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THE GEOLOGY OF SAINT HELENA ISLAND

By Reginald A. Daly

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CONTENTS.

Introduction; Acknowledgments.

The naturalist, like the sociologist and historian, has found few of the deep-sea islands more intriguing than Saint Helena. In the Atlantic Ocean the lonely "Old Rock" is one of the most remote from continental shores. Africa is nearly 1,900 kilometers distant and South America about 3,000 kilometers distant. With the exception of the still smaller Ascension Island, the 115 square kilometers of Saint Helena form the only dry land in an area of 15,000,000 square kilometers, or three per cent of the earth's surface. These two bits of land may thus be regarded as "primary triangulation points" in the geological survey of the globe. No adequate geological map of Saint Helena has, however, been published. As explained in the writer's "Geology of Ascension Island," he was enabled, through participation in a Shaler Memorial expedition from Harvard University, to spend some time on Saint Helena. The visit lasted from November 28, 1921, to January 3, 1922—long enough to permit the making of a reconnaissance map of the rocks, here reproduced as Plate I. The new observations on the structure, physiography, and petrology are summarized in this paper. The monthly steamship service of the Union Castle Line makes the island accessible, but experience shows that few geologists land on it. Hence, it has seemed desirable to publish this report of progress on the geology, incomplete as the account must be, because of the limited time that could be allotted to the study of a very rough and structurally complicated island.

During the visit, many courtesies were received from His Excellency the Governor, R. F. Peel; Mr. Arthur Hands, the Governor's efficient Secretary; Harbormaster R. R. Bruce; the Honorable H. J. Bovelle; the late Dr. W. J. Arnold; Mrs. Eden Thomas; and Messrs. Benjamin Grant, Edgar James, J. K. Gibson, T. Broadway, R. A. Legge, and E. J. Warren. In London, Rear Admiral F. C. Learmonth, Hydrographer of the British Navy, gave valuable information and donated charts of the island. For all these kindnesses the writer wishes to express deep appreciation. His thanks are also due to the War Office, London, for permission to copy topographic data from their excellent contour map of Saint Helena (No. 1853, published in 1904; contour interval, 100 feet; scale, 1: 25,344); and especially to Dr. H. S. Washington and Miss Mary G. Keyes for generously undertaking the ten rock analyses.

The costs of travel and subsistence in the field were met by a grant from the Shaler Memorial Fund.

Publications Relating to Saint Helena.

Since its discovery in 1502 by the Portuguese navigator, de Nova, Saint Helena has had a romantic history, connected with: British-Portuguese, British-Dutch, and British-French wars; the exploitation of the East Indies and the whale fishery of the South Atlantic; the rise, tragic duration, and thrilling suppression of the Atlantic slave-trade; the melancholy story of Napoleon's end; and the shifting of trade routes through the coming of the steamship and the building of the Suez canal. Around these historical and geographical topics a considerable literature has grown. Its bibliography is too voluminous to find a fitting place here; however, a few references to standard works dealing with the absorbing human history may be of use to geologists who intend to land on and study this remarkable island.

The compact description of Saint Helena in the last edition of the Encyclopædia Britannica gives a good introduction to the subject. The history and geography are well summarized in C. P. Lucas's *Historical Geography of the British Colonies*, vol. 3, 3rd ed., Oxford, 1913, pp. 387–409. The best comprehensive account is *St. Helena: a Physical, Historical and Topographical Description of the Island, including the Geology, Fauna, Flora and Meteorology* (Reeve and Co., London), 1875, by J. C. Melliss. For the historian and sociologist the following are indispensable sources of information: T. H. Brooke's *History of the Island of St. Helena . . . to 1823*, 2nd ed., London, 1824; M. Danvers' *Report on the Records of the India Office*, 1887, vol. 1, part 1; A. Beatson's *Tracts Relative to the Island of St. Helena*, London, 1816; H. R. Janisch's *Extracts from the St. Helena Records from 1673 to 1835*, Jamestown (St. Helena), 1885; D. Morris's *Report on the Present Position and Prospects of the Agricultural Resources of the Island of St. Helena*, London, 1884, reprinted in 1906; E. L. Jackson's *St. Helena*, London, 1903; the Governor's *Annual Reports to the Colonial Office*, 1902–11, by H. Galway.

The botany and zoology are treated in the books by Melliss and Morris; in *Island Life*, by A. R. Wallace, whose classic work gives references to the pioneer studies of Wollaston, Hooker, and others; and in W. B. Hemsley's paper in the *Reports of the Challenger Expedition*, Botany, Part 1, pp. 49–122.

The geologist will find certain data in the *Africa Pilot*, Part 2. He will be interested in the anonymous *Description of the Island of St. Helena, Containing Observations on its Singular Structure and Formation*, London, 1805; and in W. H. B. Webster's *Narrative of a Voyage to the Southern Atlantic Ocean in the Years 1828–1830, Performed in H. M. Sloop "Chanticleer,"* London, vol. 2, 1834, pp. 307–312. The more steadily useful works of reference include: that of Melliss, already mentioned; J. R. Oliver's *Geology of St. Helena*, a pamphlet published in Saint Helena, 1869, and reprinted in *A Few Notes on St. Helena and Descriptive Guide*, by B. Grant, Jamestown (St. Helena), 1883, pp. 34–49; C. Darwin's *Geological Observations on the Volcanic Islands*, London, 1844 (2nd ed. 1876, pp. 83–109), and *Journal of Researches*, London, 1845 (new edition, 1901, pp. 491–496). Of the more modern books that of Grant and Oliver is the most difficult to procure; only 150 copies were printed, and it has long been out of print. Oliver's account of the geology is astonishingly good, in view of its date and the fact that the author was a captain of the Royal Artillery and not a professional geologist.

Darwin's observations are of course those of a master, but his theoretical conclusions are here not so happy as they are in his writings on Ascension Island.

A preliminary note on the results of the 1921–22 reconnaissance was published in the *Geological Magazine,* vol. 59, 1922, pp. 150–156. An account of the geology of Ascension Island, studied just before Saint Helena, has been published in the Proceedings of the American Academy of Arts and Sciences, vol. 60, 1925, pp. 4–80.

The War Office map of the island is admirable, the relief being shown by a combination of contours and shading; its large scale permits of the entry of many more geographical details than are shown in Plate I. The Admiralty chart of Saint Helena (No. 1771), corrected to 1921, is nearly identical in scale; it is specially useful in giving numerous soundings. It has been reprinted by the Hydrographic Office in Washington, for distribution.

Geographical Relations.

Jamestown, the only town of Saint Helena, is situated at 15° 55′ South Latitude and 5° 42′ West Longitude, about 1,200 kilometers southeast of Ascension Island, which is the nearest land. Saint Helena measures 10.8 statute miles (17.3 kilometers) by 6.6 miles (10.5 kilometers), and has an area of about 45 square miles (115 square kilometers). This composite volcanic cone rises from the sea-floor at the depth of 4,200 meters. Nine hundred kilometers to the westward is the summit of the mid-Atlantic swell, covered with only 2,500 meters of water, while to the eastward is the extensive Buchanan Deep (the "Westafrikanische Mulde" of the German maps) with maximum known depth of 3,063 fathoms or 5,600 meters. The base of the cone is roughly 130 kilometers in mean diameter, and, like the visible island, appears to be elongated in a general northeast-southwest direction (Figure 1). The area of the base is about 12,000 square kilometers, or more than ten times the area of the base of Etna; the volume of the cone is probably at least twenty times that of Etna, the largest volcano of Europe.

Saint Helena is surrounded by a graded shelf, which, out to the break-of-slope near the 50-fathom line, varies in width from 1.3 kilometers to 3.0 kilometers. The slope from the 50-fathom line to the 200-fathom line ranges between 1 : 1.2 and 1 : 2.9. This slope evidently belongs to the edge of the detrital embankment, which was formed during the very long period of erosion suffered by the island. In contrast, the slope of the much younger, less eroded

Ascension Island, from the 50-fathom line to the 200-fathom line ranges between 1:4 and 1:7, and may be regarded as established by the constructional form of lava flows essentially, rather than by the angle of rest of submarine detritus.

The island lies in the path of the southeast trade-wind, that dominates in every month of the year. The corresponding surf is strong, but on occasion it is greatly surpassed by the famous "rollers," attributed by hydrographers principally to major storms in the

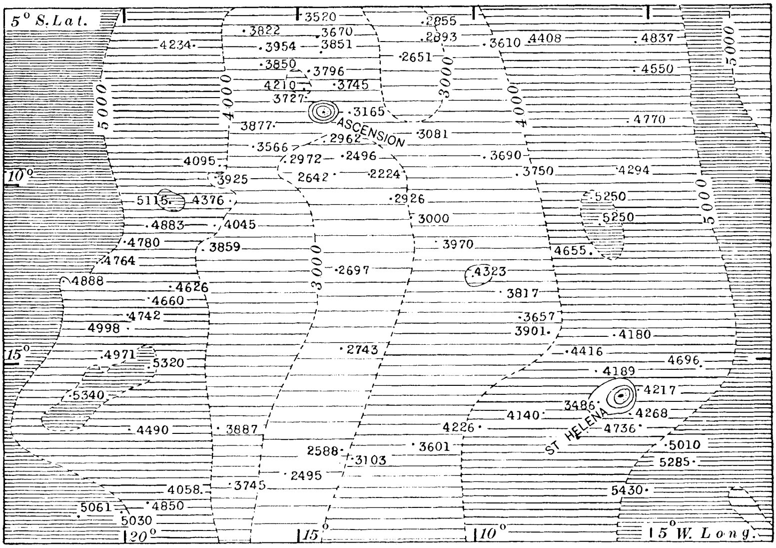

FIGURE 1. Map showing position of Saint Helena with reference to Ascension Island and to the mid-Atlantic Swell. Depths in meters.

North Atlantic. While the power of the rollers is said to be not quite so great as at Ascension, it is sufficiently remarkable. Melliss describes the example of February 17th, 1846, originally detailed in the *Saint Helena Gazette* of that year. The size of the waves that then broke on the northwestern side of the island is exemplified by the apparently authentic fact that the brig "Rocket" of 230 tons, which had been anchored off Jamestown, was "lifted with her hull in a vertical position, her bows up, and her stern down, and as the wave broke not a single trace of her was seen." A meteorological chart of the Indian Ocean, issued by the Hydrographic Branch of the

British Navy Department bears an engraved copy of a picture of the "Rocket" in this vertical position as the wave broke.

Throughout the year a rather slow ocean current passes the island with a set toward the west. It represents the southern fringe of the South Equatorial Current, which upstream is continuous with the Benguela Current running northwards from the Cape of Good Hope. Wind and current directions largely explain the fact that the land fauna and flora of Saint Helena, both of waif origin, have strong affinities with animals and plants of Africa and the Indian Ocean region; and explain as well the prolonged, social and commercial relations of the Saint Helena people with the East Indies in the days of sailing ships. On the other hand, the marine molluscs along the island shores most resemble those of the West Indies.[1] This conclusion of the conchologist raises the question whether at some past epoch, such as the Glacial period, there was a different set of winds and ocean currents at Saint Helena. If at such a time, not too remote, the dominant winds and currents came from westerly directions, the colonization by West Indian types of marine larvae could be accounted for, and also the strong sea-cliffing on the present leeward shore of the island might be better understood. Since the Hawaiian Kauai and other islands show similar, extraordinary cliffing on sides now to leeward, one can hardly withhold some sympathy for the hypothesis that there was a prolonged, important shift of wind-belts during the Quaternary period.

According to the Atlantic Atlas, issued by the Deutsche Seewarte (Hamburg, 1902), the average monthly temperatures of the sea surface around Saint Helena are for:

February	23°.4 Centigrade
May	22.8
August	20.1
November	20.7

The same authority indicates the southeast trades as blowing during each of the four months listed.

For the field naturalist the climate is good. At sea-level the summer temperature of the air ranges from 68° to 84° Fahrenheit (20° to 29° C.); the winter temperature, from 57° to 70° F. (14° to 21° C.). The higher, interior region is about 5° C. cooler. Melliss details the rainfall data. The mean annual rainfall at Longwood (altitude, 1,750 feet) for a five-year period was about 47 inches (112 cm.); that for Jamestown averages a little less than 10 inches

[1] E. A. Smith, Proc. Zool. Soc. London, 1890, p. 247.

(25.4 cm.). The summer rains are heavier but less continuous than those of winter.

Rugged as it is, Saint Helena offers an unusually agreeable field for geological study. Roads and paths are numerous; rock outcrops are abundant, except in the flatter parts of the interior; shelter and subsistence can be had with the hospitable inhabitants of the uplands as well as at Jamestown. The weather conditions of the winter must be at least as favorable as in December, 1921, when neither rain nor heat prevented field work on any day.

Physiography; General Structure.

The emerged part of the great cone is essentially a basaltic doublet, affected by minor intrusions and extrusions of more salic and alkaline rocks. Nearly five-sixths of the visible mass was erupted within an area centering in the southwestern half of the island. In spite of many irregularities of structure, this part may be regarded as an exogenous dome, formed principally of flows of basalt which were directed outwards from the focal area. For convenience the dome, including also tuffs, breccias, dikes, and at least one intrusive sheet of basalt, as well as several subordinate alkaline bodies, will be designated the Main Massif. From James Valley to the eastern cliffs of The Barn, a somewhat similar but much less extensive structure is found; it will be called the Northeastern Massif.

Both massifs have been deeply eroded by numerous, more or less centrifugal streams, which are usually active only after heavy rains and are represented by dry water-courses during much of the year. In the past the streams may have had much greater persistence and power. Thompson, Old Woman, Swanley, Lemon, Friar, Young, Breakneck, James, Fisher, Sharks, and Deep Valleys are the more important trenches that have been cut by streams consequent on the initial relief of the Main Massif. These valleys are all steepsided, flaring, and canyon-like, reaching depths of 300 meters or more (Plates II, III, and IV, *A*). Nearly all of the principal valleys reach the sea at grade, but a dozen or more short valleys have been truncated by the inwardly marching sea-cliffs, and are now mouthing at the summits of cliffs, 100 to 200 meters above sea-level. Even the relatively long Young Valley hangs nearly 20 meters over the beach at its mouth. The constructional surface of the interstream areas is probably nowhere preserved in perfection, though certain small flattish surfaces, such as Deadwood Plain, have probably been lowered by erosion no more than a few scores of meters.

With the progress of stream-cutting, an extensive mass of weak basaltic rocks, here called the Sandy Bay Complex, was uncovered (Plates V, VI, and VII). It underlies the bedded lavas which constitute the larger part of the visible Massif, and most of its outcrop occurs in the so-called Sandy Bay District—hence the name chosen (Fig. 2). The rocks of the complex have yielded to the erosive agents so rapidly that a broad, amphitheatral valley, drained by obsequent and subsequent, wet-weather streams flowing into Sandy Bay proper, has been developed. The amphitheater, measuring 5 kilometers in diameter, furnishes some of the finest scenery of Saint Helena, which is already noted for its rugged grandeur. The rim of the half-bowl culminates in the highest point of the island, Diana's Peak (altitude 2,697 feet or 841 meters, according to Melliss; 2,704 feet according

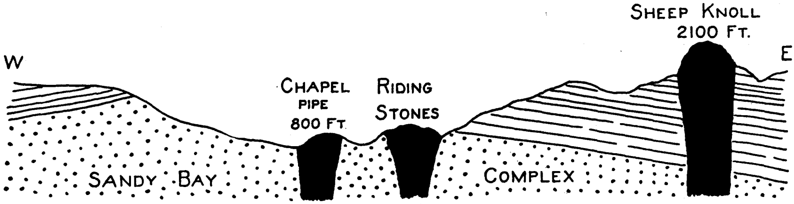

Figure 2. Section through three of the phonolitic pipes in the "Great Basin," showing also the relation of the thick mantle of basaltic flows to the Sandy Bay Complex. The many vertical dikes of basaltic material, constituting part of the Complex, are not shown.

to Lucas). Other peaks on the rim are Actæon Mountain (2,685 feet), High Peak (2,616 feet), Hooper's Ridge (2,269 feet), and White Hill (1,779 feet). From the 12-kilometer ridge bearing these points a dozen wet-weather streams converge into the main water-course along the axis of the half-bowl, which may be referred to as the Great Basin.

Because of the general shape of the half-bowl, Darwin considered it to be a huge explosion-crater. This view was adopted by Oliver, Melliss, and other writers. However, there are serious difficulties in the way of its acceptance.

So great an explosion must have spread a thick layer of fragmental material over the slopes outside of the "crater"—a deposit similar to, but much heavier than that which, to depths of 50 meters or more, veneers the basaltic and trachytic masses around Cricket Valley of Ascension Island. There is no trace of such a widespread, superficial formation in Saint Helena. Hence the supposed catastrophe, if it actually happened, must have taken place so long ago that the enormous mass of débris has been completely removed by erosion. Such an amount of stripping is conceivable, but it does not seem probable.

The crater hypothesis faces a more positive objection. Within the Great Basin, as shown on the geological map (Plate I), there are three phonolithic necks or crater-fillings. One of these is the well known peak, called "Lot"; the other two are located at the Baptist Chapel and Riding Stones hill. All three have been considerably cut down by erosion, but their heights range from 800 to 1,500 feet. Nearer the sea many dikes within the basin crop out at heights of 1,000 feet or more. Allowing for the erosion of all of these bodies, one can not doubt that the imagined explosion-crater must originally have been very shallow in comparison with its length and breadth. An accurate estimate of its dimensions is impossible, but the mean depth could have been little more than 200 meters, while the area would measure a large fraction of 20 square kilometers. This relative shallowness is hardly to be expected for a basin resulting from so extensive an evisceration.

Again, the shape of the basin is not quite that of a crater or caldera due to a major explosion. From Diana's Peak a long ridge runs through Green Hill and White Hill to Sandy Bay Barn. In ground-plan this ridge is convex to the Great Basin, and not concave to it. as would be anticipated if the crater hypothesis were correct. If, to meet the objection, one should assume specially rapid, erosional retreat of the crater-cliffs at, and immediately to the northwest of, Diana's Peak, so that the grand, apse-like cirque between Riding Stones and Diana's Peak was thus developed, erosion would be credited with an effectiveness sufficient to explain the Great Basin as a whole. Removal of rock by explosion becomes a superfluous hypothesis.

Powell valley, just east of the Great Basin, is clearly an erosional feature. Its two cirque-like heads are of the same quality as the ten or twelve scalloping valley-heads within the Basin. Quite as evidently the wide amphitheater (Devil's Punch Bowl) at the upper end of Rupert Valley owes its origin to erosion. Yet both Powell and Rupert valleys have been cut in the strong basaltic flows of the Main Massif. Between The Barn and the Flagstaff Hill-Deadwood region, where a large body of weak rocks have been exposed, a still wider trench has been opened, and no one is likely to suggest that explosion has there coöperated with the obvious cause, erosion.

