse fragments and sands, and though in part originally reddish and purplish, the red color has generally been deepened by oxidation from exposure.

Besides the scoria, there are on some of the cones, especially those toward the borders of the pit, numerous large blocks of gray, compact, scarcely vesiculated rock. Some of the masses about a cone near the place of descent measured over a hundred cubic feet. The masses must have been torn off from the throat of the volcano's conduit, this being the only conceivable source. They indicate therefore the action of vast projectile force at these isolated centers when the cones were in progress, and its continuation even to the close of the ejections; and they also are probable evidence of very rapid work in the cone-making. A few of the other cones were grayish in color as if from the abundance over their slopes of these projected grayish stones; but I was unable from want of time, to verify this supposition.

The cones stand, or appear to stand, on the rough, fresh-looking, scoriaceous lavas of the bottom, these lavas spreading away from beneath them. It was evident that the opened fissures or vents which gave exit to the cinders, first poured out the lavas; and then followed the cinder ejections as the fires declined and the liquid lavas of the vent became somewhat stiffened. The cinder material is proof of powerful projectile work; for the fragments of the exploding bubbles were thrown upward, as the heights of the cones prove, many hundreds of feet—more than nine hundred to make the highest cone.

The fresh-looking lavas, occurring about the base of the more western of these cones, were found to continue eastward throughout the crater, with little change of features and with the same relation to the bases of the several cones, as if all were of one epoch of eruption—the epoch of the last outbreak of Haleakala; the lavas seemed to have come from the latest outflows of several subordinate vents, after the crater had made its great discharge through the two gateways down the mountains.

This scoriaceous lava of the crater contained in many places much augite and chrysolite in largish grains or crystals, being both augitophyric and chrysophyric.

4. *Lavas of the walls and summit.*—The lava of the walls was in part scoriaceous; but, where examined on the south and southwest sides, it was commonly a very compact, rather light gray variety of basalt, like that of the projected blocks about some of the cones. The layers of compact basalt had often one or more parallel planes of fine or coarse vesiculation, sometimes at intervals of one to three or four feet.

At one locality on the ascent of the mountain the solid gray rock had been found to be a convenient stone for stone implements of various kinds, and a large manufacture had apparently been carried on there; and yet near by, the lavas that were so solid had occasional planes of coarse vesiculation, each one to three or more inches thick. Pendulum Peak, near the summit, just north of the southwest corner of the crater (the place of descent) consists largely of this compact light-gray basalt, with rarely any vesiculation visible without the aid of a pocket lens.

This compact basalt or doleryte is a common rock also over the lower slopes toward Paia. It appears thus to be to a large extent the material of the older lavas; yet not only of the older. But at the summit on the west side, along the two miles passed over before reaching the place of descent, the compact variety of the basalt was rather the exception. There were large areas of the same scoriaceous lava that covers the bottom of the crater, and in some places it was equally augitophyric and chrysophyric, the augite in well-defined crystals. One of these areas was just north of Pendulum Peak; and a large region on the west border of the crater, looked as if successive streams of lava had recently flowed one over another, piling up layer on layer, so that by this means the surface for a breadth of a mile or more westward from the summit line had derived its unusual steepness of 15° to 16°. The lava-streams of the surface had the appearance of being overflows from the crater; as if the great pit had been full to the brim before the outbreak and had poured out from time to time small streams like those of a full lava-lake in Kilauea. But they more probably came from fissures cut through to the summit at the time of the last or some one of the later eruptions.

The fact that lavas of the summit are so very chrysolitic, even at a height of nearly 10,000 feet, has an important bearing on the question as to the effect of high specific gravity in determining the distribution of materials in liquid lavas.

Crystals of augite and large grains of chrysolite are common in the loose material at the base of the cinder cones at the summit, near the place of descent, and colored glassy crystals of labradorite occur with them—facts first learned from Rev. T. L. Gulick after our return. These summit cones have the recent appearance and other features of those over the crater's bottom, and appear to be of the same series and time of origin; and the cinder-slope of that side of the crater was probably made in part from the ejections of these summit cones.

5. *The probable nature of the last eruption.*—The great discharge-ways of Haleakala, one to one and a half miles wide, with the walled valleys confining them, look as if the results of enormous rents of the mountain, made when the mountain emptied itself by the wide channels. But they may have been in existence before, and have been simply used for the last of the outflows. They are, nevertheless, evidence of rents at some time, and of a vast amount of removal of material some way—by subsidence, or otherwise. The height of the walls at the gaps, 2000 feet and over at the Koolau gap, and 1000 and over at the Kaupo, are a minimum measure of the amount of material removed. In my Exploring Expedition report I suggest that the mountain was fissured across along the lines of the two discharge-ways, and the eastern block shoved off a mile or two. But a subsidence of the masses that occupied them into caverns below, leaving the walls as fault planes, may be more probable. The abyss which received them in this case had been prepared during a long period of undermining through ejections. Still there is some reason to believe in the grander view of a subsidence of the whole eastern block, after the cross-fracturing. The island, as is seen on the map, is abruptly narrowed (instead of widened) at the spots where the Koolau and Kaupo streams reach the sea; and the part to the eastward is small, as if narrowed by such a subsidence. Moreover, the mean height of the eastern crater-wall is lower than that of the opposite or western by 500 to 1000 feet. A subsidence of 1000 feet increasing in amount to the eastward would account for the narrowing and for the very short eastern radius of the eccentric volcano. The question merits consideration.

The evidence that the lavas were discharged in both directions at once at the last eruption consists in the nearly uniform appearance of the fresh lavas over the bottom of the crater from one end to the other, and their continuing into and apparently being the streams that descend the Kaupo and Koolau discharge-ways. Mr. J. M. Alexander has remarked that the crater is probably a double one, a combination of two great craters, as Mokuaweoweo at the summit of Mt. Loa is compound in structure. This is no doubt historically true; but at the latest of the eruptions there was probably one action over the whole, the distinction for the time obliterated.

The period of the last summit eruption is unknown. I learn from Mr. Bailey of Wailuku, Maui, that, according to an island tradition, a *lateral* eruption of the mountain occurred about 150 years since in the district of Honuaaula of the southern part of East Maui, at an elevation above the sea probably of about 400 feet.

6. *Activity of the Crater ending in Cinder-ejections.*—The origin of the *crater* of Haleakala needs, I believe, no explanation beyond that given in the remarks on the origin of craters generally: that a volcanic crater and the mountain containing it commence to form together about an opened vent which discharges both vapors and lavas; that the crater is a result of the projectile action and the discharge of material from below, and generally also of subsidence into the cavity which is made by the discharge; and that it does not become closed before the central vent ceases to discharge, and commonly is not then closed.*

Haleakala is an example of a basaltic volcano which reached its end, through declining fires, in cinder ejections; but it left its great crater open, and 2000 to 2500 feet deep, with the greater part of the bottom free from the cinders notwithstanding the amount discharged. The latest down-plunge or subsidence by which the vast pit and perhaps also its discharge-ways were made, may therefore have filled full the empty subterranean chambers which former outflows had produced, and left the mountain solid instead of hollow. Mt. Kea on Hawaii, 13,805 feet in height, also ended its work with cinder eruptions; but the ejected material of lavas and cinders obliterated so far the old crater that no visitor of the region has yet found traces of its former limits. Whether Mt. Kea is a hollow mountain or not remains to be ascertained.

Since the above was written, the results of the pendulum investigations of Mr. E. D. Preston at the summit of Haleakala have been made known in a paper published in the number of

* This J., xxxv, 33, Jan. 1888. The view is the same published in my Exploring Expedition Report, 40 years since.

this Journal for November last,* and have afforded unexpected evidence on these doubtful points. They have led him to the important conclusion that "the density of the mountain is at least equal to its surface density," and that, therefore, unlike some results obtained on the continents, "it is a solid mountain," so that the interior must have been left filled by the subsidence of rock that made the great crater at the summit. He states also that "the zenith telescope observations at the foot of the mountain indicate the same fact."

Mr. Preston states further that at Kohala, on the *north* coast of the island Hawaii, the plumb-line deflections were half a minute *southward*, which, he adds, is well explained by the position to the southward of all the great mountains of Hawaii. He records also that at Hilo, on the *east* coast, the deflection was a fourth of a minute *to the northward.* Mr. Preston remarks that "there is no explanation" of this result at Hilo "unless we assume that the south side of Hawaii, where the volcanoes are active, is much less dense than the north side where the fires have been slumbering for centuries." But to the north of Hilo is a long reach of ocean, the coast of Hawaii there trending northwest; the summit of Mt. Kea, 13,805 feet high, is 25 miles distant and bears N. 75° W.; and that of Mt. Loa, 13,675 feet high, is 35 miles distant and bears S. 63° W.; and the center of gravity of the combined mass (the lowest level over 5000 feet) bears probably a little south of due west. It appears, hence, that we have here evidence that Kea is like Loa, *not* solid; that it is a hollow mountain, as inferred above from the absence of a summit crater; but Mr. Preston is probably right in his inference that Mt. Loa is the more cavernous of the two. Additional plumb-line and pendulum observations are, however, much to be desired.

2. *West Maui.*

West Maui has lost the original slopes of its great cone and its crater through erosion. It has been supposed that remains of three great craters may be distinguished in the mountains: the largest at the head of Wailuku or Iao valley on the north border of which rises the highest peak, Puu Kukui, 5788 feet high; another in the less deep valley of Waihee, just north of this; and a third at the head of the Olowaiu valley, to the south.

I examined only the Wailuku valley, the largest of the three, —so named from the village on the coast near its entrance. The valley is a deep cut into the mountains, remarkably grand in its precipitous walls with thin crested summits. It widens

* Vol. xxxvi, 305.

somewhat toward its head, and in this upper part an extensive plateau occupies the center. The torrent of the valley is here divided between two tributaries, one running either side of the plateau. The height and rather bold sides of the plateau at the head of the valley, and its size and position, taken in connection with its location near the center of the mountain range, appear to make it pretty certain that the plateau represents the floor, or rather what is left of the central area, of the great crater. I looked for the edges of lava streams in the enclosing walls in order to make out their pitch and the thickness of the beds. But dense vegetation so covers everything that distant views are of no geological value, and one day's excursion was not sufficient for a climb of the heights.

As to the former crater condition of the other two valleys mentioned, I know nothing from personal observation. The idea of their having been craters is based on the size, depth, and boldness of the walls and the ampitheater-like head. But these features are common results of denudation in old volcanic islands, and therefore, in the question here considered I give them little weight.

3. *The Eccentric form of the Maui Volcanoes.*

The map of Maui illustrates a Hawaiian feature of volcanic mountains which may be common in other regions. The chief crater of the mountain is not at its center. In Haleakala the ratio of the radii east and west of the crater is 2 : 3; and in West Maui, 8 : 11. The shorter radius is to the south-southeast of the crater in one and to the southeast in the other.

In Hawaii it is not easy to mark off the true base of Mt. Loa. But we have the fact that in both the summit crater and Kilauea, the form is oblong, and each has its intenser activity in the more southern portion—the south-southwestern in one, and the southwestern in the other. The effect is not due to the to the winds, for the mountains consist almost solely of lava-streams.

4. *Drift-made ridge of consolidated coral sand.*

The positions of the high ridge of consolidated coral sand of Wailuku are indicated on the map. Whether proof of elevation or not is yet undecided. I was informed that the sands are at the present time drifted by the trade-winds to the farther inland limit of these ridges and over their surfaces—a fact which seems to show that present conditions are sufficient for their production.