On a much smaller scale the principle of specially rapid retreat of the edges of strong beds, when overlying weak beds, is illustrated at the picturesque gorge in James Valley at the foot of High Knoll; here a series of massive flows overlies a layer of tuff. These analogies and the topographic details of the Great Basin itself strongly support the view that the Basin has been formed by erosion, which became greatly accelerated as soon as the weak Sandy Bay Complex was discovered by the streams. See Plate I.

Between Castle Rock Point and Manatee Bay, where the Complex rocks crop out, a series of spectacular, cliffed amphitheaters together form a smaller replica of the Great Basin; there an explosion hypothesis is entirely gratuitous.

It is natural to inquire whether the basin form was originally impressed by circumferential faulting, of the type shown at volcanic sinks. For these there is no evidence in the field. Within a region of continuous outcrops and ample exposure of the rocks in three dimensions, the traces of the appropriate faults could hardly escape detection. Yet only one fault was discovered, at a point 600 meters west of Diana's Peak, and its trend is parallel to the northeast-southwest system of dikes in the Basin. Moreover, the topographic and structural relations of the mantle of lava flows to the Sandy Bay Complex are such as definitely to negative the sink hypothesis.

The conclusions are: that erosion has obviously removed much of the rock now missing from the Great Basin; and that the differential erosion seems quite competent to have produced this grand feature, though, of course, the original dome probably bore a few small craters before erosion got well under way. The explosion-crater and sink hypotheses are not supported by field facts. The Great Basin seems therefore best explained as an erosional form, like La Caldera of Palma Island of the Canary group (C. Gagel).

The basaltic lavas of the Main Massif have been penetrated by many narrow, basaltic dikes, and by half a score of larger, pipe-like masses of alkaline rocks. Some of the latter may be classified as monolithic volcanic necks. These include the prominent peak, Lot (Plates V and VIII); the round mass at the Chapel in the Great Basin; and the Sheep Knoll (Plate IX) and two other masses mapped in Powell valley (Powell's Gut of the War Office map). The bodies mapped at Castle Rock (Plate X, *B*) and Hooper's Rock, and also the conspicuous column, Lot's Wife (Plate XI, *B*) may also represent true necks. Those shown on the map at Riding Stones and High Knoll (Plate XII) are perhaps best described as crater-fillings.

High Hill (Plate X, *A*) is a true endogenous dome, that is, originally a viscous mass which rose centrally above its crater rim and initially attained the dome form. If once existing, similar domes on the three necks of phonolite have been eroded away. For the origin of Great Stone Top (Plates XIII, *A*; XIV, XV) and Little Stone Top (Plate XIII, *B*) see page 55.

Each of the alkaline-rock bodies seems to have been erupted as a monolithic mass. Because of their strength they usually project well above the surrounding basalts. The heights of the more conspicuous peaks of this origin are as follows: High Hill, 2,314 feet; Hooper's Rock, 2,220 feet; Castle Rock, 1,670 feet; Lot's Wife, 1,516 feet; Lot, 1,491 feet; Chapel pipe, 800 feet; Riding Stones pipe, 1,200 feet; Sheep Knoll, 2,100 feet; neck east of White Hill, 1,400 feet; pipe 600 meters southeast of last, 1,300 feet; Little Stone Top, 1,550 feet; Great Stone Top, 1,620 feet; Speery Island, about 200 feet (Plate XVI).

The Northeastern Massif is a composite, exogenous, basaltic dome, the growth of which was largely or wholly completed before the northeastern flows of the Main Massif were erupted. Here also deep erosion has penetrated a thick cap of bedded lava flows, exposing a very friable mass of still older basaltic rocks. This basal terrane is composed of tuff and other weak rocks, cut by an immense number of narrow, basaltic dikes, some of which cut the overlying mantle of flows. From the name of a prominent spur on which the basal terrane is well exposed, it may be called the Knotty Ridge Complex. The Barn (altitude, 2,019 feet) is a homoclinal remnant of the thick capping of flows (Plates XVII–XIX, *A*). On the other side of the wide trench which has been cut along the outcrop of the Complex is Flagstaff Hill (altitude, 2,275 feet), a similar remnant of the mantle of flows. On the southwest the imbricated flows of this series continue across Rupert Valley, where they dip steeply under younger flows from the focal area of the Main Massif. The Deadwood Plain (altitude, 1,600–1,700 feet), on deeply lateritized basalt, appears to truncate the southwesterly-dipping flows, but the relations are here obscure. Possibly the Plain approximates to the constructional form of one or more late, flat-lying flows that unconformably overlap the steeper flows which crop out along the valley sides to the west, north, and east of Deadwood Plain.

The Knotty Ridge Complex was seen to underlie the nearly horizontal flows forming the picturesque Turk's Cap and Horse Point. The younger basalts of the Northeastern Massif continue to Saddle

Point; farther south along the shore the flows, dipping gently eastward, seem to represent emanations from the Main focal area.

Marine erosion has destroyed much of each massif. The resulting cliffs are truly majestic. To see them best one should make a boat trip around the island—an unforgettable experience. Among the finest precipices are those at Flagstaff Hill, The Barn, Great Stone Top, Sandy Hill Barn, Castle Rock, and Man-and-Horse. The heights of the cliffs range between 1,000 feet and 2,200 feet; many of their faces are unscalable. Large and small sea-stacks are witnesses to the inward march of the strand-line. Speery Island, off the southwestern shore, is a homogeneous mass of phonolitic or trachytic rock, probably a volcanic neck (Plate XVI and Fig. 3). The Upper and Lower Black Rocks, 800 meters to the northward, appear to be remnants of a wide, vertical, basaltic dike, which strikes northwest-southeast. All the other islets around Saint Helena are remnants of basaltic flows or dikes, or, less commonly, pyroclastic material.

There is no evidence that the cliffing has ever been retarded by coral reefs. If coral larvae from the Indo-Pacific region could survive the passage of the Cape of Good Hope, reefs would be possible, for the mean temperature of the Saint Helena sea-water in the coldest month is practically 20° Centigrade. On the other hand, a very slight lowering of that winter temperature could not fail to inhibit the growth of reefs. Their extinction during the Glacial period is conceivable; yet it is more probable that strong reefs have never been developed since the island was formed.

Practically all of the hanging valleys which have been truncated by the ocean waves are located on the strong rocks of the basaltic mantles. In general these rocks are well cliffed at the shore, where, therefore, marine erosion is defeating the intention of subaerial erosion to develop graded slopes, looking seaward. The case is different with the much weaker rocks of the two basal complexes. Where these rocks meet the sea-level, the wave-cut cliffs are low, and the complexes are being more rapidly destroyed by weathering and rain wash, so that a late-mature topography is found almost down to the shore itself. The contrast is illustrated by a comparison of Plate VII with Plates IV; XI, *A*; XV, XXI, and XXII.

Such a view as that shown in Plate VII, when taken by itself, might suggest the necessity of assuming subsidence, whereby a maturely dissected volcanic cone was drowned, and that so recently that the waves have not had time to cut strong cliffs. Yet the

1,500-foot and 2,000-foot cliffs to east and west of the Sandy Bay District and their relation to the wide shelf offshore prove the very prolonged stability of the island. Evidently, the degrees of resistance of the rocks to marine and subaerial agents of erosion, must be duly considered by any one who attempts to demonstrate subsidence for a volcanic island, by an appeal to the visible topography.

The outcropping of dikes close to the highest parts of the rim around the Great Basin, and the knife-edge character of part of that rim suggest some loss of height for Saint Helena by the erosion of its superficial flows. In the Great Basin itself, the flows dip outwardly at angles varying from 8° to 15°. Prolongation of the planes of the highest flows at the rim to the center of the Basin would give an arched surface with a northeast-southwest axis. The most elevated point would be about 1,000 feet to 300 meters above the level of Diana's Peak (2,697 feet or 841 meters). Allowing for some denudation at the rim, the original height of the Main Massif may thus be estimated as approximately 4,000 feet or 1,220 meters. An initial height of the same order is obtained by extrapolating along the planes of the surface flows at the interstream spurs which have been least denuded. Oliver's estimate of 10,000–15,000 feet seems to be much too high.

The initial height of the Northeastern Massif was probably one or two hundred meters less.

The planes of the youngest flows at the sea-cliffs, when prolonged outwards, cut sea-level at distances averaging about 1,000 meters, though along the southern and southwestern shores the maximum distance may approach 2,000 meters. The 50-fathom line, which roughly locates the edge of the coastal shelf, is at a mean distance of about 1,800 meters from the shore. Somewhat more than one-half of the mean width of the shelf is thus due to wave-cutting in the solid rock. The remainder of the shelf is a detrital embankment, made up of: the débris from wave-action along 50 kilometers of shore-belt; débris from the hundreds of kilometers of canyons and broader valleys; and débris of marine organisms. The area of the shelf inside the 50-fathom isobath is nearly equivalent to the area of dry land. The time taken to form the shelf was long, and during that period Saint Helena appears to have been unaffected by any important change of level.

In some important respects Darwin's conception of the general structure differs from that just described. He distinguished an older series of "basaltic strata" and a younger series of "gray, feldspathic[2] lavas" and tuffs, the second series being the product of eruptions from the great central crater. He described the relation of the two series in the following passages: "We thus see that the circumference of the island is formed by a much-broken ring, or rather a horse-shoe of basalt, open to the south, and interrupted on the eastern side by many wide breaches. The breadth of this marginal fringe on the north-western side, where it is at all perfect, appears to vary from a mile to a mile and a half. The basaltic strata, as well as those of the subjacent basalt series, dip, with a moderate inclination, where they have not been subsequently disturbed, towards the sea. The more broken state of the basaltic ring round the eastern half, compared with the western half of the island, is evidently due to the much greater denuding power of the waves on the eastern or windward side, as is shown by the greater height of the cliffs on that side, than to leeward. Whether the margin of the basalt was breached, before or after the eruption of the lavas of the upper series, is doubtful; but as separate portions of the basaltic ring appear to have been tilted before that event, and from other reasons, it is more probable, that some at least of the breaches were first formed. Reconstructing in imagination, as far as is possible, the ring of basalt, the internal space or hollow, which has since been filled up with the matter erupted from the great central crater, appears to have been of an oval figure, eight or nine miles in length by about four miles in breadth, and with its axis directed in a NE. and SW. line, coincident with the present longest axis of the island . . . .

"There is much resemblance in structure and in geological history between St. Helena, St. Jago, and Mauritius. All three islands are bounded (at least in the parts which I was able to examine) by a ring of basaltic mountains, now much broken, but evidently once continuous. These mountains have, or apparently once had, their escarpements steep towards the interior of the island, and their strata dip outwards. I was able to ascertain, only in a few cases, the

[2] Along with other British geologists and mineralogists who helped in the foundation of their sciences, Darwin kept in the word "feldspathic" the "d" which is demanded by the etymology of the word. As the great standard, Murray dictionary of England notes, the spelling which now prevails in England, "felspathic," is corrupt and indefensible. Since the usage of the continental writers of Europe, like that of American writers, is uniform and correct, it is to be hoped that British writers will revert to the tradition set by Darwin and other leaders. Is there any reason why the eye of the scholarly student should continue to be offended, and his mind troubled, by having to read so often such words as "felspar" and "felspathic"?

inclination of the beds; nor was this easy, for the stratification was generally obscure, except when viewed from a distance. I feel, however, little doubt that, according to the researches of M. Elie de Beaumont, their average inclination is greater than that which they could have acquired, considering their thickness and compactness, by flowing down a sloping surface. At St. Helena, and at St. Jago, the basaltic strata rest on older and probably submarine beds of different composition. At all three islands, deluges of more recent lavas have flowed from the centre of the island, towards and between the basaltic mountains; and at St. Helena the central platform has been filled up by them. . . .

"These basaltic mountains come, I presume, into the class of Craters of elevation; it is immaterial whether the rings were ever completely formed, for the portions which now exist have so uniform a structure, that, if they do not form fragments of true craters, they cannot be classed with ordinary lines of elevation."

Accepting de Beaumont's hypothesis, Darwin offered the conjecture that "during the slow elevation of a volcanic district or island, in the centre of which one or more orifices continue open, and thus relieve the subterranean forces, the borders are elevated more than the central area; and that the portions thus upraised do not slope gently into the central, less elevated area, as does the calcareous stratum under the cone at St. Jago, and as does a large part of the circumference of Iceland, but that they are separated from it by curved faults. We might expect, from what we see along ordinary faults, that the strata on the upraised side, already dipping outwards from their original formation as lava-streams, would be tilted from the line of fault, and thus have their inclination increased. According to this hypothesis, which I am tempted to extend only to some few cases, it is not probable that the ring would ever be formed quite perfect; and from the elevation being slow, the upraised portions would generally be exposed to much denudation, and hence the ring become broken; we might also expect to find occasional inequalities in the dip of the upraised masses, as is the case at St. Jago. By this hypothesis the elevation of the districts in mass, and the flowing of deluges of lava from the central platforms, are likewise connected together. On this view the marginal basaltic mountains of the three foregoing islands might still be considered as forming 'Craters of elevation'; the kind of elevation implied having been slow, and the central hollow or platform having been formed, not by the arching of the surface, but simply by that part having been upraised to a less height."[3]

Darwin's separation of the "gray, feldspathic lavas" from the "basaltic strata" was doubtless prompted by the strong contrast between the deeply weathered rocks of the interior and the fresh rocks of the shore-belt. Careful study in the field and examination of thin sections with the microscope show, however, that the mantling flows from the high central ridge to the shore are all basaltic and without systematic differences related to their position in the island. As already stated, the mantling flows of the Main Massif, from ridge to shore, conform in dip, and their inclinations are no greater than those commonly observed in basaltic cones which have been built up by successive flows and explosions, without concurrent or subsequent updoming of the flows. Nowhere in the canyon sections is there any evidence of the curvilinear faulting, which Darwin supposed to have followed such central upthrust of the basaltic layers.

Darwin referred to rocks of Flagstaff Hill to his "upper feldspathic strata" and those of The Barn to his "basaltic strata." Here again modern methods of investigation show no mineralogical or chemical difference between these blocks of mantling flows; they are uniformly rather common types of basalt. The real differences are that the exposed flows of The Barn are thicker and dip more steeply than those of Flagstaff Hill. The dips on both sides of the Knotty Ridge Complex are relatively high, and Darwin's suggestion, that the mantling flows were lifted, anticlinally, by the upward pressure of magma which was injected into or beneath the Complex, should be seriously considered as one of the possible explanations. Oliver, too, regarded the high dips of The Barn flows as due to tilting after their accumulation.

Like other geological visitors, Darwin was struck by the profusion of dikes in the basal complexes. Writing of the Knotty Ridge Complex, he remarked: "The dikes, though so numerous on this ridge, are even more numerous in the valleys a little south of it, and to a degree I never saw equalled anywhere else: in these valleys they extend in less regular lines, covering the ground with a network, like a spider's web, and with some parts of the surface even appearing to consist wholly of dikes, interlaced by other dikes.

"From the complexity produced by the dikes, from the high inclination and anticlinal dip of the strata of the basal series, which

[3] Quotations from *Geological Observations on the Volcanic Islands*, 2nd ed. London, 1876, pp. 91, 105, 106, 108.

are overlaid, at the opposite ends of the short ridge, by two great masses of different ages and of different composition, I am not surprised that this singular section has been misunderstood. It has even been supposed to form part of a crater; but so far is this from having been the case, that the summit of Flagstaff Hill once formed the lower extremity of a sheet of lava and ashes, which were erupted from the central, crateriform ridge. Judging from the slope of the contemporaneous streams in an adjoining and undisturbed part of the island, the strata of the Flagstaff Hill must have been upturned at least twelve hundred feet, and probably much more, for the great truncated dikes on its summit show that it has been largely denuded. The summit of this hill now nearly equals in height the crateriform ridge; and before having been denuded, it was probably higher than this ridge, from which it is separated by a broad and much lower tract of country; we here, therefore, see that the lower extremity of a set of lava-streams have been tilted up to as great a height as, or perhaps greater than, the crater, down the flanks of which they originally flowed. I believe that dislocations on so grand a scale are extremely rare in volcanic districts. The formation of such numbers of dikes in this part of the island shows that the surface must have been stretched to a quite extraordinary degree."[4]

Darwin's mistake in thinking that the flows of Flagstaff Hill originated at vents centering in the Great Basin led him to believe in a specially great uplift along the axis of the Northeastern Massif, an amount of vertical movement which now appears inadmissible. Nevertheless, some displacement of the kind is probable, almost to the point of certainty. If not produced by direct magmatic pressure, according to Darwin's speculative explanation, the uplift may have been a phase of the rotation of the Flagstaff Hill and The Barn blocks on horizontal axes; each rotation increasing the original, outward dips of the lava flows by 15 or 20 degrees. As the writer studied this remarkable region, he could not resist asking himself the question whether the Northeastern Massif was torn open by a process which was like that apparently responsible for the gigantic rent in Haleakala of Maui Island, Hawaii. Simple gravity may have coöperated with magmatic pressure in the process, but, until more field data are secured, this problem relating to the Northeastern Massif must be left open.

Melliss thought it necessary to assume anticlinal upheaval of the

[4] Geological Observations on the Volcanic Islands, 2nd ed., London, 1876, p. 88.

basaltic rocks along an axis running from The Barn, through High Knoll, to High Hill at the southwest end of the island. This hypothesis is not supported by observations. Certain local changes of dip, instanced by Melliss in support of his view, are to be readily explained as variations in the original attitudes of the lava flows. His topographic evidence breaks down when it is realized that High Knoll and High Hill are due to massive, local extrusions of magma.

Finally, it may be noted that faulting is extremely rare in Saint Helena. If it were widespread, its effects could not fail to be manifest in the magnificent exposures of the sea-cliffs and canyon scarps. During a complete circuit of the island in a whale-boat, only one fault was visible in the cliffs. This occurs at Crown Point, northwest of the summit of Sugarloaf Hill. The fault-plane is nearly vertical and strikes about N. 15° E.; the downthrow, on the east; the displacement, about 10 meters.

It is hardly necessary to dwell on the fact that volcanic heat and hot springs have long ceased to affect sensibly the surface of the island. According to Melliss the St. Helena Monthly Register for 1810 reported a warm spring near Longwood. The temperature is there stated to have been 66° Fahr. or 6° "above the temperature of the surrounding atmosphere at the time of examination." These measurements evidently prove nothing of importance, the mean annual temperature of the ground not being stated. Melliss could not find the spring.

Rock Formations.