II. Island of Oahu.

From the map of Oahu, Plate 4, it is apparent that the island (*a*) consists of two eroded mountain regions, an eastern and a western, separated by a plain sloping gently downward to the opposite coasts and upward toward the eastern mountains. A more remarkable feature (*b*) is the long and high precipice fronting northeastward, and thus facing the tradewinds. Besides these characteristics (*c*), there are lateral or subordinate volcanic cones on the sea-border, of which Diamond Head and its companions, Punchbowl, and the Koko Head craters on the eastern cape (Plate 4, figs. 1, 2, 3), are examples. The island is the only one of the group that has (*d*) a nearly continuous coral reef fringing the shores. It owes to this reef the harbor of Honolulu, the one good harbor of the group, and also the possibility of a much larger and better one at Pearl River, seven miles west of Honolulu; the cutting of a channel through the reef is all that is needed, as has long been recognized, to make these capacious inner waters available for shipping*. Another interesting feature (*e*) is the existence of an *elevated* coral reef on the borders of the island, having its inner limits approximately indicated on the map by a dotted line.

The facts on which the following account of the island is based and the views deduced from them are for the most part contained in my Expedition Geological Report. The visit in 1840 gave me nearly a month for study, which was industriously employed in excursions over and around the island. The accompanying map, on Plate 4, differs little, excepting in improvement in outline and topography, from the colored geological map of my Report, and the outline of the elevated coral reef and its coral rock and sand bluffs are copied from it. The view of the tufa cones on the same plate are simply new drawings from some of my old sketches. For fuller particulars and some views not reproduced—as those of Kaneohe Point and Aliapaakai, I refer to the Report. My recent visit (in 1887) gave me an opportunity for another excursion around a large part of the island (taken with President Merritt), and

* Honolulu, the capital of the Hawaiian Kingdom, was a collection of thatched huts in 1840, with exceptions only in a Custom House, an unfinished coral-rock church, and a few dwellings of civilized aspect. To-day it is city-like in its houses, its streets electrically lighted, its public squares, large Hospital grounds, spacious Government buildings—among them a palace good enough for any potentate—and its excellent hotel; and, through the addition of groves and avenues of introduced palms and tropical trees (some of which are always in flower or fruit) it is fast becoming a place of ideal beauty. Honolulu is the center of all the island activities, including inter-island navigation. It is not out of place to repeat here that steamers start every week or two for Hawaii and Kilauea—one route by Hilo to Keauhou, and thence up by horseback and wheels, the other by Punaluu on the south coast, where there is a good hotel and a carriage road all the way to the volcano. A carriage road from Hilo to Kilauea is in prospect.

for further explorations, refreshing old memories and adding new facts; and this return to the subject affords an occasion also for reconsidering former conclusions.

1. *Features, structure, and origin of Oahu.*

1. *General features; Contrast with the island of Maui.*—Like Maui, Oahu is in origin a volcano-doublet—that is, as regards rock-structure, it was the united work of two great volcanoes, a western and an eastern. But unlike Maui, its two volcanic cones or domes have suffered so great loss that the position of either crater is wholly a matter of conjecture.

A large part of the loss Oahu has suffered is due to denuding agencies. East Maui, as the map on Plate 3 illustrates, has lost in this way comparatively little of its original evenness of surface owing to the recency of its extinction. Its windward gorges are narrow, and only shallow gulches occur over the leeward surface. The ratio of its diameters at base, 1:1·3, is probably very near the original ratio. West Maui is profoundly gorged on all sides and most deeply so to windward, illustrating results of longer wear than East Maui has had. But something of the old slopes remain, and in the base we have still the ratio of its old diameters, 1:1·4, with the outline little indented. The double lesson is taught: (1) what denudation from descending waters does to a volcanic cone 5° to 10° in slope in the region of the trades; (2) what, on the contrary, the sea cannot do, no encroachments of note existing to attest to its power, notwithstanding the length of the era of denudation.

Oahu resembles Maui in having the western mountain-cone the most time-worn and the smaller in area, but here the likeness ends. Both of its mountains are deeply eroded. Further, East Oahu has only part of its old slopes left. They remain only on its southern, western and northern sides; the northeastern are cut off by the great precipice, twenty miles long, which is made for the most part of the edges of the lava-streams that slope southward and westward. The sharp-edged serrated ridge, making the summit of the precipice, is from 1000 to 3000 feet in height, and at its northeastern base, from Kualoa eastward, there is in general only a narrow strip of low land with low hills, the width but three or four miles except in the Kaneohe peninsula. The precipice continues beyond Kualoa northwestward, but not the low land at its base.

These features have occasioned peculiarities in the results of denudation on East Oahu. The leeward or south and southwestern sides have long and deep valleys, some of them heading in broad amphitheaters under the crested mountain ridge. The windward side, along the 20-mile precipice, on the contrary, has buttresses and shallow alcoves, with a buttress here and there lengthening out into a ridge; and only farther northwest, beyond Kualoa, are there the longer valleys or gorges and ridges and the mountain architecture characteristic of deeply worn windward slopes.

The only broad valley of the leeward or south and southwestward slope that is continued upward with gradual ascent to the very edge of the precipice is that of Nuuanu, behind the city of Honolulu. It is the valley to the left in fig. 2 on Plate 4. Six miles up it ends in the "*pali*," or precipice, and overlooks the northeastern sea-border plains and hills. The height of the "pali" is only 1207 feet above the sea; but on either side are the highest peaks of the range, Konahuanui 3105 feet in height, and Lanihuli, 2775 feet.

Great denudation on the *leeward* side of an island is an exception to the usual rule. It is a consequence, on Oahu, of the sharp-crested 20-mile precipice. The trade winds become chilled on striking the summit of the precipice and ready, therefore, to drop their moisture; but as they are moving on, they get beyond the summit before much of the moisture falls, and so the *leeward* slopes receive the water. In the upper part of the Nuuanu valley, within two miles of the *pali*, 132 inches of rain fall a year, and nearly 100 inches less than this at Honolulu, although brief sprinklings occur almost daily over the city. Konahuanui and Lanihuli, as seen from Honolulu are generally under clouds, but from Kaneohe they are usually uncovered.

A nearly similar condition exists in West Maui, owing to the thinness of the rocky walls at the head of its great valleys. Very broad valleys are consequently made on the leeward side, as in Oahu; but these valleys soon end below in a slender gulch, which may be, for the most of the year a "dry run;" the excessive dryness and heat of the lower plains evaporating powerfully and supplying no water.

2. *Orographic condition of East Oahu.*—From the facts mentioned, it appears to be plain that the chief structural difference between East Oahu and East Maui is that the latter is a whole volcanic mountain, and the former a piece of one. By some means the Oahu mountain-cone or dome has lost, as I concluded in 1840, a large piece from its mass—all that once existed northeast of the 20-mile precipice. The size of the lost piece it is not easy to determine. The lava streams of the leeward slopes, which dip away from the precipice mostly at an angle of 3° to 5° (as seen in the intersecting valleys), must have come from some point or points beyond it to the northeastward.

Following the leeward slopes around westward and northward we find all pointing upward toward the higher part of the mountains, as if the source were somewhere in that direction; but just where, remains in doubt; and it may be even questioned whether there may not have been two or more great craters along the line.

No point or region has a more reasonable claim for consideration in this respect than the head of Nuuanu valley. In situation and width, and the features at its head, it is just what should be looked for in a great discharge way. On my recent visit I sought for facts bearing on the question and found the dip of the beds to diminish from 3° to 1° toward the top, and at the "pali," the beds were very nearly or quite horizontal. This is favorable to the conclusion that the crater was either at its head or near by it, just beyond the precipice. The low land below, over the Kaneohe peninsula and between this peninsula and the "pali," is a region of tufa hills and other small cones, unlike any part elsewhere of the north or northeast coast. In addition, at the head of Nuuanu valley, very near the top of the "pali," there are the remains of a red cinder cone. Besides this, on descending the steep "pali" by the path, there is to the east of the path a long broad slope, 35° to 40° in angle, consisting of reddish layers of volcanic cinders, scoria, earth and stones—indicating cinder ejection from some point above.

It is therefore most probable that the center of volcanic activity for East Oahu was in the vicinity of the "pali," above the low region a little to the northeast of it. The cinder cones above mentioned may have been results of the last efforts of the declining fires, like those of Haleakala and Mt. Kea.

In 1840, I was led to locate the central crater on the Kaneohe peninsula, because the head of the "pali" was so near the southern foot of the mountain; I thought it must have been farther off. But the fact that the volcanic mountains of East and West Maui are eccentric in ground-plan, and that the same feature quite certainly characterized this Oahu cone, makes the position near the "pali" the most probable. In Haleakala the center of the crater is only six miles from the southern shore; and this distance in the Oahu crater, on the above supposition, would be about seven miles. The idea of an eccentric cone fourteen or fifteen miles in the transverse diameter through the crater is thus strongly favored. On further comparison with Haleakala, we find that the part of the longer diameter of the mountains which lies northwest of the center of the crater is about 19 miles in length on Maui, and on Oahu it would be nearly 25 miles. The small dip of 1° to 3° prevails widely about the mountains at Kualoa point and to the northward, as well as in the upper part of the Manoa valley, west of the Nuuanu; and from this it may be inferred that the East Oahu mountain was a dome, like Mt. Loa, rather than a cone like Haleakala. The existence of one or more craters west of the "pali" has been urged, and is possible. I know of no special facts sustaining it. The amphitheater at the head of Manoa valley is referred to by Mr. Brigham as probably the site of a crater; but I was more inclined from my examination to make it an amphitheater of erosion.

3. *Origin of the long precipice on Oahu.*—The long precipice of East Oahu has been attributed to erosion. But I have found no evidence that such transverse walls are legitimate effects of erosion, either fluvial or marine. As illustrated on Maui (p. 91), the sea works with extreme slowness in battering lava-cliffs, and cannot work at all below the limit of forceful wave-action—a level not twenty feet beneath the surface. Fluvial action makes long valleys in the long descending mountains and capes which the sea is incapable of obliterating. Land waters have done grand work in alcoving the long precipice, and carving battlements and temples out of the rocky piles that were left, as is well exhibited in the Kualoa bluffs, while the sea has not even scraped away the small tufa cones on its borders. It might be said that the cones of Kaneohe and the "pali" have been made since the era of erosion; but this disconnects their origin by a very long era from the period of activity in the crater.

Another view with regard to the origin of the precipice is that of my Expedition Report, namely that it was made by a profound fracturing of the mountain-dome across from southeast to northwest, and a drop-down of part of the outer or eastern section. The line of fracture was irregular—the course rather of a series of fractures; and subsidences of varying extent may have taken place along the line, becoming smaller to the northwest, where high ridges are left between the precipice and the coast. The amount of displacement was not less than the height of Konahuanui, 3105 feet, and probably much exceeded this.

Great catastrophic subsidences are not uncommon in volcanic regions. In the account of Maui and its crater the fact of a subsidence not less than 2500 feet, accompanying and following some one of its eruptions, appears to be placed beyond doubt. Hawaii has plain evidences about its crater of subsidences hundreds of feet in amount of displacement if not thousands; and there are high precipices, like that at Kealakekua Bay, for which there appears to be no other probable source of origin.