The foregoing account of the physiography of the island as a whole necessarily took notice of the leading structures. In order not to obscure the essential outlines of the subject, certain observations bearing on structure were not described; these may now be considered in connection with a description of the various rock formations of the island.

Dominant Rocks of the Main Massif. In general the bedded lavas of the mantle have dips which are centrifugal from a focal area in the Great Basin. This area is somewhat elongated in a northeast-southwest direction, extending from Riding Stones, through the peak, Lot, to a point about 1.5 kilometers southwest of Lot. In spite of the existence of at least three necks in the focal area, it is quite unsafe to assume that any or all of them represent the vents through which the greater part of the Main Massif was erupted. The necks are phonolitic or trachytic and seem to be distinctly younger than even the youngest basalts of the mantle. Conceivably these pipes were filled with basaltic magma, from which surface flows were fed, before it was replaced by the salic magma. On the other hand, there are no visible necks in the Northeastern Massif, where a quite similar mantle of basaltic flows was independently formed. At both centers the flows seem, rather, to have issued from fissures, which were there specially numerous, but qualitatively not different from the fissures, also dike-filled, in the other parts of the island. In other words, Saint Helena appears to be a composite volcano of the central type, but the "center" of eruptivity was a considerable area, tensioned, cracked, and periodically flooded by lava moving up the cracks, and not the simple pipe of the text-books. Because of the narrowness of the fissures, the magma near the surface must have quickly solidified, in the form of the existing dikes, so that eruptions were doubtless short-lived in each case. On the other hand, the persistence of the localized fissuring seems to necessitate the assumption of the existence of as persistent a magmatic column at great depth. It must be remembered that Saint Helena was already old before it appeared above sea-level, and that the observer in the field is looking at merely the top part of a volcano which was nearing extinction at the time of the first appearance of dry land.

Localized fissure-eruption has, apparently, been dominant during the later stage of growth of other oceanic volcanoes which have been studied by the writer; for example, the Samoan Tutuila and Manua Group, and several of the Hawaiian Islands. The eviscerated Krakatoa has similarly great exposures of the rocks far below the original surface, and there also one may suspect that the later lava flows emanated from local, though considerable, areas where fissuring was chronic. Is there a tendency for the eruptive mechanism to change its character as a basaltic volcano ages and attains a height of several kilometers?

The outward dips of the flows at the rim of the Great Basin average about 7 degrees. The mean of the mid-slope dips outside of the Basin is nearly 10 degrees, or twice that computed from the dips entered on Melliss's map. That map is wrong in showing horizontality for the flows along the northwestern shore. The cliff sections do exhibit horizontal lines of contact, but the flows are really dipping seawards at angles of from 5 to 15 degrees.

The flows of the mantle range in thickness from a meter or less to somewhat more than 30 meters. At Cole's Rock in the Great

Basin, one apparent flow has a minimum thickness of 55 meters. The average thickness is about 5 meters, a rule applying also to the mantle flows of the Northeastern Massif. In the cliff below High Knoll, seventy-five different flows in regular superposition may be counted.

The basalts are commonly amygdaloidal and, at their surfaces, scoriaceous. In some cliff sections the scoriaceous phases are seen to be strongly reddened. No generally accepted explanation of this type of reddening is at hand; a new suggestion on the subject has recently been published by the writer.[5] The thicker flows are of trappean habit. Columnar structure is rather rare; cliff outcrops are usually block-jointed or hackly. Occasionally ropy surfaces may be seen, but altering processes have been too active to allow many good exposures of the original backs of the flows. Block or aa lava seems to have been very seldom erupted in either massif.

No good representative of lava tunnels, so common in Hawaii, was found. A possible example, however, occurs at Munden's Point, where at the height of 10 meters above sea-level, an opening, 23 meters long, 1.7 meters in maximum height, and 2 meters in width, rises along the dip of a basaltic flow at an angle of 15 degrees. Whether some deepening and widening through the action of water has occurred, could not be determined.

Xenoliths are exceedingly rare in the flows of the island. Those found were merely fragments of older basaltic masses.

Pyroclastic deposits are not very conspicuous in the mantles of either of the two massifs. Those of the Main Massif are usually regular interbeds of brown tuff, one to two meters in thickness, among the flows. Much thicker, local deposits have been made at points where flank or subsidiary eruptions have taken place. Examples were seen: at an old quarry near Jamestown; at Tripe Bay, 700 meters northeast of Southwest Point; and along the shore south of Egg Island, which itself, however, is composed of basaltic flows. A considerable body of tuff is exposed at the surface of The Saddle, 1.5 kilometers north-northeast of High Hill, and apparently represents the residual of a steep-sided, adventitious cone, built on the youngest lava flow of the region. Basaltic tuffs, interbedded with thin basaltic flows, partly surround the trachytic rock of High Hill, and may be the product of explosion which prepared the way for the rise of that alkaline magma.

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[5] These PROCEEDINGS, vol. 60, 1925, p. 22; Publication No. 340, Carnegie Institution of Washington, 1924, p. 101.

One or more subsidiary centers of explosive eruption off the shore of Manatee Bay may be assumed, in order to account for strong local, northerly dips of certain lava and tuff beds in the adjacent cliffs.

Sill and Dikes. Some additional remarks concerning the many dikes may be useful. Beforehand, a note will be made on the only intrusive sheet seen in the whole of this massif.

In Thompson valley (see Plate I) a slightly curved, lenticular, sill-like mass, with greatest thickness of about 12 meters between the exposed roof and floor, cuts across a half-dozen basaltic flows at low angles. This sheet, showing pronounced columnar jointing, is probably basaltic. It was seen only at a distance, and no opportunity was given for closer study. A similar columnar sheet crops out on an inaccessible cliff along the seaward side of The Barn; it has an estimated thickness of 5 meters.

The dikes cutting the mantling flows in both massifs are naturally best displayed on the sea-cliffs, but it seems clear that the number rapidly decreases upwards. Nearly all of the dikes actually seen in the interior of the island, excepting the regions that include and immediately surround the basalt complexes, have been indicated on the geological map, Plate I. Because of the extensive lateritization a considerable number of others must have escaped notice. On the other hand, only a small fraction of the number exposed along the sea-cliffs has been plotted. Hence the map fairly expresses in principle the great contrast between the coast and upland sections with respect to the abundance of dike outcrops.

Three possible explanations suggest themselves. Many dikes may have risen into the pile of flows above sea-level, but not far above that level. Other dikes are likely to represent the feeding channels of some of the flows themselves and therefore continued upwards only to the levels of their respective outflows, which in their turn were covered by flows from younger fissures. Or, thirdly, some of the older dikes may have been truncated by erosion during the leisurely growth of the island cone. Darwin published a section (Figure 10 in his *Geological Observations*) which he interpreted as illustrating the third of these alternatives. The present writer was not able to find a similar case and doubts that prolonged intervals between the flows of the mantles were at all common. Nevertheless, a decided erosion-unconformity between the basalt complexes and their respective mantles of flows is possible, if, indeed, it may not already be regarded as probable. Unfortunately, time failed for special study of this important point in the field.

For the same reason the examination of the two basal complexes was most incomplete. In both areas the physical difficulty of actually traversing the ground is great, and the climbing often dangerous. The rocks are treacherously friable; their surfaces are commonly obscured by a thin, veneering plaster of detritus, which is constantly being washed down the steep slopes in wet weather. The partial study of the Sandy Bay Complex showed it to be a comparatively homogeneous, poorly stratified mass of brown and red, basaltic tuff, agglomerate, and thin slaggy flows, cut by a host of dikes of the same, basaltic composition. Occasionally the obscure bedding of the tuffs could be made out; the dips are variable in direction and low, with observed maximum of 8 degrees.

Many of the dikes in the Complex are only a few centimeters or decimeters in width. They are highly irregular, pinching out and thickening rapidly, and form many local networks of unmappable intricacy. These thinner dikes are more or less altered, and like the surrounding tuffs, are usually brown in color, so that the two types of rock can hardly be distinguished at a little distance from the outcrop. The agents of erosion have not been very definitely controlled by any lithological difference between dike and tuff, so that the majority of the dikes have not interfered with the development of a digitate pattern for the gulches cut in the Complex. (See Plates V–VII.) Several multiple dikes, each composed of single dikes numbering from three to six were seen along the main road to Sandy Bay.

In contrast, the topographic effect of the larger dikes is striking. Most of these form a "swarm," striking northeast-southwest, parallel to the length of the island (see Plate I). Being resistant to the weather, they tend to project above the surface of the rest of the Complex. By far the greater number are basaltic (Plates VI, VII and XXI). No simple dike of phonolitic or allied composition was found. The boldly projecting, neck-like masses of Castle Rock and Lot's Wife appear to be local enlargements of a master dike, which, at least to the northeast of Lot's Wife, is of basaltic composition (Plates VI, VII and XI, *B*). Again the writer had to mourn the lack of time for a close study of this important problem: the time and space relations between these large alkaline bodies and the conspicuous basaltic dike which runs into them. It would be particularly necessary to test the hypothesis that the alkaline magma displaced or replaced the basalt of the dike, using the same fissure for the ascent. A second question would be whether the basalt was already solid when the other magma was emplaced.

Similar problems relate to the dikes which on both sides trend directly into the phonolite of Lot (Plate V). The prominent Partridge Rock seems to be a local swelling in one of these dikes.

Melliss regarded the Speery Island (Figure 3), Castle Rock, Asses Ears, Lot's Wife, and Lot alkaline bodies as all located on a single curved fissure. Careful study in the field seemed, however, to show that, while Castle Rock and Lot's Wife are situated on the same, nearly straight fissure, Lot is situated on a second, parallel fissure. The Speery Island mass may be on a third line of fissuring.

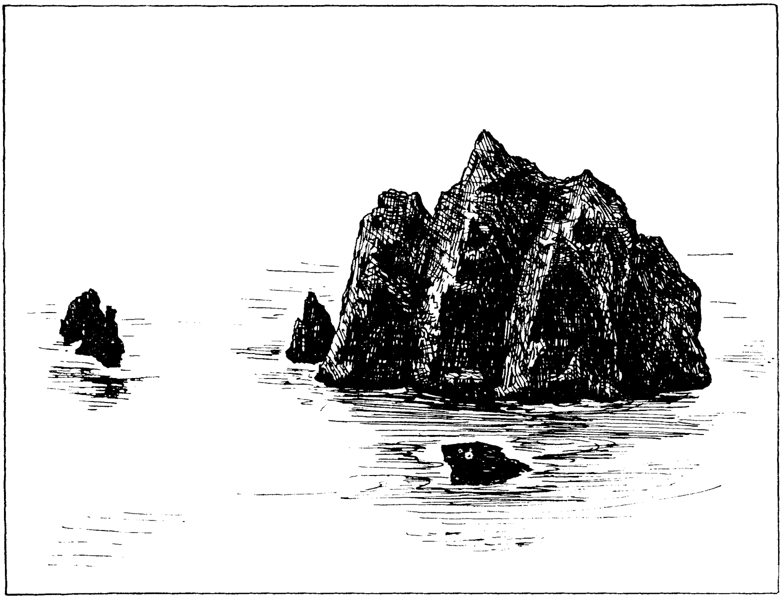

FIGURE 3. Speery Islet (right), a monolithic pipe of alkaline trachyte, now forming one of the largest sea-stacks at Saint Helena. The outlying rocks are basaltic, remnants of dikes and flows.

The profusion of dikes in Saint Helena is in striking and easily understood contrast with the extreme rarity of dikes exposed in the much younger Ascension Island, the constructional surface of which has been only slightly modified by denudation. Possibly, too, the remarkable tensional conditions that have affected the Saint Helena cone were never matched in the more youthful island.

South of the Bencoolen plateau-ridge, a 4.5-meter, vertical dike of phonolite cuts the basaltic flows for a long distance (see Plate I).

At the shore, near Elephant Rock, a dike-like intrusion of phonolitic trachyte, with a width of 10–15 meters and exposed length of 100 meters or more, cuts across the basaltic flows, here almost horizontal. The dike strikes N. 45° E. and at sea-level is nearly vertical. With the eye it can be followed far up the unscalable, 1,600-foot cliff of Great Stone Top, the dike bending gradually but rapidly, until the angle of dip, which has swung to the east-southeast, becomes no more than about 50 degrees. At the 1,000-foot contour the dike apparently passes directly into the huge phonolitic dome of Great Stone Top, for which, in fact, it seems to have been the feeder.

Three hundred meters west of Rofe Rock (wrongly printed "Rough Rock" on the War Office map) is a pod-like intrusion of phonolite or trachyte, which has parted and hoisted the basaltic flows, so that at the western contact of the intrusive the easterly eight-degree dip of the flows has been changed to a 45-degree dip to the west (Plate XV). The intrusive is about 250 meters long and 60–70 meters thick at the cliff section. A landing on the specially forbidding shore was not possible on account of the surf; hence a detailed study of this intrusion was not made. It seems to be a chonolith or cross-cutting laccolith.

From a boat a 20-meter intrusive sheet of light-colored, massive rock, probably phonolite or phonolitic trachyte, was seen to cut across the flows just to the eastward of the chonolith. At the top of the cliff the sheet dips at an angle of 20–25 degrees eastward; lower down it gradually becomes nearly vertical, and near sea-level it may connect with the chonolithic body.

Alkaline-rock Necks and Domes. The descriptions of the phonolitic and trachytic bodies, already given, are based largely on the topography and ground-plans. Actual contacts with the older basalts were seldom seen, though doubtless other contacts would be found during a more prolonged field study of the island. Basaltic xenoliths were observed in the phonolites. In no case was any mass of phonolite or trachyte seen to be cut by basalt, and it appears that all of the mapped, highly alkaline bodies are younger than the youngest exposed body of basaltic habit. Thus, so far as existing data permit one to judge, Saint Helena is here contrasted with Ascension Island, where the youngest basalts were erupted through the highly felsic, trachytic domes, necks, and crater-fillings.

The Great Stone Top dome recalls the trachytic domes so wonderfully preserved in Ascension Island. In spite of considerable denudation, this Saint Helena dome may be fairly well understood. Its maximum thickness, measured upward from the point where its feeding dike broke through the basalts to the surface, was originally at least 200 meters, and it may have been 300 meters. On its west-northwest side the dome sent a thick, sluggish flow down to a point about three-fifths of the way to the center of the Little Stone Top dome (Plate XIII, *A*). On the north the Great Stone Top dome has been vertically cliffed by the cutting of the Sharks Valley stream; and, on the east and south, partly destroyed by the waves. The cliffs thus produced are among the most imposing of the island. These natural sections show clearly that the dome magma accumulated on top of the basaltic flows (Plates XIII, *A*; XIV, and XV).

Though there is no connection at the visible surface, the Little Stone Top dome may be connected underground with the chonolith

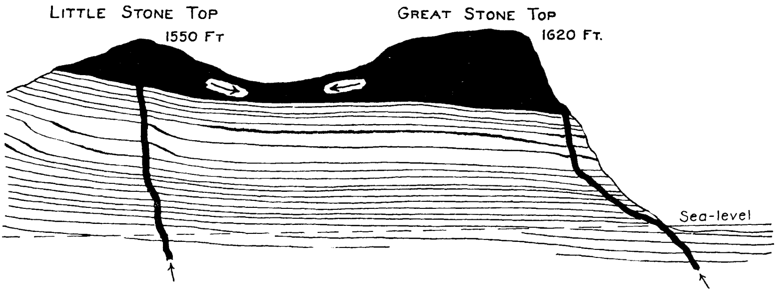

FIGURE 4. Section through the two phonolitic domes of Great Stone Top and Little Stone Top (solid black), showing: their relation to the underlying, older flows of basalt; the confluence of thick tongues from the domes (arrows); the visible dike-feeder of the dome of Great Stone Top; and the hypothetical dike-feeder of the dome of Little Stone Top. Much of the larger dome has been destroyed by marine and subaerial erosion.

just described. The phonolite of this dome has a gray phase and a greenish phase. The former may be merely the bleached equivalent of the green rock, but it is also possible that two different effusions of the phonolite are here represented. Both phases show the same carious weathering as that so characteristic of the soda-trachytes of Ascension Island. The Little Stone Top dome sent a stubby outflow eastwardly, and this offshoot became confluent with the great tongue from the Great Stone Top dome (Fig. 4 and Plate XIII). A second, highly viscous flow from the Little Stone Top mass seems to have been responsible for the thick flow of phonolite forming the Bencoolen ridge on the northeast. The Sharks Valley canyon has been cut through this flow into the underlying basalts. A third, shorter tongue crept down and now constitutes Boxwood Hill.

The High Hill body is another clear case of a monolithic, exogenous dome (Plate X, *A*). Its extrusion followed a period of heavy explosion, apparently at the same vent. The large mass of pyroclastic material is not shown on the map (Plate I). The tuffs and breccias dip about 25 degrees away from the dome, which probably filled a crater of some size.

Two of the phonolitic necks exhibit unusual types of jointing. At its top, the Lot pipe has a marked, nearly vertical system of joints, so that the rock is there columnar. From 30 to 40 meters below the summit this structure fades into that of a more massive, non-columnar phase with blocky jointing, not unlike the common kind in granite. The top of Castle Rock is even more strongly columnar

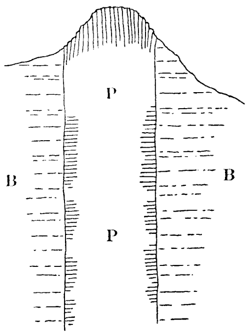

FIGURE 5. Diagram of cliff section of Castle Rock, seen from the west, showing at the top vertical, columnar jointing in this volcanic pipe (P), and along its sides horizontal, columnar jointing. The wall rocks are basaltic flows (B). The jointing is not apparent in the axial part of the pipe.

(Plate X, *B*). In the sea-cliff making the exposed face of this body, the vertical section has the appearance shown more or less diagrammatically in Figure 5. About 50 meters below the summit the vertical joints become inconspicuous, and, as at Lot, the structure tends to become massive. Another 50 meters farther down, however, a well developed system of horizontal joints, extending 5 or more meters from each vertical contact, is to be seen. These structural elements are presumably connected with the cooling contraction of the respective pipes.

Neck of Trachydoleritic Basalt at High Knoll. West of The Briars, the steep wall of James valley exhibits the eroded edges of many basaltic flows belonging to the Main Massif. At the top of the slope is the prominence called High Knoll (Plate XII). This hill is an erosional remnant of a vertical monolithic pipe of trachydoleritic basalt. On the outcrop the pipe measures about 180 meters in length and 60 meters in maximum width. Its major axis runs roughly northeast, or parallel to the axes of several dikes which crop out in James Valley. In fact the pipe narrows down to a width of 15 meters at the brink of the canyon-like cliff, and it looks as if the pipe is a gas-fluxed enlargement of one of the major dikes. The pipe itself, fine-grained throughout, was formed in the midst of a local series of tuffs and breccias, dipping steeply away on all sides of the pipe. The whole forms, in fact, a good example of an adventitious or lateral eruption on the flank of the main volcano.

Rocks of the Northeastern Massif. In principle the Knotty Ridge Complex is similar to that exposed in the Sandy Bay District; the description of the one will serve for the other, so far as the writer's limited information permits an account at all. Here also the dips of the tuffs and breccias, where seen, are low, in no case exceeding about 15 degrees. The seeming homogeneity of the complex is well illustrated in Plates XVII and XVIII. From a general view one could hardly be prepared for the discovery, made on closer acquaintance with the terrane, that it is a bewilderingly intricate assemblage of dikes in a matrix of weak pyroclastics. Besides countless networks of dikes, two main systems or "swarms" have been recognized. The one consists of many single, vertical dikes striking northeast-southwest, and thus parallel to the dominant system of dikes in the Sandy Bay Complex. This fact, as well as the general similarity of the two complexes, suggests that both are but part of one great basal formation.

Even more abundant are the dikes of the second system, striking N. 10–20° W. Some of them are nearly vertical, but the majority, simple or multiple, dip to the westward at angles ranging from 60° to 80°, with an average dip of about 70°. All the individual dikes are narrow, from a few centimeters to 3 meters in width. Chilled contacts are the rule, even in the multiple dikes. On the razor-back ridge connecting The Barn with Flagstaff Hill is the outcrop of a multiple dike, which is made up of nearly 200 single dikes, between which no tuff or other different material could be found. It was doubtless this section which so impressed Darwin, whose astonishment was manifested in the quotation on an earlier page. As he so clearly saw, this unrivalled example of multiple dikes implies a prolonged state of tension in the Saint Helena cone—a condition which can hardly fail to stimulate speculation as to the cause.

The mantling flows of The Barn have relatively steep dips of 25–30 degrees to the north-northeast. The average dip of the corresponding flows in Flagstaff Hill is about 22 degrees to the southwest, but farther along the ridge running to Sugarloaf Hill, it flattens to 5 degrees with a persistent strike of about N. 35° W. In the region between Banks Valley and Rupert Valley, the strike changes rapidly to N.-S. and N. 20° E., and then to N. 10° W., the dips increasing from 15 degrees to 35 degrees, always to the westward. The westerly dips persist to the floor of the Devil's Punchbowl, at the head of Rupert Valley, and to the eastern slope of the ridge between the two forks of Rupert Valley creek. On the ridge due east of Jamestown the flows dip 5 to 15 degrees to the northwest and also seem to belong to the Northeastern Massif. South of a line joining Turks Cap Bay and Longwood, and west of a line drawn between Jamestown and the head of Rupert Valley, the flows of the Northeastern Massif are unconformably covered by the flooding basalts from the Main focal area of eruption.

The younger flows of the Northeastern Massif are usually thin, from one to six meters in thickness, though some of those in The Barn are 30 meters thick, and one flow, at the Waterfall across the Complex from the Barn (Plate I), is 60 meters thick. These thicker flows show a decided tendency to take on a columnar structure.

The abnormally high dips of these flows demand explanation. A brief treatment of the problem has already been given in the section dealing with the physiography of the island. Here the list of questions suggested may be increased by the following: Is the prevailing, 70-degree, westerly dip of the Knotty Ridge dikes a departure from the normal vertical position of dikes, because these bodies have shared in the same rotatory displacement which would explain the high dips of The Barn flows?

Laterite. Over three-fourths of the island the basaltic rocks are greatly altered to the depth of several meters. The alteration is most profound in the eastern half of the island, especially on the gently sloping plains of the Deadwood, Longwood, and Prosperous Bay districts, where the surface rocks are deeply lateritized (Plates XIX, *A* and XX, *B*). The rim of the Great Basin is partly lateritized; there also the collection of fresh rock material is practically impossible. On slopes greater than 12–15 degrees the blanket of laterite is comparatively thin, as expected from the fact that rain-washing there has been more effective than on gentler slopes. The depth of the laterite in general is the greater because of the former, long-continued density of forest growth. The deforestation since the discovery of Saint Helena has already accelerated the dissection of the lateritized rocks, so that badlands have been developed over a considerable fraction of the surface between the central ridge and the eastern shore. Along the walls of a multitude of gulches the laterite, in variegated tints of gray-white, blue, purple, yellow, brown, and red, presents a bizarre appearance.

During the alteration of the basaltic rocks, the laterite has become seamed with veins of black oxide of manganese, which also forms nodules of considerable size. Other veins and nodules of the very pure, white to cream-colored clay, halloysite, outcrop at the surface.

On the Prosperous Bay plain, thin deposits of brown phosphate cover the lateritized basalt; they doubtless represent an ancient bird rookery.

Calcareous Sand Dunes. At various localities along the shore dune sands in moderate volume are to be found. They are composed of small fragments of shells, chiefly marine, mixed with varying amounts of basaltic grains. Melliss mentions their occurrence at Lot's Wife Ponds, Banks, Ridge, and Rupert Beach. The writer studied the sands at two localities.

One is situated at the 200-foot contour on the southeast side of the steep valley which mouths at Potato Bay, an inlet just east of Sandy Bay. There the poorly cemented, cross-bedded sand forms a continuous mass, about 10 meters thick, which is merely an erosion remnant. The nature and position of outlying patches show that the original thickness was of the order of 30 meters at least. This slightly impure limestone rests on basaltic flows which had been eroded before the deposition. The dune structure is typically displayed. At present the trade-wind is actively eroding the deposit, but no new calcareous material is being moved up from the beach, some 300 meters distant. Much of the carbonate has been dissolved by rain-water and now forms a tough travertine cement for talus and gravel, lower down in the gorge.

The second locality visited is on the opposite side of the island, at or a little above the 700-foot contour at the top of the cliff about 300 meters east of Sugarloaf Hill summit. The old sand rests on eroded basalt in a col which opens directly on the sea-cliff. Here also the deposit, now one to five meters thick, has been greatly diminished by wind and rain-wash, and no new additions are being made. The sand is poorly cemented with calcium carbonate, which forms travertine on the slope just below. In this deposit of sand

Darwin found land-shells, bones of birds and some large eggs, apparently of water-fowl. The land-shells represented one living and two extinct species.

From the site of the deposit to the beach the mean slope is approximately 45 degrees, and the upper part of the cliff is still steeper. The carriage of this moderately coarse sand up so high and so precipitous a cliff-slope, would indicate a surprisingly great strength of the wind at some former time. The difficulty of understanding the deposit would be lessened if it were shown that the slope to the beach were then gentler than at present. A somewhat more favorable, ramp-like course of the drifting sand may in fact be readily assumed; yet here, as at Potato Bay, the winds of the former time must have been very strong. It should be added that explanation of the notable height of the dune sand is hardly to be found in an assumed uplift of the island, as a whole or in part. No sign of the strand-line corresponding to so recent an emergence was discovered.

Darwin emphasizes another, more general question, which can hardly fail to occur to every geologist who studies these sands in the field. Darwin wrote: "It is remarkable that at the present day there are no shelly beaches on any part of the coast, whence calcareous dust could be drifted and winnowed; we therefore look back to a former period when before the land was worn into the present great precipices, a shelving coast, like that of Ascension, was favourable to the accumulation of shelly detritus."[6] It seems quite clear that all of these old dune deposits date from an epoch long subsequent to the stage when Saint Helena had a shelving coast, like that of Ascension; deep canyons and high sea-cliffs had already been developed beforehand. But the significance of the first clause of the sentence quoted is now the important thing.

Ascension Island has some strong beaches made up of calcareous detritus; Saint Helena now has none, its beaches being composed of volcanic rocks, usually in the form of boulders or large-pebble gravels. Yet at certain places offshore, at depths of 5 to 10 fathoms, there are large patches of nearly white sand, which are visible from high points on the cliffs. Good examples were seen off Potato Bay and Sandy Bay. These contemporaneous sands can hardly be anything else than masses of broken shells and algal remains. If the sea-level were lowered with moderate speed, some of this sand would be thrown landward by the waves and blown still farther in that direction by the

[6] Geological Observations on the Volcanic Islands, 2nd. ed., London, 1876, p. 99.

wind. Dunes so formed would grow and migrate until the bench, wave-cut at the new sea-level, again attains a profile of equilibrium, or until sea-level has risen once more.

The first alternative is exemplified by the post-Glacial, 5-meter, eustatic lowering of sea-level, which will be discussed on later pages.

The second cause for a change of régime may be sought in the much more important, eustatic changes of sea-level that were connected with Pleistocene glaciation and deglaciation. Which of these events was genetically connected with the formation of the old dunes, can not be declared in the light of known facts. Perhaps the second suggestion has some advantage, for the Glacial period was presumably a time of specially strong winds, such as must be postulated in order to explain the lift of the sand to great heights on the steep-to shores.

Report of Graywacke in Saint Helena.

Coming directly from Ascension, where a large collection of granitic and syenitic projectiles was made, the writer was specially desirous of exploring Saint Helena for analogous witnesses to a possible "continental" terrane beneath this cone. The result of his search, like that of Melliss, was entirely negative, nor had Webster and Darwin, the early collectors of granitic fragments in Ascension, a different experience when they studied the more southerly island. During three centuries a comparatively large number of intelligent inhabitants have been observing natural and artificial sections at their leisure; none has found a single fragment of quartz-bearing, granitic, gneissic, or sedimentary rock.

Hence Reinisch's description of a Saint Helena graywacke, containing angular pieces of quartzite, quartzite schist, tourmaline-bearing sandstone, phyllite, gneiss and granite, occasioned surprise and caused special research in the field.[7] This specimen was labelled as from the "Laing-Berg." a name quite unknown to the geography of Saint Helena. As already suggested, on page 151 of the 1920 volume of the Geological Magazine, the simplest explanation of the presence of the graywacke among the Saint Helena rocks examined by Reinisch is, that it was brought to the island from South Africa (Laingsburg region?). Was it imported by one of the Boer prisoners who were marooned here during Kruger's war, the specimen being later sent to Germany along with samples of the volcanic rocks? A gold-seeking prospector might easily care to take with him from

[7] R. Reinisch, Deutsche Südpolar-Expedition, 1901–1903, Band II, Geographie und Geologie, Berlin, 1912, p. 646.

Africa a specimen of the matrix of the Dwyka conglomerate. Reinisch himself expresses uncertainty that the graywacke originated in the island.

This negative result of prolonged field study of the question whether "continental" rocks underlie Saint Helena is not surprising, when one considers the great depth of the sea bottom surrounding the island cone. Light rocks should not be expected to occur in this part of the earth's crust, though their existence in the mid-Atlantic swell, beneath the Ascension cone, may be readily credited.

Petrography.

Not far from ninety-nine per cent of the volume of visible Saint Helena is of femic, basaltic nature. The remainder is almost entirely salic, phonolitic. Here, as in Ascension, Kerguelen, Tutuila (Samoa), Hawaii, and many other deep-sea islands, lavas intermediate in composition between basaltic and highly salic types are exceedingly rare, if not quite absent. The trachydoleritic basalt of High Knoll suggests, rather than represents, an intermediate chemical type; it will be described along with the dominant basaltic flows. The phonolitic bodies as a group will then be considered.

Basaltic Flows.

Reinisch described a number of specimens of basaltic habit, collected by a party belonging to the German South Polar Expedition.[8] Each of these rocks was referred to trachydolerite, but, since all except one specimen were profoundly altered by weathering, the classification remains doubtful. Reinisch's analysis of the one, comparatively fresh lava is copied in Col. 1. of Table I. He states that alkali-feldspar and a trace of nephelite occur in the groundmass of this specimen, which is one of the flows in Ladder Hill, overlooking Jamestown. The pyroxene is a "Titanaugit." Otherwise the list of mineral constituents is the same as that of an ordinary olivine basalt.

In all parts of the island flows of *olivine-rich basalt* appeared to be abundant. On the divide between James and Rupert valleys one of these flows was sampled for analysis. The exact locality is an outcrop on the road from Jamestown to Longwood at a point 200 meters east of The Briars cable station.

The sample, specimen No. 2882, has the habit of a dark gray, por-

[8] R. Reinisch, Deutsche Südpolar-Expedition, 1901–1903, Band II, p. 643.

phyritic basalt, poor in vesicles. The phenocrysts include olivine, reaching 5 millimeters in length, and augite in somewhat smaller individuals. Thin shells of serpentine surround some of the olivine crystals, but in general the rock has suffered little alteration. In thin section the olivine is colorless; the augite is pale gray with a suggestion of green. The groundmass is composed of basic labradorite, near $Ab_{30}An_{70}$, augite, olivine, much magnetite (probably titaniferous, like the pyroxene), and apatite. There is no discernible glass. The texture is doleritic to fluidal.

An analysis of specimen No. 2882, by H. S. Washington, gave the result shown in Col. 2, Table I; the norm in Col. 2, Table II. This basalt evidently has a strong tendency toward a picritic composition.

Perhaps even more abundant among the flows is a practically *normal olivine-poor basalt.* Representing these, specimen No. 2876 was selected for analysis. The specimen was taken on the path skirting the southwest slope of The Barn, where there is a steep cliff of basaltic rock forming what appears to be a thick flow. This cliff rock is quite fresh, compact, non-vesicular in the actual hand specimen, and dark gray with a greenish tinge. Microphenocrysts include augite; rare, small olivines, making up about 4 per cent of the rock; faintly zoned plagioclase, ranging from acid bytownite to acid labradorite. The groundmass is much like that of specimen No. 2882, but the feldspar appears to be more acid and near $Ab_{50}An_{50}$.

An analysis of specimen No. 2876, by H. S. Washington, is given in Col. 3, Table I; the norm in Col. 3, Table II. Though the silica is a little lower and the titanic oxide higher, this analysis agrees rather closely with the average analysis of the world's basalts, as named by authors.

Among the *olivine-poor basalts* of the Main Massif, specimen No. 2926, from a flow, was selected for analysis. It was collected at the sharp turn in the road about 900 meters southwest of the top of Diana's Peak. This rock is dark greenish-gray, compact, trappean, and non-vesicular. The microphenocrysts include a few minute olivines and somewhat more abundant laths of basic labradorite. The dense groundmass is the usual combination of pale greenish augite, labradorite, much iron ore, with apatite. The texture is strongly fluidal.

An analysis of specimen No. 2926, by H. S. Washington and Mary G. Keyes, is given in Col. 4, Table I; the norm in Col. 4, Table II. The rock may be regarded as a common basalt, slightly enriched in soda.

TABLE I.

SAINT HELENA ROCKS OF BASALTIC HABIT.

	1	2	3	4	5	6
SiO_2	43.72	45.50	46.12	47.10	49.99	50.02
TiO_2	.81	4.47	4.72	2.18	2.80	1.82
Al_2O_3	17.32	11.87	15.24	18.56	18.81	18.37
Fe_2O_3	7.21	3.09	5.70	1.94	4.62	4.25
FeO	6.03	9.25	6.42	9.55	7.16	6.78
MnO	—	.11	.11	.09	.12	.05
MgO	6.01	10.40	7.21	4.64	2.82	3.26
CaO	12.00	10.69	8.85	8.01	6.72	6.75
Na_2O	3.40	2.52	3.77	4.98	3.91	4.81
K_2O	1.57	.84	1.37	1.25	1.04	2.00
H_2O+	1.80	.98	.20	.37	.69	.94
H_2O-		.37	.05	.36	.65	.23
P_2O_5	.32	.14	.54	.52	.58	.34
Cr_2O_3	—	.12	—	—	—	—
SO_3	—	—	—	.20	—	—
	100.19	100.35	100.30	99.75	99.91	99.62
Sp. gr.	—	2.962	2.922	2.902	2.831	2.813

1. "Trachydolerite," flow, Ladder Hill; "tolerably fresh" (R. Reinisch).
2. Olivine-rich basalt, flow, road near cable station (H. S. Washington); BaO nil; ZrO_2, nil; Cl, nil; specimen No. 2882.
3. Olivine-poor basalt, flow, path from Knotty Ridge along southwest slope of The Barn (H. S. Washington); specimen No. 2876.
4. Olivine-poor basalt, flow, sharp turn in road, 900 meters southwest of top of Diana's Peak (H. S. Washington and M. G. Keyes); specimen No. 2926.
5. Olivine-poor to olivine-free basalt, flow, road 800 meters due west of summit of High Knoll (H. S. Washington and M. G. Keyes); specimen No. 2893.
6. Trachydoleritic basalt, pipe or crater-filling at High Knoll (H. S. Washington and M. G. Keyes); specimen No. 2908.

Since olivine-poor basalts constitute the greater part of Saint Helena, it was thought advisable to have still another sample analyzed. The specimen chosen, No. 2893, was collected on the road one-half mile due west of the summit of High Knoll. It was taken from the trappean, middle part of a normal flow. The petrographical description would be practically identical with that of specimen No. 2926 and need not be repeated.

The analysis of specimen No. 2893, by H. S. Washington and Mary G. Keyes, appears in Col. 5, Table I; the norm in Col. 5, Table II.

TABLE II.

NORMS OF ROCKS OF BASALTIC HABIT, TABLE I.

	1	2	3	4	5	6
Quartz	—	—	—	—	3.96	—
Orthoclase	9.45	5.00	8.34	7.23	6.12	11.68
Albite	8.91	19.65	27.77	26.20	33.01	36.16
Anorthite	27.24	18.90	20.29	24.46	30.02	22.80
Nephelite	10.79	.71	2.27	8.80	—	2.27
Corundum	—	—	—	—	.20	—
Diopside	24.08	26.56	15.77	9.68	—	7.51
Hypersthene	—	—	—	—	11.88	—
Olivine	5.18	14.87	7.49	13.95	—	7.67
Magnetite	10.44	4.41	7.19	2.78	6.73	6.03
Hematite	—	—	.80	—	—	—
Ilmenite	1.52	8.51	8.97	4.26	5.32	3.50
Apatite	.67	.34	1.34	1.34	1.34	.67
Water, etc.	1.80	1.35	.25	.93	1.34	1.17
	100.08	100.30	100.48	99.63	99.92	99.46

Note: Norms for Nos. 1, 2, and 4 computed by H. S. Washington.

TRACHYDOLERITIC BASALT OF THE HIGH KNOLL PIPE.

This monolithic mass fills a vertical, perhaps flaring, channel or crater-opening through a body of local tuffs. The tuffs dip away from the pipe-rock, apparently on all sides, at angles of 20° to 35°. The rock of the pipe, specimen No. 2908, has a uniform appearance; it is dark gray, compact, without macroscopic phenocrysts. A few small pores are filled with zeolites. The thin section exhibits a few small anhedra of phenocrystic olivine and more abundant crystals of zoned feldspar. The cores of these feldspars are basic labradorite; the narrow outer shells appear to be oligoclase. The groundmass is a confused aggregate of pale augite, much magnetite, and obscurely developed feldspar laths; the latter may include potash-feldspar as well as plagioclase more acid than labradorite.