The small western island of the Hawaiian group, Niihau, has a bold precipice as its eastern face, 1500 to 1800 feet in height above the sea, and the lava-streams of the island pitch from the precipice to the westward, showing that the streams flowed from a point to the eastward, and that a large piece, perhaps the larger part, of an old volcano has disappeared. Kauai, north of Niihau, has its Napali cliff, a dozen miles long, along its southwest side, in a line with the Niihau cliff. Molokai, to the east of Oahu, was once, as its lava-streams prove, a doublet of volcanoes, like Maui; but it has been shaved down to a strip of land 35 miles long, and not a fifth of this in mean width. The eastern part has an alcoved precipice facing the north, which rises to a height of 2500 feet above the sea. It encloses a strip of land along the sea shore, and on this spot, thus walled in, it has been found convenient to locate the Leper quarantine-ground of the islands. Lanai, a narrow island south of Molokai about 20 miles long, has a bold front to the south and gradual slopes from it in other directions. Thus such precipices are rather the rule in the Hawaiian group; and if seashore erosion is not the origin—as an island like Tahiti, with its profound radiating gorges as a result of fluvial action and its non-gorged coast, appears to show*—fractures and subsidence must be.

A great volcano is a disgorger of lava in vast floods and so it makes its mountain; and it may make also empty cavities at the same time and as a consequence. As long as the ascensive force keeps the liquid lava-column of the active volcano fully up to the summit crater, the mountain may have only local cavities. But whenever a great discharge takes place, a coequal cavity may result; and if the discharge is from fissures at the base of the cone, 15,000 to 18,000 feet below the sea level (not a greater depth than exists in the neighboring seas) an enormous cavity may be left, which only the renewed action of the ascensive force would fill. If the mountain *then* became extinct with no return of the liquid, it would be a hollow mountain; and the greatest of subsidences which the Hawaiian facts seem to indicate, are small compared with the possible consequences of such a condition.

4. *The Tufa and other Lateral cones of East Oahu.*—Several of these cones, as already stated, are represented on Plate 4.

Punchbowl, fig. 2, stands on the northern border of Honolulu (at P on the map).† Its highest point is 498 feet above tide-level. The tufa of the beds constituting it, though rather feebly consolidated, is quarried on the west side of the cone, and specimens may there be conveniently obtained. It is a yellow to brown, in part resin-lustered, palagonite-like rock, bearing evidence in its constitution and in the dip of the beds,

* This Journal, xxxii, 247, 1886.

† The sketch was taken in 1840 from the deck of the ship Peacock as she lay in the harbor. The native huts at its foot are omitted.

that mud-making warm waters were concerned in the deposition; and its being of brown, in place of red, color, is probable evidence that the temperature of the water was below 200° F.

Diamond Hill, fig. 1, makes the prominent cape east of the city; its bold southern brow has a height of 761 feet above the sea at its base. It is, like Punchbowl, a fine example of the typical tufa-cone in its broad and shallow, saucer-shaped crater, with the stratification parallel to the bottom of the saucer and to the original outer slope. These slopes have become deeply trenched, as the view shows, by descending waters; and since 1840, the southern brow has lost something of its boldness. Two other cones stand in a line to the north of it, the first, a place of lava outflow. The three vents appear to be situated on a single line of fracture.

The Koko Head tufa-cones are situated at the east extremity of the island. The view (fig. 3) was taken from the eastward at sea. The larger or more northern of the two cones is much denuded inside and out. The other low cone, situated on the Point, is worn to its center by the sea, and has thereby been made to exhibit to the passing vessel (as it goes from or toward Honolulu) the dip of its tufa beds inward and outward, and thereby the true structure of such a cone.

Artesian borings on Oahu afford some facts bearing on the history of Diamond Head and Punchbowl. The borings were made by Mr. J. A. McCandless of Honolulu, and records of a number of them have been received from him through Prof. W. D. Alexander.

The following section is from James Campbell's well, at the west foot of Diamond Head, not far from the sea-level.

	Thickness.	Depth.
Gravel and beach sand	50 feet	----
Tufa like that of Diamond Head	270	320 feet
HARD CORAL ROCK, like marble	**505**	**825**
Dark brown clay	75	900
Washed gravel	25	925
Deep red clay	95	1020
SOFT WHITE CORAL	**28**	**1048**
Soapstone-like rock	20	1068
Brown clay and BROKEN CORAL	110	1178
Hard blue lava	45	1223
Black and red clay	28	1251
Brown lava	249	1500

The well went down 1178 feet before reaching the solid lava of the bottom. In its upper part it passed through 270 feet of tufa, indicating that the tufa-cone extended below the sea-level to this depth, and therefore had a total height of over 1000 feet. Below the tufa, between the 320-foot and 825 foot levels, there are 505 feet of *hard coral rock;* and then on the 1045-foot level, a 28-foot layer of *soft white coral* and at a greater depth, brown clay and broken coral. As the well is close by the west foot of the Head and passes through so much of its tufa, it is quite certain that the 505-foot stratum of limestone was made before the tufa-eruption; and that the beds underneath it mark earlier conditions over the site.

As regards a supply of fresh water the well was a failure—an exception to the usual experience. The water came up salt and a much stronger brine than sea-water. It was under some pressure, as it stood a foot above the level of surface wells near by.

Other borings have been made in Waikiki—the sea-border district just west of Diamond Head. The section afforded by the deepest of the Waikiki wells is here inserted for comparison. It is that of the King's well, No. 2—about half a mile west of Diamond Hill and 350 yards from the seashore.