An analysis of specimen No. 2908, by H. S. Washington and Mary G. Keyes, gave the result shown in Col. 6, Table I; the norm, in Col. 6, Table II. The rock may be classified as a *trachydoleritic basalt.*

Phonolites and Phonolitic Trachytes.

The salic bodies of Saint Helena (domes, necks, crater-fillings, a few thick flows, an irregular injection or chonolith, and two strong dikes) are true phonolites and closely allied soda-trachytes. In the latter nephelite is occult or a very subordinate constituent; even in the true phonolites of the island the proportion of nephelite is not known to exceed 12 per cent by weight. The range of chemical composition is shown by the five analyses now to be described.

Phonolite of "Lot." Prior has already given a good mineralogical account of a specimen from the neck, "Lot." He showed it to belong to the phonolites.[9]

The material of "Lot" seems to be nearly or quite homogeneous in a chemical sense. Though the mass is monolithic, there are some variations, due to the local development of facies slightly coarser in grain than the average of the neck, and facies slightly more charged with vesicles than the average, though at no place were such pores seen to be abundant. Here and there in the great outcrop, a faint platy, fluidal structure could be discerned, but its relation to the practically vertical contact walls of the neck was not determined. For about 30 meters down from the top of the neck, as exposed, there is a well developed, vertical, columnar jointing, which merges below into much more massive rock with imperfectly formed, widely spaced joints resembling those in many massive granites. Under the hammer the rock is extraordinarily sonorous.

As an introduction to the analysis some petrographic details, largely identical with those given by Prior, may be mentioned. The specimen selected for analysis, No. 2933, is fine-grained, light greenish-gray, and slightly porphyritic, with a peculiar shimmer due to the fluidal arrangement of the dominant feldspar. The larger crystals are anorthoclase, which also constitutes the bulk of the rock. This feldspar gives "curious undulose extinctions" and shows "very conspicuous wavy lines of parting" (Prior). The next most abundant mineral is aegirite-augite, slightly pleochroic and zoned. The narrow, outermost shells of some of these zoned pyroxenes have the low extinctions of true aegirite, but most of the pyroxenic material

[9] G. T. Prior, Mineral. Mag., vol. 13, 1903, p. 256.

seems to be aegirite-augite. Prior reported the dominant pyroxene to be aegirite and also found cossyrite in the "Lot" rock; the latter has not been identified by the present writer. A few small aggregates of iron-ore suggests that they may be late-magmatic replacements of some such mineral as aegirite or riebeckite. Nephelite occurs in many minute, commonly rectangular euhedra. Magnetite and very rare and inconspicuous apatite are the accessories.

An analysis of No. 2933, by H. S. Washington, is given in Col. 9, Table III; the norm is stated in Col. 9, Table IV.

Phonolite of Little Stone Top. The rock mass of Little Stone Top may be a composite and not a single body, like that at "Lot" or at Hooper Rock. However, the limited time available for the study in the field did not permit a definite conclusion on this point; it was then assumed that Little Stone Top is truly monolithic and since the freshest material was found in the coarse talus on the north side of the peaklet, it was decided to take it for chemical analysis (specimen 2887).

This specimen like all the others collected at Little Stone Top, has strong resemblance to the rocks of "Lot," "Lot's Wife," and Hooper Rock; it is slightly darker in tint than any of these, but shows the same peculiar shimmer and fluidal structure. Qualitatively the petrography is very similar to that already given for the phonolite at Hooper Rock, but here nephelite is probably less abundant, while apatite seems more abundant.

The analysis of specimen 2887 by Mary G. Keyes appears in Col. 7, Table III; the norm, in Col 7, Table IV.

Phonolite and phonolitic trachyte of the Sheep Knoll Dome-pipe. The large, monolithic mass which constitutes the conspicuous Sheep Knoll has petrographically much resemblance to the Chapel neck of phonolite. The Sheep Knoll rock is everywhere fine-grained to compact, with a rather dark, greenish-gray color. No gas-pores were observed. In the hand-specimen none of the minerals stands out, but under the microscope some ragged prisms of aegirite-augite are in the relation of phenocrysts to groundmass. The latter is composed of: a sanidine-like feldspar, apparently identical with that in the "Lot" phonolite and probably anorthoclase; nephelite; aegirite-augite; magnetite; apatite; and some cossyrite (?). The content of nephelite is variable and probably does not surpass ten per cent of the rock in any specimen. This mineral is largely altered to a murky mass, probably hydronephelite. For analysis specimen No. 2929, collected on the southeast side of the Knoll, near the contact with the flat-lying, basaltic flows, was chosen. The analysis, by Mary G. Keyes, is entered in Col. 8, Table III; the norm, in Col 8, Table IV.

TABLE III.

SAINT HELENA ROCKS OF PHONOLITIC HABIT.

	7	8	9	10	11
SiO_2	56.94	59.58	60.90	60.92	62.34
TiO_2	1.47	1.30	.30	.37	.66
Al_2O_3	16.89	16.9[illegible]	1[illegible].47	18.[illegible]1	17.35
Fe_2O_3	3.73	2.73	1.62	2.66	1.70
FeO	3.36	4.13	1.41	2.88	2.53
MnO	.17	.16	.17	.12	.19
MgO	.41	.24	.06	.05	.09
CaO	3.11	2.62	.85	1.68	1.31
Na_2O	8.06	7.12	7.60	7.70	6.88
K_2O	3.86	4.04	6.23	4.70	5.79
H_2O+	.03	1.22	1.19	.43	1.23
H_2O-	.70	.38	.20	.18	.28
P_2O_5	1.02	.15	.24	.34	.27
ZrO_2	—	—	—	—	.14
S	—	—	—	—	.02
	99.75	100.57	100.24	100.04	100.78
Sp. gr.	2.671	2.635	2.514	2.671	2.600

7. Phonolite of Little Stone Top (M. G. Keyes); specimen No. 2887.
8. Phonolite of Sheep Knoll dome or crater-filling (M. G. Keyes); CO_2, nil; specimen No. 2929.
9. Phonolite of Lot pipe or neck (H. S. Washington); specimen No. 2933.
10. Phonolite of the "Chapel" pipe (H. S. Washington and M. G. Keyes); specimen No. 2919.
11. Trachytic phonolite of Hooper Rock pipe or crater-filling (H. S. Washington); BaO, nil; Cl, nil; specimen No. 2925.

In this specimen, which is compact and of rather confused crystallization, no nephelite could be demonstrated. The analyzed facies of the Sheep Knoll mass may be classified as a soda-trachyte or as a phonolitic trachyte; it is probably transitional into the true phonolite, found on the northwest side of the body.

Phonolite of the Chapel Pipe. The round, monolithic pipe or neck at the Baptist Chapel in the "Great Crater" is composed of a shimmering, trachytic phonolite, much like the phonolite of Little Stone Top in field habit and in microscopic details. The feldspars, aegirite-augite, nephelite, and accessories are all sensibly like those of the "Lot" phonolite. Here also cossyrite fails and aegirite is quite subordinate to the aegirite-augite.

Specimen No. 2919, from the Chapel pipe, has been analyzed by H. S. Washington and Mary G. Keyes, with the result shown in Col. 10, Table III; the norm is given in Col. 10, Table IV.

TABLE IV.

NORMS OF ROCKS OF PHONOLITIC HABIT, TABLE III.

	7	8	9	10	11
Orthoclase	22.80	23.91	36.70	27.80	34.47
Albite	49.78	55.54	46.11	55.28	52.92
Anorthite	—	2.22	—	.56	—
Nephelite	8.52	2.56	9.94	5.25	1.99
Corundum	—	—	.20	—	—
Acmite	2.31	—	—	—	1.39
Wollastonite	1.16	.35	—	.12	—
Diopside	5.13	7.74	2.46	4.93	4.15
Olivine	—	—	—	—	.61
Magnetite	4.18	3.94	1.62	3.94	1.85
Ilmenite	2.89	2.43	.61	.76	1.21
Hematite	—	—	.48	—	—
Apatite	2.35	.34	.67	.67	.67
Water, etc.	.73	1.60	1.39	.61	1.67
	99.85	100.63	100.18	99.92	100.93

Note: Norms of Nos. 7, 8, and 10 computed by H. S. Washington.

Phonolite of Hooper Rock. The specimens collected from the neck or crater-filling at Hooper Rock are much like those from "Lot," but are of a slightly darker, bluer shade of color. They show the same shimmer on the dominant feldspar, which is arranged fluidally, trachytically, in the manner usual for all these Saint Helena bodies of alkaline rock. The leading constituents are anorthoclase, soda-sanidine (?), small euhedra of nephelite, and aegirite-augite. Ragged grains of a brown mineral, probably cossyrite, and a few granules of a colorless, diopsidic pyroxene, with magnetite and apatite are the accessories. The nephelite is not quite so abundant as in the specimen from "Lot."

Specimen No. 2925 from the Hooper Rock body has been analyzed by H. S. Washington, with the result given in Col. 11, Table III; the norm appears in Col. 11, Table IV.

Other Alkaline-rock Bodies. For the remaining masses of phonolitic habit, chemical analyses are not available. From the study of thin sections the best classification of some of the masses seems to be as follows: Great Stone Top dome, Bencoolen flow, the mapped dike alongside that flow, and the Riding Stones pipe or crater-filling, as phonolites; the two small pipes between Sheep Knoll and Sandy Bay Barn, and the Speery Island mass, as phonolitic trachytes with merely traces of nephelite. The High Hill crater-dome is represented by one specimen only, a soda-trachyte without visible nephelite.

The reference of Castle Rock and the chonolithic intrusion near Rofe Rock to the general group of phonolite-trachyte rocks is based on field habit and not at all on chemical or microscopic study, and is therefore tentative.

Some Comparisons and Conclusions.

Including Saint Helena, the writer has recently studied three deep-sea islands; the other two are Ascension, also in the Atlantic basin, and Tutuila of the Pacific Samoan group. During the mapping of each island he made special efforts to collect for analysis only fresh rocks, and particularly those samples which promised to give approximate average analyses for the leading rock-types of that island. Most of the specimens were analyzed in the laboratory of H. S. Washington; the remainder were analyzed by E. G. Radley and H. E. Vassar. Thus a high degree of analytical accuracy was ensured. Under the conditions a direct chemical comparison of the three island complexes is permitted.

For each island a simple, equal-weight average of all the available analyses of the basaltic rocks was computed, and, after the exclusion of water, reduced to the total of 100.00. See Table V. Averages for the corresponding analyses of the salic rocks are given in Table VI.

Of course none of these arithmetic means can be held to represent precisely the average composition of the actual, variable mass of

TABLE V.

COMPARISON OF AVERAGE ANALYSES: BASALTS (COMPUTED AS WATER-FREE AND TO 100.00).

	1	2	3	4	5	6
No. of analyses	4	3	5	5	50	198
SiO_2	47.62	49.68	48.44	46.97	49.35	49.87
TiO_2	3.57	2.76	4.29	.83	2.59	1.38
Al_2O_3	16.27	16.13	13.27	17.02	14.05	15.96
Fe_2O_3	3.87	4.02	4.06	11.32	3.40	5.47
FeO	8.17	7.47	8.27	4.30	9.94	6.47
MnO	.11	.24	.15	—	.21	.32
MgO	6.33	5.33	8.21	5.51	6.36	6.27
CaO	8.65	8.78	7.72	9.34	9.73	9.09
Na_2O	3.82	3.70	3.47	3.33	2.90	3.16
K_2O	1.14	1.31	1.55	1.05	1.00	1.55
P_2O_5	.45	.58	.57	.33	.47	.46
	100.00	100.00	100.00	100.00	100.00	100.00

1. Saint Helena, four flows.
2. Ascension Island, three flows.
3. Tutuila Island, Samoa, five flows.
4. Kerguelen Island, Indian Ocean, five flows.
5. Plateau basalt, fifty flows (see Publ. No. 340, Carnegie Inst. of Washington, 1924, p. 118).
6. Average of 198 analyses of basaltic rocks, world-wide distribution.

rocks concerned. Nevertheless, even from the limited data, certain conclusions may be derived:

1. Table V shows the great similarity of the average visible basalts in Saint Helena, Ascension, and Tutuila. Column 4, giving the average analysis of Kerguelen Island basalts, shows that the dominant effusive of this Indian Ocean cone is chemically almost identical with the dominant effusive in the other three, Atlantic and Pacific, islands.

2. All four averages are strikingly like the average computed for basaltic rocks all over the world (Col. 6, Table V). The 198 analyses used in the computation of this world average were chiefly made from basalts erupted on the continents. It appears, therefore, that the average visible basalt of the deep-sea basins is nearly or quite the same, chemically, as the average visible basalt of the continents.

3. That conclusion strengthens belief in the fundamental hypothesis of an eruptible basaltic substratum, everywhere underlying the crust of the earth, whether this crust itself be Sial (continental) or Sima (sub-oceanic). Because gravity so largely controls the differentiation of magmas, we should expect the average visible basalt of such central vents as those of our islands, to be somewhat more alkaline and aluminous, or more felsic, than the basalt of the undisturbed substratum. For the same reason the stated average analysis of the world basalts, which have been largely collected from eruptions of the central type and hence were more or less affected by gravitative differentiation, is likely to be a little more salic and felsic than the substratum. On the other hand, the great fissure-eruptions are most simply explained as tolerably direct emanations from the substratum. Erupted with relatively high speed, the plateau-basalts have not been so much exposed to change by differentiation (and assimilation) as the typical basalt of central eruptions. Thus we may assume the composition of the substratum to agree rather closely with the average analysis of the plateau-basalts, such as that given approximately in Col. 5, Table V. In principle Washington has come to the same conclusion.

Some students of earth-physics do not favor this hypothesis of a basaltic substratum. They prefer to think of the continental Sial as resting directly upon a general (world-circling), very thick shell of crystalline, peridotitic rock. Their belief is based on two sets of data: first, the speeds of earthquake waves in the earth-shells above and below the Mohorovičić discontinuity at the depth of 50–60 kilometers; secondly, the results of experiments on the compressibility of rocks and minerals. The correlation of the two kinds of record is, however, laden with difficulty and as yet is far from proving the existence of a peridotitic shell so close to the earth's surface. There is even some uncertainty as to the identification of the impulses which are instrumentally registered close to the center of any earthquake. Still more important may be the uncertainties as to: the importance of anisotropy, of elastic after-effects, of elastic hysteresis, and of allied complications in the physics of the earth's surface shell. These elements of the problem need much additional study, especially experimental study. One of the most significant experimental investigations would be to determine the effect of high pressure on the rigidity of crystalline rock and glass. Until this and other mysteries are dispelled, it seems safer to trust a reasonable conclusion from a host of field observations. The phenomena of fissure eruptions, the major central eruptions of the Saint Helena type, the normal sequence of eruption throughout the world, and the facts of isostasy seem clearly to demand a general substratum of hot, glassy, highly rigid, but very weak and therefore eruptible basalt.

TABLE VI.

Comparison of Average Analyses: Phonolites and Soda-trachytes (reduced to 100.00).

	1	2	3	4	5	6
No. of analyses	5	5	2	25	19	11
SiO_2	60.23	65.71	66.38	57.45	62.63	59.96
TiO_2	.42	.43	.65	.41	.62	.61
Al_2O_3	17.74	15.40	17.00	20.60	17.06	19.74
Fe_2O_3	2.49	3.46	2.12	2.35	3.01	2.11
FeO	2.87	1.12	1.33	1.03	1.98	1.37
MnO	.16	.22	.05	.13	.13	.20
MgO	.17	.27	.29	.30	.63	.56
CaO	1.92	1.07	1.62	1.50	1.51	2.75
Na_2O	7.50	6.36	5.35	8.84	6.26	6.21
K_2O	4.93	4.96	4.47	5.23	5.37	5.15
H_2O+	.82	.91	.40	2.04	.71	1.02
H_2O-	.35		.24			.20
P_2O_5	.40	.09	.10	.12	.09	.12
	100.00	100.00	100.00	100.00	100.00	100.00

1. Saint Helena, five rock-bodies, phonolitic.
2. Ascension, five rock-bodies, soda-trachytic.
3. Tutuila, two rock-bodies, soda-trachytic.
4. Average phonolite, world, 25 analyses.
5. Average alkaline trachyte, world, 19 analyses.
6. Auvergne, France, 11 analyses, phonolites.

4. The general field habit of the Saint Helena phonolites is remarkably similar to that of the classic phonolites of the Auvergne. The likeness appears also in the average analyses of the two groups of rock-bodies (Cols. 1 and 6, Table VI). The average phonolite "of the world" (Col. 4) is a little lower in silica and higher in soda than either of the former averages.

5. As noted in the Ascension memoir, the average trachyte of

Ascension Island is nearly identical with the average trachyte of Tutuila Island (Cols. 2 and 3, Table VI). In all these strongly alkaline rocks, normative quartz is abundant, and in some cases quartz is not occult but is present as a kind of micropoikilitic mesostasis, as if the last mineral to crystallize. Such free, modal quartz makes up about 10 per cent of the Ascension trachyte. If 10 per cent of silica be subtracted from the Ascension average (Col. 2) and the remainder re-calculated to 100.00 per cent, the oxide proportions obtained are close to those in the average phonolite of Saint Helena. Is this relation significant for the theory of the differentiation of soda-trachyte and phonolite?

6. Though trachydoleritic types are found among the Saint Helena lavas, the overwhelming body of lava is clearly not essexitic or trachydoleritic, but is common basalt. Here, as elsewhere, there is nothing to indicate a primary origin for the trachydoleritic type of effusive; it is most simply explained as a differentiate of common basalt.

7. Chemical varieties intermediate between the trachydoleritic basalt and phonolitic types of Saint Helena have not yet been identified in the island. Nevertheless, the structural relations, volume ratios, and order of eruption agree with the hypothesis that the phonolitic types have been derived from the common-basaltic magma, and presumably by a further advance of the same process of differentiation as that through which the trachydoleritic type originated.

Further, this process is in all probability very nearly the same as that responsible for the phonolitic trachytes and soda-trachytes of the deep-sea islands. The modes of occurrence and other field relations of all such trachytes are almost, if not quite, identical with those of the deep-sea phonolites. It will be remembered also that among others, M. Boule, P. Glangeaud, and H. S. Washington have found phonolite and soda-trachyte transitional into each other and thus in each case as facies of the same eruptive body.[10] The importance of the problem is suggested by the great number of volcanic islands—each a gigantic, composite cone with merely a small, upper part visible—which display the Saint Helena type of relation between phonolite, phonolitic trachyte, or soda-trachyte to dominant basalt. The list of such islands includes:

[10] M. Boule, Bull. service carte géol. France, No. 54, 1896, p. 20; P. Glangeaud, ibid., No. 123, 1909, p. 86; H. S. Washington, Amer. Jour. Science, vol. 39, 1915, p. 519.