	Thickness.	Depth.
Sand and coral	38 feet	----
WHITE CORAL ROCK	**22**	**60**
Yellow sand	43	103
Hard lava	47	150
WHITE CORAL ROCK	**110**	**260**
Blue clay	25	285
Tough clay and CORAL	65	350
Blue clay	30	380
HARD CORAL ROCK	**40**	**420**
SOFT CORAL	**30**	**450**
Tough clay	5	455
WHITE CORAL ROCK	**40**	**495**
Tough clay	30	525
WHITE CORAL ROCK	**100**	**625**
Tough clay	5	630
CORAL and clay	**70**	**700**
Tough clay	28	728
Black sand	2	730
Lava	120	850

In this well, the upper 320 feet probably correspond approximately to the upper tufa-made portion of the preceding. It is remarkable that tufa is wholly absent, although the distance from the active vent was so small; but this is accounted for by the direction of the trade winds, which would have carried the ejected material seaward—the direction in which the hill is elongated. Moreover the tufa-cone although 1000 feet high may have been thrown up in a single year or less. Instead of tufa for the upper part, there are, underneath 38 feet of sand and coral, 22 feet of white coral rock; 110 feet more of the coral rock above the 260-foot level, and 65 feet of "tough clay and coral" next above the 350-foot level. Further, beginning with the 385-foot level, coral rock is continued to the 700-foot level, or for 315 feet, with the exception of 40 feet of clay divided between three layers; and this 315-foot layer of limestone appears to correspond to the 505-foot layer between 320 and 825 feet in the other section. The solid lava-stream of the bottom of the well was reached at 730 feet. The amount of water obtained proved that the lava-stream was one of those from the mountain. It is overlaid by 2 feet of volcanic sand and 28 of tough clay, the sand serving to contain the water and the clay to confine it, conditions suited to make the well a success.

In these sections the intercalated beds of so-called "clay" vary widely in position and thickness, and appear to be, in general, local deposits from mountain streams, or tufa deposits from one source or another. In another boring in Waikiki, a bottom of solid lava was reached at 375 feet; and in a third, Goo Kim's well, at 475 feet. The former had an intercalated lava-stream at a depth of 206 feet, and the other at 150 feet. In Goo Kim's well, which was nearly a mile from the seashore, there were 26 feet of coral rock above the 150-foot level, and 194 feet of coral rock above the 430-foot level but with two intercalations of a 20-foot layer of "clay" in the stratum. The facts as to the varying levels of the "clay" beds and the intercalation of lava-streams show what accidents the living species of the sea and its reefs were exposed to. They make the existence of a *continuous* 505-foot stratum of coral limestone underneath the tufa of Diamond Head the more remarkable.

The artesian wells made within the limits of the city of Honolulu might be expected to throw light on the history of Punchbowl.

1. A well in "Thomas Square," just south of Punchbowl, afforded the following section.

Soil 6 feet, with 6 of black sand and "clay" 4	16 ft.	---
White coral rock	200	216 ft.
Brown clay	44	260
Coral rock	10	270
Brown clay	60	330
White coral rock	50	380
Brown clay	80	460
Bed rock or lava, penetrated	49	509

2. In "Mr. Ward's well," below Thomas Square, on King street, there were at the top 15 feet of loam and sand, then 180 feet of "hard coral rock," carrying the depth to 195 feet; again 24 feet of coral and shells above the 219-foot level; and

then, underneath 109 feet of "yellow clay" which may be Punchbowl tufa, 23 feet of coral rock above the 393-foot level, and 107 feet of white and yellow sand below it; with the bottom lava at 508 feet covered by 4 feet of quicksand. An abundant flow of water was obtained.

3. South of the last, in the "Kewalo well," begun near the sea-level, beneath 6 feet of black volcanic sand, there were 50 feet of coral rock over a 40-foot layer of hard lava; then 190 feet of coral, divided in two by an intercalated 30-foot layer of "clay," over the 350-foot level; with the bottom lava-bed at 620 feet.

4. Section from a well in the Palace yard:

Soil 4 feet, black sand 4	8 feet.	---
Coral rock	64	72 feet.
Hard lava	6	78
White coral rock	60	138
Clay	240	378
Coral rock	75	452
Clay and gravel	254	707
Lava or bed rock penetrated	55	762

Of the above sections 1, 2 and 3 have a thick bed of clay on the 260-foot to 280-foot level; 1, 2 and 4 on the 330-foot, 370-foot and 378-foot levels; 1 and 2 and 3 on 460-foot, 500-foot and 535-foot levels; and No. 4, a layer 254 feet thick on the 707-foot level or the bottom rock. It is possible that one or more of these of "clay" may be decomposed tufa of Punchbowl origin. But to refer all to this source would make the period of eruption of very improbable length. The "black sand" below the soil in Honolulu is naturally referred to this source. But more investigation is required for a decision. There is no evidence that Diamond Head and Punchbowl were of simultaneous origin.

5. *West Oahu.*—The mountains of West Oahu cover at the present time a much smaller area than those of East Oahu. Their original dimensions we have no data for estimating. The highest peak, Kaala, in the northeast part of the group of summits, has a height, according to the government survey, of 3586 feet—which is 681 feet greater than that of Konahuinui; and besides this, there are, in the southeastern part, peaks of 3105 and 3110 feet. These elevations, and the deep and open valleys divided off by sharp ridges, are sufficient evidence that the mountain range is but a small remnant of the once great volcanic mountain, probably a loftier mountain than that of East Oahu. Denudation has had a far longer time for its dissecting work, and has done much to diminish the area it covers. Whether great loss has resulted also from subsidence is not ascertained.

The fact that the volcano of East Oahu was in full action long after the extension of the western cone, is shown (as I first observed in 1840 and again in 1887) by the encroachment of the eastern lava-streams over its base, and the burial in part of the valleys. The accompanying sketch is a view, looking westward from the plain made by the encroaching lavas, showing how the lavas dammed up the already made valleys of West Oahu, and forced the drainage waters to take a north or south direction, nearly parallel with the base of the mountain, in order to reach the sea. The courses of these streams are shown on the map. The depth of burial by the East Oahu lavas was probably some hundreds of feet.