In the Atlantic basin: Ascension, Madeira, Porto Santo, Azores (Sao Miguel, Terceira, Graciosa), Selvagems, Canaries, Cape Verdes (Fogo, Brava, Sal, Sao Nicolao, Boavista, San Anteo, Sao Thiago), Sao Thomé, Fernando Noronha, Nightingale, Gough;

In the Indian Ocean basin: Possession, Heard, Kerguelen, Réunion;

In the Pacific basin: Society group (Tahiti, Raiatea), Samoan group (Savaii, Tutuila), Hawaii, Juan Fernandez group (Masafuera), Easter, Marquesas group (Nouka Hiva).

When to this list, incomplete as it is, the many similar rock associations on the continents be added, it is clear that the genetic problem of the phonolites is one of the most significant in petrology.

Saint Helena cone a Load on the Earth's Crust; Mode of Support.

In 1886 Faye published the results of his comprehensive study of the value of gravity at deep-sea islands. In all cases the computed anomaly is positive and was phrased by Faye in terms of the excess number of vibrations of the pendulum per day.[11]

The mean of seventeen determinations of the anomaly at as many islands is + 5.26 vibrations; the anomaly at Jamestown, Saint Helena was + 9.32 vibrations. At Jamestown the station was 10 meters above sea-level. In 1912 Hayford and Bowie published their computations of the Free Air, Bouguer, and New Method anomalies for this station, expressed in dynes.[12]

The values were:

$$\text{Free Air } (g_0 - \gamma_0) = +.228$$
$$\text{Bouguer } (g_0'' - \gamma_0) = +.227$$
$$\text{New Method } (g - g_c + 0.007) = +.058$$

The correction for topography and assumed isostatic compensation (which was supposed uniform and distributed to a depth of 113.7 kilometers) was +. 177 dyne.

Five years later Bowie issued a table giving the following data for the Jamestown station[13]:

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[11] H. A. Faye, Comptes Rendus, vol. 102, 1886, p. 651; see also O. Fisher, Physics of the Earth's Crust, 2nd. ed., London, 1891, p. 252.

[12] J. F. Hayford and W. Bowie, Special Publication No. 10, U. S. Coast and Geodetic Survey, 1912, p. 81.

[13] W. Bowie, U. S. Coast and Geodetic Survey, Special Publication No. 40, 1917, p. 57.

Theoretical gravity	978.418	dynes
Correction for elevation	− .003	"
Correction for topography and compensation	+ .177	"
Observed gravity	978.712	"
New Method anomaly, based on formula used in 1912	+ .112	"
New Method anomaly, based on 1917 formula	+ .120	"

The following table shows the New Method anomalies, given for various deep-sea islands in the 1912 and 1917 publications.

	Elevation (meters)	*Anomaly, 1912* (dynes)	*Anomaly, 1917* (dynes)
Jamestown, St. Helena	10	+ 0.058	+ 0.120
St. Georges, Bermuda	2	+ 0.018	+ 0.080
Honolulu, Oahu	6	+ 0.052	+ 0.075
Mauna Kea, Hawaii	3,981	+ 0.183	+ 0.206

All four anomalies, computed with 1917 data, are larger than those computed with 1912 data. The cause of these discrepancies is not apparent. By letter Dr. William Bowie has suggested that in part the differences may be explained by "some readjustment of the network of gravity stations of the world." All of the gravity stations today have their values based on the absolute value of gravity at Potsdam. The differences are partly "due to some adjustment made at the Potsdam office of the Prussian Geodetic Institute between the dates of publication of the two (1912 and 1917) volumes."

The New Method anomalies are calculated on the assumption that isostasy is complete at these island stations. This assumption means that the lavas forming the emerged islands and their bases above the sea bottom were merely transferred parts of the "crust"; that is, that they were originally parts of the layer above the assumed level of isostatic compensation. Each cone is, in effect, supposed to be supported because the material immediately beneath in each case has expanded to an amount nearly equal to the respective volumes of the cones. Yet geologists are not able to point to any condition which would lead to such localized expansion of the crust under volcanic cones. They are likely to agree that important expansion of the kind is highly improbable.

The New Method anomalies have been computed according to Pratt's explanation of isostasy. Airy's "mountain-root" explanation is clearly preferable in the case of the cordilleras of the Alpine type, but we have no good ground for postulating the existence of deep-going, light "roots" under the deep-sea volcanoes.

One may well doubt that the correction for topography and isostatic compensation at Jamestown is as great as 0.177 dyne. The Saint Helena cone is slightly porous, but its density from surface to sea-bottom is probably higher than that of a continental layer at the same level. Below the base of the cone the density of the crust can hardly differ essentially from the density of the surrounding crust.

Probably, therefore, the excess mass represented in this island is much greater than the excess computed on the assumption of uniform, isostatic compensation to the depth of 113.7 kilometers. The Bowie anomaly of 1917 itself means an excess of matter in the cone below the station which is equal to a layer of rock with the density of 2.7 and a thickness of nearly 1,200 meters.

Born gives the Bouguer and Free-air anomalies for a number of deep-sea islands.[14] From his table the values shown below have been abstracted.

	Height of station (meters)	*Bouguer anomaly* (dynes)	*Free-air anomaly* (dynes)
St. Vincent, Cape Verde Ids.	10	+ .288	+ .289
Ascension	5	+ .201	+ .202
Ascension, Green Mountain	686	+ .153	+ .218
St. Helena, Longwood	533	+ .263	+ .314
St. Helena, Jamestown	10	+ .296	+ .297
Bermuda	2	+ .298	+ .298
Fernando de Noronha	10	—	+ .268
Isle de France, Mascarenes	16	+ .257	+ .259
Kerguelen	15	+ .113	+ .115
Oahu, Honolulu	4	—	+ .251
Hawaii, Mauna Kea	3981	+ .283	+ .669
Ualau, Carolines	2	+ .311	+ .311
Taihae, Marquesas	15	+ .187	+ .189

The average Bouguer anomaly for twenty islands, listed by Born, is + .243 dyne. The corresponding force represents the attraction of a layer of rock with the density of 2.7 and thickness of more than 2,400 meters. Such a layer would approximate in attractive power to the mass of the average island cone, measured from the sea-bottom, minus the mass of water displaced.

[14] A. Born, Isostasie und Schweremessung, Berlin, 1923, p. 144.

Assuming no compensation, the excess mass in the Saint Helena case would be equal to a layer of 2.7 rock with thickness of about 2,800 meters. Can one doubt that a large part of this huge mass, like the cone of Ascension, is supported by the strength of the crust? Barrell has already shown the necessity of attributing even greater strength to the sub-Pacific crust.[15]

On the other hand, Born believes the deep-sea volcanic cones to be unstable, and agrees with Molengraaff in the view that they are all slowly sinking.[16] Saint Helena does not seem to comfirm this hypothesis. The sea-cut cliffs surrounding the emerged part of this great cone have heights so great that we must believe the island has kept a nearly constant relation to sea-level for hundreds of thousands of years—probably since a pre-Glacial epoch. The detrital shelf is correspondingly broad and its surface has practically the same depth below sea-level as the shelves around continental shores, where there is no hint of subsidence since pre-Glacial time.

The stability of Saint Helena is further suggested by the feebleness of seismic activity in the island. On this subject Melliss wrote (page 73 of his book): "Earthquakes happen so rarely, and when they do are so slight, that they scarcely need be noticed as occurring at all. Four only have been recorded during the last 370 years—viz., one on the 15th June, 1756; another in 1780; one on the 21st September, 1817; and the last on the 15th July, 1864." The low seismicity must also be inferred from the existence of many slender erosion columns, and from the rarity of recent landslides. Even a rather weak earthquake could not fail to dislodge many large masses of weak rocks from the peaks and very steep valley-walls and sea-cliffs of this exceptionally dissected island.

Conceivably some compensation for such cone-loads as Saint Helena takes the form of the downbending of the crust, so that each cone is surrounded by a broad belt of water somewhat deeper than the general sea-bottom in the region concerned. Thus there might be a kind of regional compensation for each cone-load. The available soundings do not permit of a decision as to whether any cone actually stands in a depressed, basined area of the kind. In any case, however, the crust elastically supports considerable loads. These probably represent maximum shearing-stresses of 100–300 kilograms per square centimeter.

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[15] J. Barrell, Jour. Geology, vol. 33, 1915, p. 37.
[16] G. A. F. Molengraaff, Kon. Akad. Wetenschappen, Amsterdam, 1916, p. 619.

In the continental areas the crust may be weaker. This possibility is suggested by the apparently isostatic response of the crust after the water of Lake Bonneville was evaporated. There the negative load was much smaller than the load represented by any of the deep-sea volcanic cones, with respect both to mean pressure per unit area of the crust and to the area loaded.[17] The sensitiveness of the crust in Pleistocene Utah may be connected with the special amount of fracturing and faulting suffered by the whole Great Basin region near the close of the Pliocene. Perhaps also the crust was there weakened also by the associated injection of magma. On the other hand, the strength of the suboceanic crust is probably somewhat increased by the pressure of the ocean water.

The question of the horizontal variation in the strength of the crust is wide open, but both geological and gravity observations clearly show the suboceanic crust to be able to bear permanently a load equal to a large fraction of a volcanic cone, built up from the sea-bottom.

When we remember that the cone, considered as an extra load on the crust, could sink only by downpunching of the crust beneath, much as holes in metal sheets are punched with a die, we have great difficulty in believing in the final, complete disappearance of the cone through isostatic adjustment. For this reason alone one must doubt that the deep-sea volcanoes keep steadily sinking because of their own weights. Still more compelling are the field proofs of stability for Saint Helena during the larger part of a million years at least. Explanation of coral atolls and barrier reefs by isostatic adjustments is not supported by the relevant facts observed at Saint Helena.

A reasonable interpretation of the gravity anomalies at the oceanic islands throws doubt on one of Wegener's fundamental assumptions—that the suboceanic part of the earth's crust has practically no strength at all. If continental blocks have actually migrated far into oceanic regions of the globe, the only possible condition for overcoming the elastic resistance of the suboceanic crust seems to be the foundering of that crust at equal pace with the continental sliding.[18]

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[17] G. K. Gilbert, Monograph 1, U. S. Geol. Survey, 1890, p. 379.

[18] A. Wegener, Die Entstehung der Kontinente und Ozeane, 3rd ed., Braunschweig, 1922, p. 92 (translated into English, London, 1924). See R. A. Daly, Amer. Jour. Science, vol. 5, 1923, p. 365; Proc. Amer. Phil. Soc., vol. 64, 1925, p. 283; Our Mobile Earth (New York, 1926), p. 270.

Recent Emergence: A Eustatic Change of Sea-level.

In 1919, as a member of a field party sent out by the Carnegie Institution of Washington, the writer studied evidences of coastal emergence in Florida and in Samoa. His report, *The Geology of American Samoa,* has recently been published by the Institution as part of a memorial volume (Publication No. 340), dedicated to the memory of Alfred G. Mayor, the lamented, able leader of both expeditions, whose devotion to science cost him his life in the fullness of his powers. During these investigations recent emergence to the extent of at least 4 meters was demonstrated in each of the two regions, which are about 10,000 kilometers apart. Combining that result with those attained at some other localities, and also with the published data of workers in Canada, the British Isles, the Atlantic coastal plain south of New York, the West Indies, Brazil, Patagonia, New Zealand, Australia, and various Pacific islands, it seemed justifiable to assume that this recent emergence of a few meters was due to world-wide or eustatic sinking of sea-level. That hypothesis was described in the Geological Magazine, vol. 57, 1920, pp. 246–261, and in the Proceedings of the National Academy of Sciences, vol. 6, 1920, pp. 246–250.

The amount of the eustatic shift was there stated to be about 20 feet or 6 meters. The inner edges of the rock benches of the deep-sea islands actually studied were in no case more than about 14 feet above the present mean sea-level. It was noted that the inner edges of the benches now being cut by the undamped waves of the same islands are generally covered with a few feet of water at mid-tide, the accompanying sea-cliff rising steeply from that depth. Hence, in order to determine the correct shift of level, a few feet should be added to the maximum height of the rock benches. Detailed observation in Samoa suggested that this additional amount for well exposed deep-sea islands should be taken as about six feet; and the total shift of level was accordingly described in 1920 as about 20 feet.

Later field studies and discussions with other observers have since indicated that the eustatic shift here considered may have averaged no more than 15–16 feet or 5 meters.

Absolute equality for the emergence all over the ocean is of course not to be expected, even if the deleveling was eustatic. Any world-wide displacement of ocean-water changes the gravitational potential and also causes elastic changes in the earth's body. For both reasons the ultimate shape and radii of the geoid must differ somewhat from its shape and radii that ruled before any change was made. These secondary effects would be small and could not be easily separated from the deleveling effect of the primary displacement of sea-water.

Possibly it is safer to describe this eustatic shift as a "5-meter" emergence, rather than as a "6-meter" or "20-foot" emergence. For the present the average shift of level over the whole ocean is taken to be about 5 meters. The regional variations from that average, due to the gravitational and elastic effects just noted, are probably confined to a range of 1 meter above, and 1 meter below, the average of about 5 meters.

The Shaler Memorial expedition to South Africa and the mid-Atlantic islands offered a chance to test the hypothesis at new and distant localities. At the Cape of Good Hope (Plates XXIV and XXV) and near Luederitzbucht in Southwest Africa, emergence of 4–6 meters was proved. Excepting at one of the oldest parts of Ascension Island (Southwest Bay), no suggestion of a similar deleveling could there be found. However, Ascension is a very young island, so young that the eustatic shift may well have taken place before Ascension reached its present size. Or Ascension may have recently sunk, leaving no good trace of the former strand-level. In any case the lack of positive evidence at this locality can not be regarded as significant. On the other hand, Saint Helena, a much older island, shows recent emergence to the extent demanded by the eustatic hypothesis.

At many points along the leeward side of the island, the very steep or quite vertical cliffs rise from the inner edges of inclined rock-benches which are strikingly similar to those cut in the lavas of Tutuila and other islands of the Samoan group (Plate XXII).[19] Most of the Saint Helena benches are, at their inner edges, about 10 feet above high-water mark or 11 feet above mean sea-level. The spring and neap tides at Jamestown have respective ranges of 2.8 and 1.3 feet. The inner edge of a bench at Munden's Point is exceptionally high, at 19 feet above mean sea-level. Its seaward slope is about 1:9, and its width, 130 feet. Outside it is edged by a wave-cut cliff from 3 to 5 feet in height; this young cliff plunges vertically into about 6 feet of water. Like many others, the bench is cut in strong, massive flows of basalt. Some of the benches are cut in ancient coarse talus, or rock-slide material, which was cemented into a very strong mass, after the manner of the older beach-rock formations within the

[19] See also Plates 6, 7 and 8 in *The Geology of American Samoa*, referred to in the text.

tropics. Since the degree of cementation is also possible through the action of spray from the surf, such benches are probably not certain indications of emergence, though their heights and widths agree well with those of the benches developed on the solid ledges of lava.

The average slope of the benches is 1:5 or 1:6, agreeing rather well with the average slope of the present sea-bottom, close inshore. By special soundings such profiles were obtained at three sections, indicated as follows:

Distance from shore, in feet.	*Depth in feet.*		
	A	B	C
100	27	36	36
200	51	36	42
300	60	60	57
500	78	81	87
1000	141	117	—

A. Off the point on the west side of Lemon Valley Bay.

B. Off the point 1000 meters to the northeast.

C. Off the point 1300 meters farther to the northeast, near the mouth of Breakneck Valley.

The significance of the benches so far described is somewhat obscured by the existence of other, lower benches, which represent merely the backs of outwardly dipping flows of basalt, the over-burdens of which have been recently quarried away by the waves. Differential erosion of the kind could often be observed, where tuffaceous interbeds have been thus removed. The suggestion that the higher benches have been similarly formed by the waves acting at the present sea-level is opposed by several facts.

Ascension Island suffers wave-attack which is about as effective as that at Saint Helena, and the rocks and structures now being cliffed are essentially similar in the two islands. Yet inclined benches, systematically developed as at the more southerly island, are not seen at Ascension.

Secondly, one may well doubt the ability of the waves to maintain these benches while driving back vertical or nearly vertical cliffs, which are 150 to 200 meters high and are bottomed at the inner edges of the benches. Though the benches have ramp shapes, the bases of the cliffs are wetted only during a few days in the year; even then the blows of the surges at the tops of the benches can hardly be very effective.

Any doubts as to the proper interpretation of the higher benches were dissipated when a number of dry sea-caves were found at their inner edges. The caves give unequivocal evidence of a sensibly uniform emergence of at least 4 meters but not greater than 6 meters.

One of the largest of the dry caves is a conspicuous black hole in the lava flows at Hickshall Point, the cape next west of the axis of Breakneck Valley (Plate XXIII, *B*). The cave is fronted by a ramp-like, sea-cut bench, of which the inner edge is generally about 3.5 meters above mean sea-level; at one place it is 6 meters high. The floor of the cave at its mouth is 3.5 meters above the same datum; the roof, at 10–11 meters. The width at the opening is 8 meters. The length of the tunnel, measured from the cliff face, is 33 meters. At the inner end of the cave its floor is about 9 meters above mean sea-level and is composed of thousands of well-rounded boulders and pebbles. These are 55 meters from the actual shore. The flooring boulders are dusty and evidently have not been disturbed for a long time. Those in the outer half of the cave are toughly cemented with calcium carbonate, which was doubtless precipitated from spray during the slow emergence. Probably, too, spray wets this part of the floor when the heaviest rollers of the present epoch are playing.

Five small sea-caves have been cut into the strong basalts at the inner edge of the Munden's Point bench. At their mouths their floors are 3 to 6 meters above mean sea-level. On the bench in front some rude pits, resembling pot-holes, were excavated by the waves. The opening of one of these nearly circular holes is 4 meters above mean sea-level; it could hardly have been formed except below sea-level.

Other dry caves were seen at 300–400 meters southwest of the causeway at Jamestown, and again on Chubb's Point, about as far northeast of Munden's Point. These and still others less conspicuous testify to the same amount of emergence. The common height of 3–4 meters at the floors where the caves open upon their respective benches, is certainly less than the amount of the emergence. The caves now being cut by the waves have their lips from 1 to 4 or even more meters below mean sea-level (Plate XXIII, *A*). A depth of 2 to 3 meters seems quite common. A proper, corresponding addition to the observed heights of the dry caves must give an amount of emergence somewhat greater than 4 meters.

On the other hand, the recent emergence was clearly not as much as 9 meters, because at several points along the shore fairly thick beds of weak tuffs crop out in the cliffs with full exposure to the sea, at heights of 9 to 10 meters, and yet are not specially excavated.

Besides the evidences from benches and sea-caves, the recent cliffing of the gravel deltas of James and Rupert creeks may be noted. In spite of much artificial modification of the seaward edges of these deposits, it seems clear that the sea waves have there developed scarps from 3 to 6 meters in height. At Rupert Valley the scarped edge has been used as the base of a wall of fortification.

The technique of measuring so slight a change of level is obviously delicate. It was only by weighing together all of the observations made along the leeward shore that an estimate of the shift of level became fixed as close to 5 meters.

On the windward side of Saint Helena no dry cave or bench corresponding to those just described was discovered. Because of the more rapid abrasion along the windward shore, such comparatively small features would soon be destroyed.

The essential similarity of the caves and benches at Saint Helena with those at the Cape of Good Hope, 3,000 kilometers away, and with those in Samoa, 16,000 kilometers distant—with respect to both form and height above sea—is a personally observed fact. Emergence of coasts by practically the same amount has been proved at many other localities, described by the authors listed in the 1920 paper and also in various writings published since 1920. Still other instances have been brought to the writer's attention either by letters or orally.

Among the new examples are those derived from: West Africa (L. D. Burling, personal communication); the 1,200-kilometer chain of the Hawaiian Islands (N. E. A. Hinds, C. K. Wentworth, and H. S. Palmer); Nauru Island, west-central Pacific (Bohne); Henderson Island, south Pacific; New Zealand; Norfolk Island, south Pacific; South Australia (Howchin); Bermuda (R. W. Sayles and T. H. Clark); Cayman Islands (C. A. Matley).

Studer's statement of recent emergence of Kerguelen Island of the Indian-ocean basin was overlooked in 1920; the change of level in that other distant oceans seems to match the eustatic hypothesis perfectly.[20]

The fiducial points are steadily increasing in number; the strength of the explanation is bound to increase still faster.

Naturally field evidence of a recent eustatic shift of sea-level may be wholly negative, or else not easily discerned, in those parts of the earth where, during the last few millenia, there has been warping or

[20] T. Studer, Zeit. deut. geol. Ges., vol. 30, 1878, p. 346.

faulting of the crust. The notable deleveling connected with the catastrophic earthquake of 1923 in Japan is only one example of crustal movements in that archipelago during the last few centuries. In addition, Japan is celebrated for its continuing bradyseismic displacements. The difficulty of there testing the reality of a eustatic change of sea-level, supposed to take place some thousands of years ago, is apparent.

Another illustration is found in any of the belts peripheral to the lands which were depressed by the weight of Pleistocene ice-caps. If the assumed eustatic shift occurred 3,500 years ago, the corresponding strand-marks on the broad belts outside the "hinge-lines" of warping must have been drowned in consequence of the post-Glacial isostatic adjustments, which, in Europe at least, still continue. Thus the southern coasts of Nova Scotia and Newfoundland show no trace of the 5-meter strand-line, and there is good reason to believe that these regions have continued to sink during the last 3,500 years, because of the post-Glacial isostatic flow within the earth.[21] The close adherence of the long Micmac terrace of the lower St. Lawrence to a maximum height of 5–6 meters may possibly indicate that this famous bench is located close to the hinge-line of the isostatic movements during the last 3,500 years; for at that line the eustatic change should be well registered.

The fact that post-Glacial isostatic adjustments continue in northwestern Europe tends to weaken confidence in the correlation of the eustatically emerged strand-line with any terrace or beach in that region. Nevertheless, some of the late-Neolithic beaches of Scandinavia or the British Isles may yet be shown in their proper relations to hinge-lines, so that the two kinds of deleveling may be distinguished. It seems not impossible that the writer's tentative reference of the eustatic change to late-Neolithic time shall be substantiated by closer study of the problem. If the change was due to an increase of existing ice-caps, the date of the lowering of sea-level could be readily placed just after the "post-Glacial optimum" of temperature. Nansen and Ramsay are both sympathetic with this suggestion as to cause.[22]

If this eustatic change of sea-level could be proved and then dated, its demonstration would be useful for several reasons.

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[21] See Amer. Jour. Science, vol. 1, 1921, p. 388.

[22] F. Nansen, The Strandflat and Isostasy, Christiania, 1922, p. 288. W. Ramsay, Bull. Comm. géol. Finlande, No. 66, 1924, p. 16; Suomen Muin. Aikak. Furska Forn. Tidskrift. Vol. 36, No. 2, 1926; Fennia, 47, No. 4, 1926. Cf. R. Gradmann, Hettner's Geog. Zeit., 1924, p. 241.

In the first place, it would aid in the estimation of the speed of marine erosion of hard rocks exposed to the waves of the open ocean. For example, since the eustatic change, the waves acting on the leeward side of Saint Helena have been able to destroy only a part of each visible rock-bench which has emerged. If the lowering of sea-level took place thirty or more centuries ago, the slowness of the attack on strong, basaltic rocks by the unretarded waves of the open ocean would be clearly shown. Measured by that scale, the time taken to cut the 200-meter to 300-meter cliffs in similar rocks, and under similar conditions of wave-attack, would turn out to be more than one million years. The abrasion on the windward side of the island is perhaps more than twice as fast.

Geologists may well be interested in this particular problem also because of its analogy with those relating to the much greater eustatic changes that were connected with Quaternary glaciation. A close analysis of the facts dealing with the last oscillation may be expected to throw some light at least on the nature of the earlier oscillations. The proof of the one would tend to remove doubt which might be entertained as to the reality of the others.

Again, the demonstration of the 5-meter shift would give an automatic test of the stability of shore-belts during the last few thousand years. Since the change of sea-level was in any case no later than the beginning of the Christian era, there is already evidence that a very large part of the earth's crust has escaped important warping for at least 1,900 years.

As already implied, the archeologist must be interested in any general change of sea-level which during human times has affected the location of shore-sites, kitchen middens, and sea-ports.

Nansen, after accepting the explanation of the 5-meter shift by the assumed post-Glacial increase of ice-caps, suggests another possibility, which implies a specially delicate application of the principle of world-wide change of sea-level. He thinks that "a sinking of sea-level would also be caused by the gradual isostatic depression of the sea-floor, caused by the previous increase of the water masses of the Ocean [through the last great melting of glacial ice]." (Quoted from the paper referred to above.) One may well doubt that, under the relatively small stresses involved, the earth could yield enough non-elastically, during a period so short as post-Glacial time, to make this imagined effect important. Yet Nansen has opened a broad field of inquiry as to the relation between eustatic shifts of the kind here considered, on the one hand, and the principles of geophysics on the other.

Age of Saint Helena.

Except the dune and beach deposits, no fossiliferous beds are known in the island. Its great absolute age is proved by the depths and widths of the valleys and by the heights of the sea-cliffs, which in most cases are cut on strong rocks. Further testimony to the antiquity of the emerged part of the Saint Helena cone is given by T. V. Wollaston, Sir Joseph Hooker, Melliss, and others who have analyzed the fauna and flora.

A convenient summary of their results is contained in Chapter 14 of Wallace's "Island Life." After emphasizing the existence of a heavy forest cover on Saint Helena as late as the sixteenth century, and also the vicious character of the deforestation by the early settlers, Wallace first considers the beetles. Of these no fewer than 129 species are "truly aborigines" and 128 species are found "nowhere else on the globe." The beetles are "equally remarkable for their generic isolation." Wallace concludes: "The rich insect fauna of Miocene age found in Switzerland consists mostly of genera which still inhabit Europe, with others which now inhabit the Cape of Good Hope or the tropics of Africa and South America; and it is not at all improbable that the origin of the St. Helena fauna dates back to at least as remote, and not improbably to a still earlier epoch." Regarding the land shells Wallace states: "Omitting the species that have probably been introduced by human agency, we have here indications of a somewhat recent immigration of European types which may perhaps be referred to the glacial period; and in much more ancient immigration from unknown lands, which must certainly date back to Miocene, if not to Eocene, times." Of the fifty species of flowering plants, forty species are "absolutely peculiar to the island," while the same may be said of ten of the twenty-six species of ferns. Hooker wrote that seventeen species of plants belong to peculiar genera. Wallace's closing paragraph repeats his principal conclusion that the fauna and flora alike are ancient, "perhaps dating back to the Miocene period or even earlier."[23]

It may be recalled that Miocene fossils have been found in the somewhat similarly dissected islands of Madeira and La Palma (Canaries); these fossils give minimum age for the bulk of the rocks constituting these huge cones.[24]

That Saint Helena dates from pre-Glacial time, and probably from

[23] A. R. Wallace, Island Life, 2nd ed., London, 1895, pp. 298, 301, 304, 308.
[24] See C. Gagel, Zeit. deut. geol. Ges., vol. 64, 1912, p. 365; and F. von Wolff, Der Vulkanismus, Stuttgart, 1914, p. 265.

pre-Pliocene time, is further suggested by Freudenberg's recent study of the age of the little dissected Etna. He has estimated the time since this much younger cone began to grow as at least 300,000 years, and perhaps three times as much.[25]

Geological History.

Darwin was of opinion that the dominant rocks of the Knotty Ridge and Sandy Bay complexes were formed under the sea. His statement reads: "The lavas of this basalt series lie immediately beneath both the basaltic and feldspathic rocks. According to Mr. Seale, they may be seen at intervals on the sea-beach round the entire island. In the sections which I examined, their nature varied much; some of the strata abound with crystals of augite; others are of a brown colour, either laminated or in a rubbly condition; and many parts are highly amygdaloidal with calcareous matter. The successive sheets are either closely united together, or are separated from each other by beds of scoriaceous rock or of laminated tuff, frequently containing well-rounded fragments. The interstices of these beds are filled with gypsum and salt; the gypsum also sometimes occurring in thin layers. From the large quantities of these two substances, from the presence of rounded pebbles in the tuffs, and from the abundant amygdaloids, I cannot doubt that these basal volcanic strata flowed beneath the sea. This remark ought perhaps to be extended to a part of the superincumbent basaltic rocks; but on this point, I was not able to obtain clear evidence."[26]

The present writer obtained no good light on this question, not even succeeding in finding any rounded pebbles or gravels. Darwin's other arguments are clearly not compelling, but the geologist who shall have time and opportunity for a close field study of the problem may well hold Darwin's suggestion as a good working hypothesis. The tuffs and agglomerates certainly have not the normal appearance of volcanic materials, deposited subaerially. The general lack of well defined bedding is a feature which might be expected in a pyroclastic mass, ejected into sea water below the level of the effective action of waves. The failure of many dikes to penetrate the overlying mantles of flows might perhaps be in part explained by strong wave-cutting, which preceded these younger floods of lava.

Darwin's hypothesis implies emergence of at least 500 meters since the complexes were covered with the mantling flows. The post-

[25] W. Freudenberg, Centralbl. f. Mineralogie, etc., 1923, p. 483.
[26] C. Darwin, Geological Observations, 2nd, ed., London, 1876, p. 85.

Miocene emergence of Madeira, La Palma, and other deep-sea cones of the Atlantic region is, in each case, of the same order of magnitude. Future research may yet lead to the question whether a large part of the sub-Atlantic crust was uplifted in pre-Pliocene time, the volcanic cones rising with it.

After the formation of the basement complexes, renewed tensions in the crust led to fissuring and the basaltic flooding of the Knotty Ridge complex. The fissures were irregularly developed, but a principal set, trending a little west of north, seem to have been the principal vents for the flows and the subordinate, associated pyroclastic material, which finally completed the Northeastern Massif. Following, though perhaps accompanying, those eruptions there was pronounced fracturing of the new mantle of flows. Probably the resulting blocks were tilted, with a notable steepening of the dips of the flows composing The Barn and also the great mass between Knotty Ridge and Rupert Valley.

Nowhere in the Northeastern Massif has a well defined, central pipe been discovered, and all of its eruptions appear to have taken place at fissures.

Basaltic flows from a large focal area, centering in the Sandy Bay District (the Great Basin of the existing topography), ran eastward and northeastward, covering unconformably the flank of the Northeastern Massif to a contour which is nearly 600 meters above sea-level. These eruptions, often accompanied by explosions, constructed a part of the Main Massif, which may have begun to grow during the later phase of the activity at the Northeastern focal area. The Main Massif was likewise chiefly the product of fissure eruptions, which were varied by explosions that caused local, subsidiary cones of basaltic tuff and breccia. Two sets of fissures were specially important; the one trending northeast-southwest, the other trending nearly at right angles to that direction. The basaltic floods continued until the Main Massif attained the maximum height of 1,000–1,300 meters above sea-level.

The writer was able to confirm Melliss's account of casts of tree-trunks in the lava flows around Jamestown. Their existence suggests that the climate during the period of lava-flooding was distinctly moister than the present climate.

Apparently after the last basaltic flow had been erupted, some of the pipes of alkaline rock were developed, and it is possible that all of the alkaline bodies date from a period subsequent to the completion of the basaltic mantle. On the other hand, a few of the pipes of alkaline rock are apparent enlargements of dike fissures, which elsewhere are filled with basalt. In these instances, the alkaline eruptions may have been nearly contemporaneous with the younger basaltic flows. Nowhere was any of the alkaline-rock bodies seen to be cut by a basaltic dike. So far as this one bit of evidence goes, it suggests approximate contemporaneity for all the strongly alkaline bodies, including: necks, like Lot; domes, like Great Stone Top and that at High Hill; and the rare flows, like that at Bencoolen. The much more femic rock filling the High Knoll neck may belong to a quite different epoch, though it too is manifestly younger than the bulk of the basaltic mantle.

Deep erosion has failed to discover any basaltic pipe which might be regarded as a dominating vent in the upbuilding of the Main Massif. Here again eruption through fissures was the rule.

Doubtless the faunal and floral colonization of the island began as soon as the Northeastern Massif was built well above sea-level. The remarkable differentiation of both fauna and flora has surely demanded a very long time, most of which has run since the Saint Helena volcanic doublet was completed. Wallace's minimum age of Miocene for the island seems to be sufficiently conservative.

The later history has been one of erosion, already described in the section on the physiography. The régime of the streams and the loci of wave action were necessarily affected by the eustatic oscillations of sea-level, which accompanied the increase and decrease of the Pleistocene ice-caps. When the sea-level was lower than now, the streams were not able to deepen their valleys to any great extent. There were several reasons for this. The streams may have been somewhat fuller than at present, but were nevertheless relatively feeble cutting agents. The basaltic rocks are hard and they formed a large part of the rock bench which was exposed by the lowering of sea-level. The gradients across the bench were lower than the gradients of the master streams inside the original, or present, shore-line. Hence, valley-deepening inside the original shore-line was delayed until the deepening downstream, on the newly emerged bench, was well advanced. The total duration of the lowered sea-level during Glacial times seems to have been too short to permit the weak streams of the island to incise themselves in solid rock so as to give a valley-in-valley effect.

During the times of lowered sea-level the ocean waves must have washed away much of the weak material on the ancient shelf, but they were not able, in the time, to cut high cliffs in the hard basalts.

The older dune deposits have been referred to the Glacial period. The last important change has been the 5-meter lowering of sea-level in post-Glacial time.

Summary.

In every case the visible deep-sea island is but a small fraction of the corresponding volcanic mass. The accessible rocks and indeed all the rocks above the surface of the sea belong among the very youngest products of the eruptivity. An account of Saint Helena must therefore be almost entirely confined to the history of merely the top of a colossal structure, most of which must remain inaccessible to the geologist. The emerged part of the great composite cone is a volcanic, essentially basaltic, doublet. The older of the two members is the Northeastern Massif, which on the west and southwest was flooded by basaltic flows from the central area of the Main Massif. Each massif seems to have been built up by lavas emanating from a localized network of fissures, rather than from a single, central vent; though this conclusion refers merely to the latest stage in the growth of the massif. Each massif is an "exogenous" dome, recalling the domes of Hawaii. The Main massif of basaltic rock has been punctured by a dozen pipes of phonolite and the closely allied soda-trachyte. In spite of deep erosion, some of these pipes now terminate upward as "endogenous" (crater) domes or crater-fillings. On the other hand, the spectacular dome of Great Stone Top appears to have been built up by emanation of the alkaline magma through a dike-fissure. So far as observed, the phonolites and trachytes are the youngest eruptives in the island; none of the necks or domes was seen to be diked by basaltic rock, or indeed by any other type of magma.

Ten new chemical analyses and thin-section study of many other specimens corroborate the impression in the field, that rock-types intermediate between basalt and the highly salic, strongly alkaline varieties of lava are but poorly represented in visible Saint Helena. As one term in such a series of transitional types, the trachydoleritic basalts are important in suggesting the mode of differentiation of the salic magmas. Nevertheless, the apparently complete absence of lavas which would be classified as between trachydoleritic basalt and trachyte or phonolite is a striking fact. This situation is parallel to that long ago observed in Iceland (rhyolite-basalt association) and in many of the deep-sea islands; in principle Ascension and Tutuila islands afford other illustrations, recently studied. The detailed process by which the trachytic and phonolitic magmas of Saint Helena were derived from the primitive basaltic magma remains

largely a mystery, but here as at Ascension the differentiation must have taken place at considerable depth.

The so-called "Great Crater" of Saint Helena is believed to be essentially the result of deep erosion and is neither a caldera nor a volcanic sink. The denudation has laid bare the very remarkable Sandy Bay and Knotty Ridge complexes, both of which deserve much more study in the field. The profusion of dikes and the presence of the amazing multiple dike at Knotty Ridge are specially noteworthy features of these deeper-lying formations.

Unlike Ascension Island, Saint Helena was not found to contain any quartz-bearing or other "continental" species of rock. The specimen of graywacke reported by Reinisch was probably by mistake included among the rocks collected from the island ledges by members of the German South Polar Expedition.

Study with the pendulum has shown that Saint Helena represents a heavy load on the earth's crust and in large part the huge cone seems not to be isostatically compensated. In spite of this apparent fact, there is no evidence that the island has subsided during a very long time—several hundreds of thousands of years. Prolonged stability is indicated by the relation of the high sea-cliffs to the well developed submarine bench all around Saint Helena. So far as it goes, this observation runs counter to the idea that atolls and barrier reefs may be explained by the isostatic subsidence of oceanic volcanoes. Clearly, too, the elastic, seemingly permanent, support of Saint Helena by the suboceanic crust goes far toward disproving Wegener's assumption of no strength in the Sima.