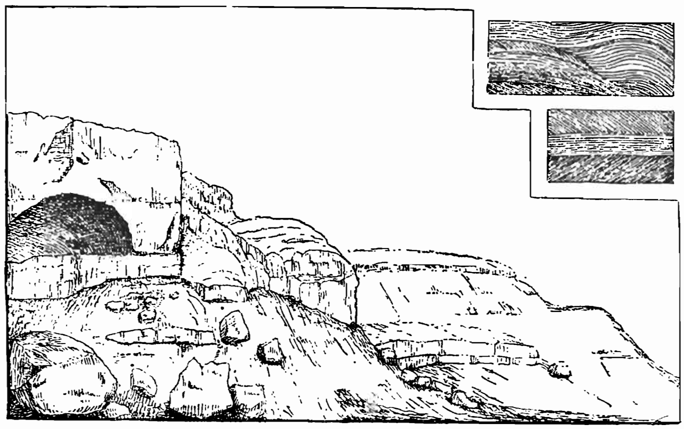
1.

2. *Evidence of recent change of level.*

1. *Elevation.*—Evidence of recent upward change of level is afforded by the elevated coral reef along the sea-border. The dotted line on the map (Plate 4) has already been pointed to as approximately the inner limit of the raised reef; the small dotted areas about Kahuku Point, the prominent north cape of the island, and in Laie, the district next southeastward, besides others west of Waimanalo, are the positions of hills or bluffs made of the reef rock and consolidated drift sands. The rock is in some parts a beautiful white, fine-grained building stone; but generally it has sudden transitions in texture and firmness, and much of it is a consolidated mass of broken corals, or else of standing corals made compact or nearly so with coral sand. Along southern or southwestern Oahu the height of the reef is fifteen to thirty feet; and I estimated the amount of elevation indicated by it in 1840 at 30 to 40 feet.

At the Kahuku bluffs, which I visited anew in 1887 (see figure 2), the solid coral reef rock extends up in some places to a height by estimate of fifty to sixty feet above tide level; and this is surmounted by drift-sand rock, made of beach coral sands that were drifted into hills on the coast when the reef-rock was submerged, adding twenty feet or more to the height. There are large caverns in the bluffs, which are mostly within the upper layer of the coral reef-rock and have the drift-sand rock as the roof. In the sketch, a faint horizontal line may be seen passing by the top of the cavern; it separates the beds of different origin. The coral reef-rock consists mostly of cemented masses and branches of corals of the kinds common in the modern reef, and also has often the corals in the positions of growth. But the wind-drift beds show the quaquaversal or variously-striking dip common in wind-made drifts, as represented in the two sections below.

2.



Kahuku bluffs of coral rock and drift-sands, with two sections of the drift-sand rock.

The change of level along northern Oahu, according to the facts from Kahuku, appears to have been at least sixty feet, or twenty feet greater than on its southern side. Even with an accurate measurement of the height of the reef-rock about Oahu the amount of elevation would remain doubtful because the coral reefs off the island are at present nowhere up to low-tide level; and this may or may not have been the fact before the change of level took place.

The surface of the elevated reef of Oahu is exceedingly uneven from unequal construction and erosion, and its interior has in some places large and winding caverns, so that an overlying formation, were there one, would afford an example of *unconformability by denudation.* It is obvious that with greater elevation, the unevenness would be as much greater, large enough to get the credit, perhaps, of representing an interval of many thousands of years, although results of the "modern" period in geology. Denudation works rapidly among limestones and especially so when the limestones have just left the water, with the usual irregularities of upper surface and texture.

2. *Subsidence.*—A gradual subsidence of the island is apparently indicated by the coral reefs, through the depth to which they have been found to extend in Artesian borings. In these borings, described on page 96, a depth of 700 to 800 feet was

found for the coral rock, and more than 1,000 for broken corals; and over 700 is reported by Mr. McCandless from a well in the Eua district, about five miles west of Honolulu. The facts lead to the inference that the subsidence amounted to at least 800 feet, and that it corresponds to the coral-reef subsidence which Darwin's theory requires. Mr. McCandless informed me that fragments of corals like those of the modern reefs were brought up from the various levels.

This evidence of subsidence to the amount stated is not, however, complete. Doubt remains because the corals brought up in fragments have not been examined by any one competent to decide on their actual identity with existing species; I could not find that any of them had been preserved. The importance of their preservation and careful study is now understood, and we may hope before long to have the doubt removed. As the case stands, the *probability* is that the limestone is to the bottom true coral-reef rock and that the depth to which it extends is, therefore, a measure of actual subsidence.

Darwin's Coral Island theory.—In the above statements the present condition of Darwin's theory of Coral Islands, is fully and fairly recognized. Much has been recently written about the theory's having been set aside or proved to be without foundation. But in truth, no facts have been published that prove the theory false, or set aside the arguments in its favor. The facts and arguments from Tahiti brought out by Mr. Murray I have shown, in my review of the subject in this Journal in 1885* (published also at the same time in the London Philosophical Magazine), to have no weight and more than this, to sustain Darwin's theory, instead of opposing it. The idea of the excavation of the lagoon-basins of coral islands by sea-waters I have also proved in the same paper to be not a possibility.

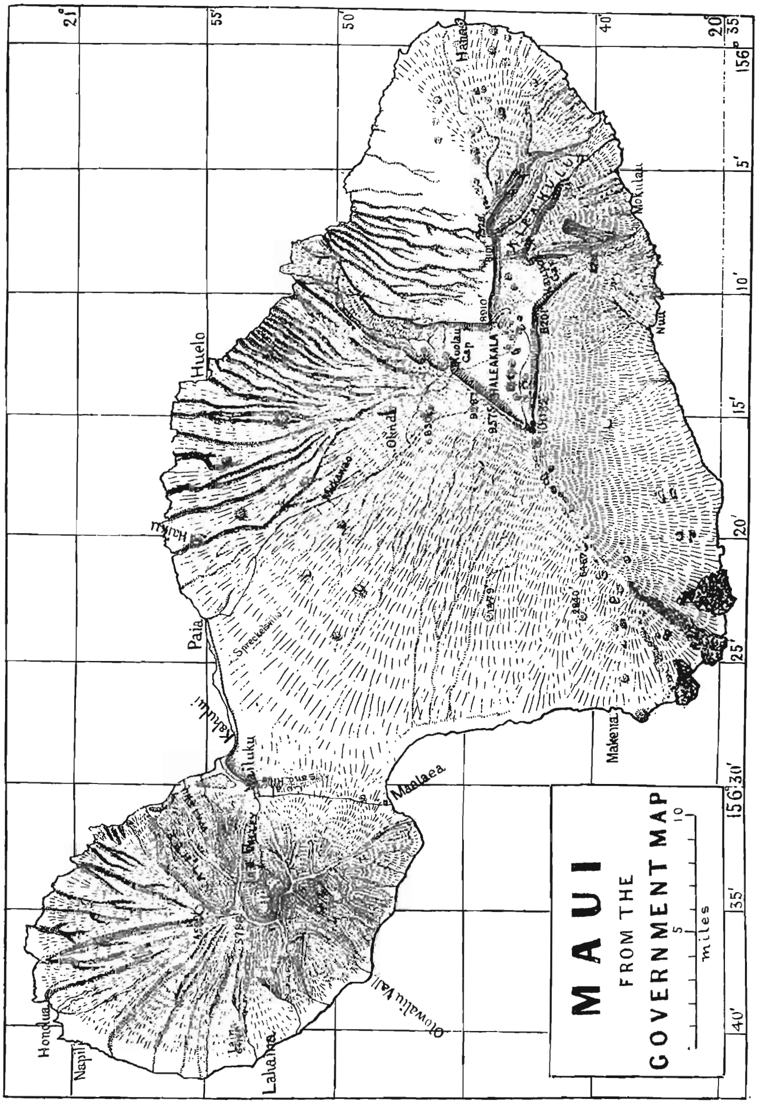
The only suggestion of real importance that has been presented is not against Darwin's explanation, but simply in favor of a possible substitute. Mr. A. Agassiz and others have suggested that deep-sea organisms may build up limestone over the sea-bottom, and thus raise the rock to the level where reef-forming corals may grow, or within 100 to 150 feet of the surface; and that, in this way, coral reefs and islands *may* have been formed without subsidence. Mr. Guppy has shown that some coral-made limestone, in the southwest Pacific, actually has a base of limestone that had been made by other life than that of reef-corals. This is all the foundation for setting aside Darwin's conclusions. It is good ground for doubting, and a good reason for investigating the nature of the coral limestone in the various coral-reef regions of the Pacific at

* Volume xxx, pp. 89 and 169.

depths below the level of 100 to 150 feet—as I state in the article referred to, where I propose that deep borings should be made, under government authority, on a sufficient scale to settle the question. The borings have been made on Oahu; but, as I say above, the fossils of the reef-rock passed through below the coral-growing limit have not been examined and the subsidence therefore is not positively proved. There are many collateral arguments in favor of the Pacific coral-island subsidence reviewed in my paper which still remain strong; but they may be held in abeyance until the borings have been satisfactorily made. These and other points are discussed at length in the paper to which I have above referred.

I took no part in the controversy with reference to the statements of the dogmatic Duke of Argyll, knowing that the subject was in good hands. But I may here say that the charge which he made that no one had dared to bring forward and discuss the facts and views published by Mr. Murray and others against Darwin's theory was the more inexcusable that my paper had appeared as recently as in 1885 in the London Philosophical Magazine. The charge was based on ignorance of the facts on all sides, and on incapacity to appreciate the spirit actuating men of true science.

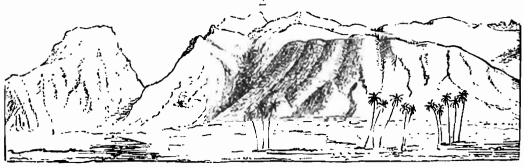
One other paper—on the question *whether volcanic action is a cause or not of trough-making over the Ocean's bottom, with a review of the ocean's depths illustrated by a new bathymetric chart*—will close this series with the exception of the promised paper on the rocks of the islands by E. S. Dana.


MAUI
FROM THE
GOVERNMENT MAP
miles
Huelo
Paia
Makena
Maalaea
Lahaina
Napili
HALEAKALA
Hana
Nuu

1

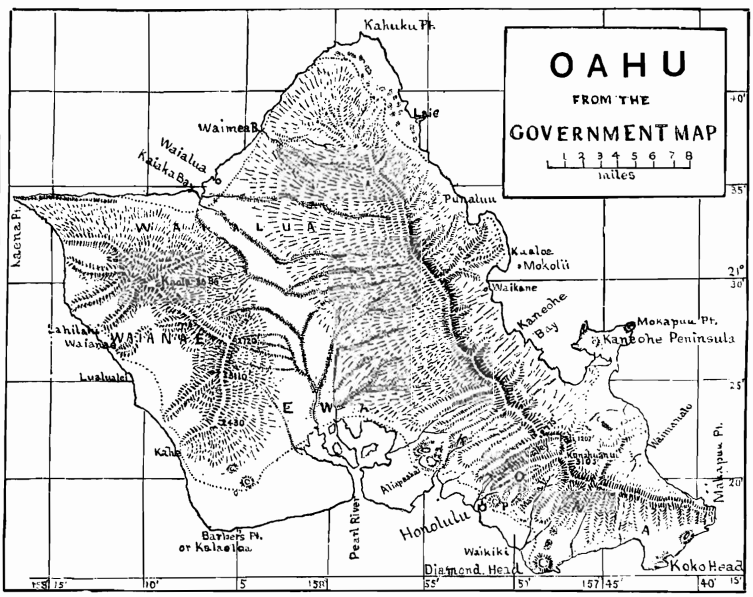
c b a

2



3

4



1. The volcanic cones: *a*, Diamond Head, or Leahi; *b*, Kaimuki, or Telegraph Hill, and *c*, Maaumae. 2. Punchbowl, or Puowaina, with Nuuanu valley to the left, and the peaks Konahuanui and Lunahili, right and left of the pali. 3. The Koko Head craters.