The strong development of sea-cliffs on the leeward side of the island suggests the query whether during at least part of Pleistocene time the wind belts of the Atlantic region were placed differently from the present wind belts. Calcareous sand dunes are represented in erosion remnants, the great heights of which are not easy to explain. There is no evidence that the dunes owe their elevations to uplift of the island, and tentatively they are attributed to the special conditions of the period, Glacial winds of very great violence being assumed.

New field data indicating a recent eustatic shift of sea-level of about five meters are described from Saint Helena and from the distant Cape of Good Hope. The existence of the corresponding bench shows the stability of the island during a period of several thousands of years.

No new facts bearing on the age of Saint Helena have been discovered. Analysis of the fauna and flora led Wallace to assign the island to the Miocene or a still earlier period.

PLATE I.

Geological map of Saint Helena.


GEOLOGICAL MAP OF
SAINT HELENA
Statute Miles
Kilometers
5°45'
15°55'
16°00'
Sugar-loaf Pt.
Banks Valley
Flagstaff Hill
Deadwood Plain
Longwood
Munden Pt.
JAMESTOWN
Rupert Valley
James Valley
Breakneck Valley
High Knoll
Lemon Valley
Dry Gut
Swanley Valley
Old Woman Valley
Egg Id
Approximate Position of 50-fathom line
High Hill
High Pk.
Thompson Valley
Southwest Pt.
Man and Horse
Hooper Rock
Chapel
Lot
Riding Stones
Sheep Knoll
Diana Peak
Deep Valley
White Hill
Powell Gut
Broad Gut
Sandy Bay
Sandy Bay Barn
Lot's Wife
Castle Rk.
Manatee Bay
Speery Id.
50 fathom


5°40'
15°55'
16°00'
Sugar-loaf Pt.
Munden Pt.
JAMESTOWN
Banks Valley
Rupert Valley
James Valley
Breakneck Valley
Lemon Valley
High Knoll
Flagstaff Hill 2275'
The Barn 2019'
Barn Pt.
Knotty Ridge
Turks Cap
Deadwood Plain
Waterfall
Prosperous Bay
Longwood
Saddle Pt.
Fisher Valley
Prosperous Bay Plain
Phonolite
Bencoolen
Shark Valley
Gill Pt.
2449'
2361'
2685'
2697' Diana Peak
Little Stone Top 1550'
Great Stone Top (1620')
George Id.
2616' High Pk.
Riding Stones
Sheep Knoll (2100')
Chapel
1491 Lot
2440'
Deep Valley
Rofe Rock
1140'
White Hill 1179'
Powell Gut
1936'
Hooper Rock
Broad Gut
2030
Lot's Wife 1510
Sandy Bay
Sandy Bay Barn
1413
50 fathoms
Phonolite and phonolitic trachyte
Trachydoleritic basalt, neck at High Knoll
Tuff
Basaltic flows and interbedded pyroclastics
Basaltic dikes; sill in Thompson Valley
Knotty Ridge and Sandy Bay Complexes
Strike and dip
Heights in feet; depths in fathoms; contour interval, 200 feet

PLATE II.

Jamestown and James Valley, seen from the Anchorage. The town is partly built on the old delta of the James Valley stream. Photograph by B. Grant.

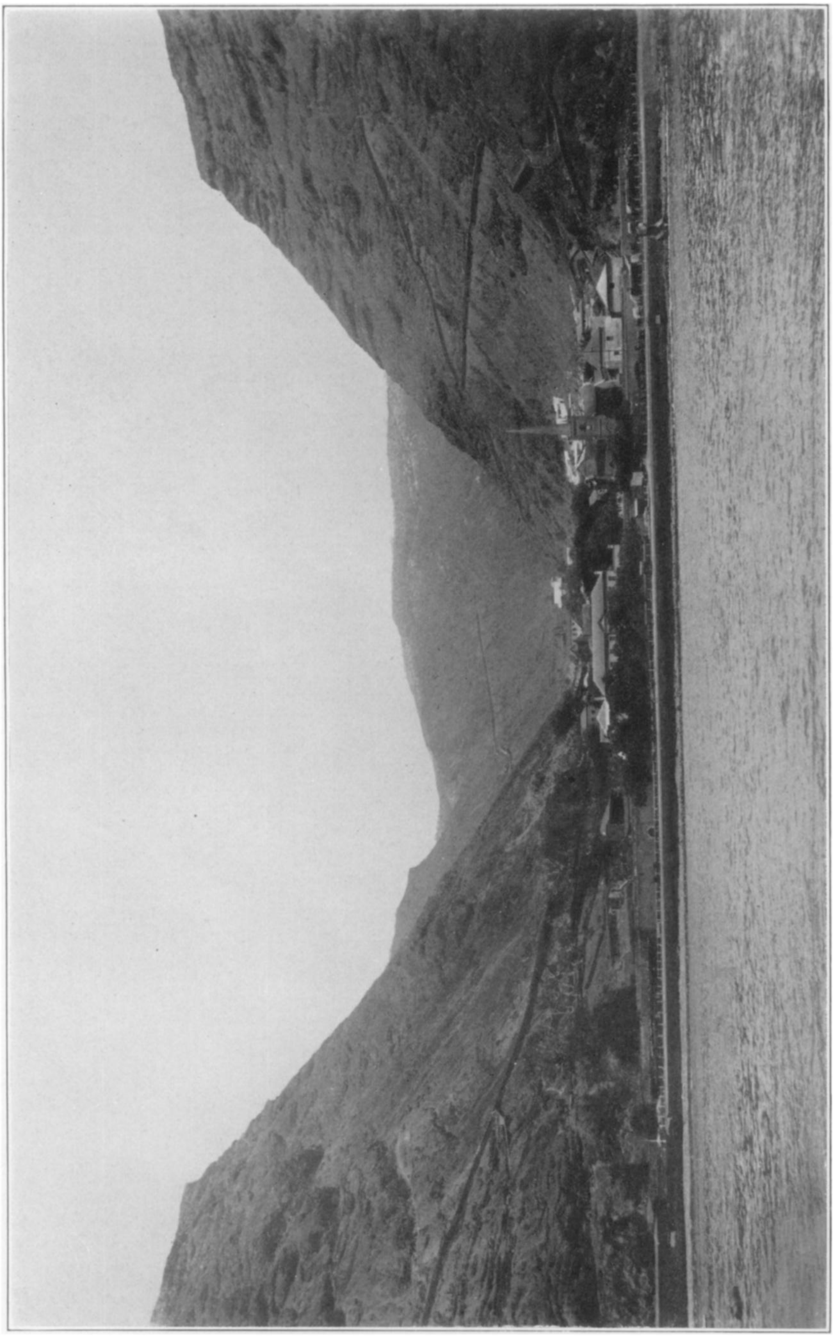

PLATE III.

Looking up James Valley from a point above "The Briars." This view illustrates the typical, profound erosion of the Main Massif by the centrifugal streams, cutting basaltic flows. Photograph by B. Grant.

PLATE IV.

FIGURE *A*. Sea-cliffs, 150-200 meters high, on the leeward side of the island, looking southwest from a ship anchored off Jamestown. The truncation of the interstream spurs by wave-cutting is conspicuous.

FIGURE *B*. The water front of Jamestown, showing the wave-cut edges of the basaltic flows of the Main Massif, and also the rock bench which was cut by the sea before the recent five-meter emergence.

FIG. A

FIG. B

PLATE V.

Looking southwest over the deeply eroded Sandy Bay Complex of the Great Basin. The prominent peak is the phonolitic neck called "Lot" (1,491 feet), of which a vertical height of about 100 meters is exposed above the weak, friable Complex. Some of the many networks and parallel swarms of dikes in the Complex can be seen. The western rim of the Great Basin (2,000–2,300 feet high) is seen in the background. The Hooper Rock neck of phonolite appears on the rim to the right of "Lot."

This view is continuous with that of Plate VI.

PLATE VI.

Looking southwest across the Great Basin, over the Sandy Bay Complex. Some of the basaltic dikes, especially those of the northeast-southwest system, can be seen; also the local, pipe-like bodies of alkaline rock, including the Asses Ears, Castle Rock (the sharp peaks on the sky-line, middle of the view).

This picture is continuous with that of Plate V. Both plates illustrate the profound erosion at the Great Basin. Both photographs were taken by B. Grant.

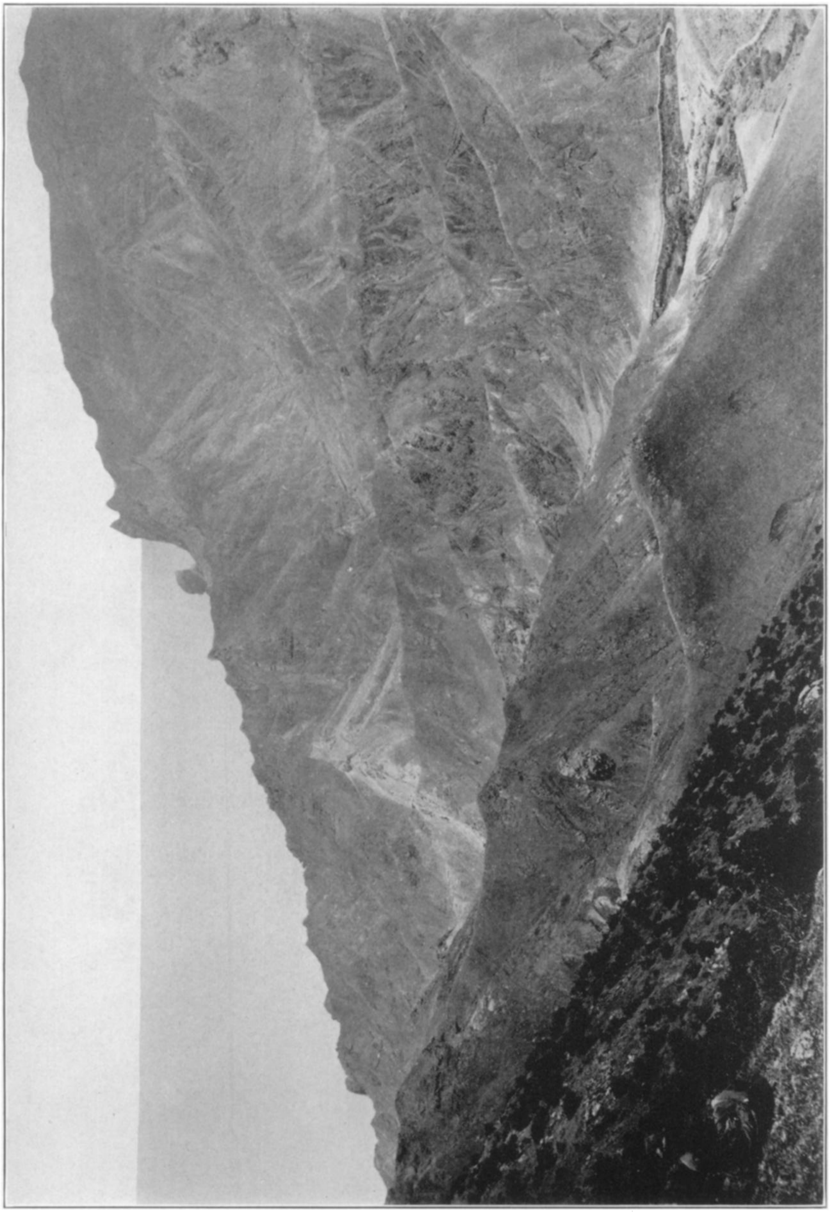

PLATE VII.

Sandy Bay and the Sandy Bay Complex at the shore; looking southwest. Note the greater speed of the subaerial erosion of the Complex, as compared with that of the mantling basaltic flows, shown in other plates. Photograph by B. Grant.

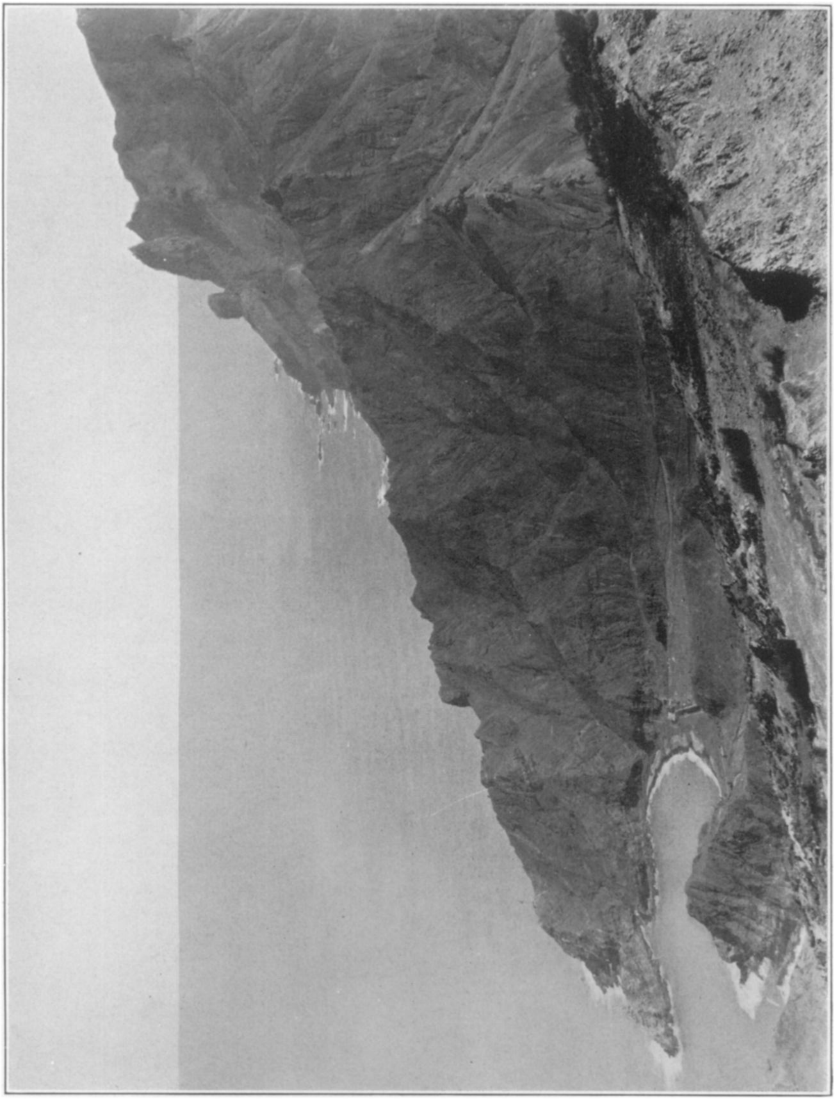

PLATE VIII.

The phonolitic pipe "Lot" (1,491 feet high), looking north from a point near the shore, Sandy Bay. The Sandy Bay Complex in the foreground. Photograph by B. Grant.

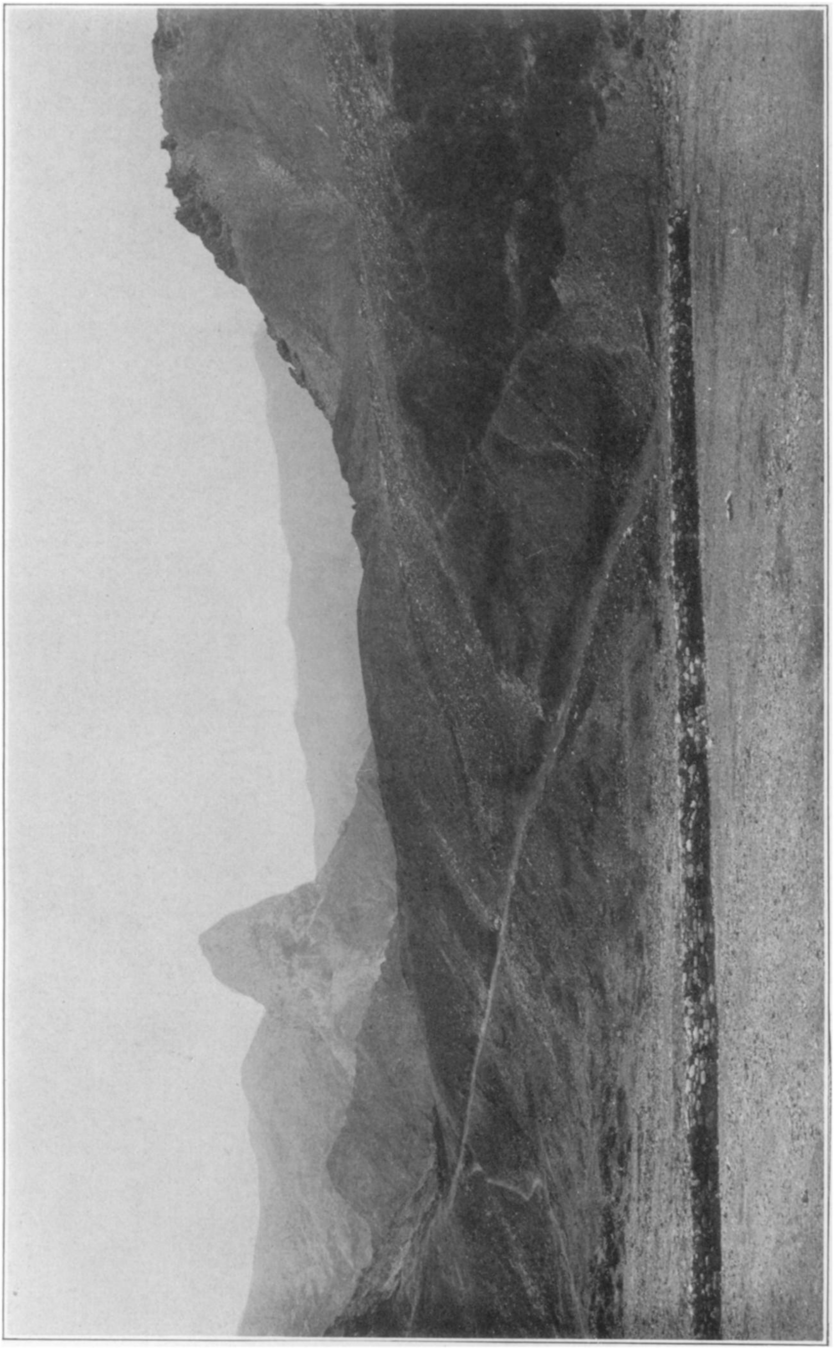

PLATE IX.

Sheep Knoll neck of phonolitic trachyte, 2,100 feet high; looking northeast. The neck is the great monolith of the background, about 100 meters high above the surrounding mass of deeply weathered, basaltic flows.

PLATE X.

FIGURE *A*. High Hill dome of trachyte, 2,314 feet high; seen from the southeast. The foreground is underlain by basaltic flows of the Main Massif.

FIGURE *B*. Castle Rock, 1,670 feet high, a well jointed pipe of phonolite.

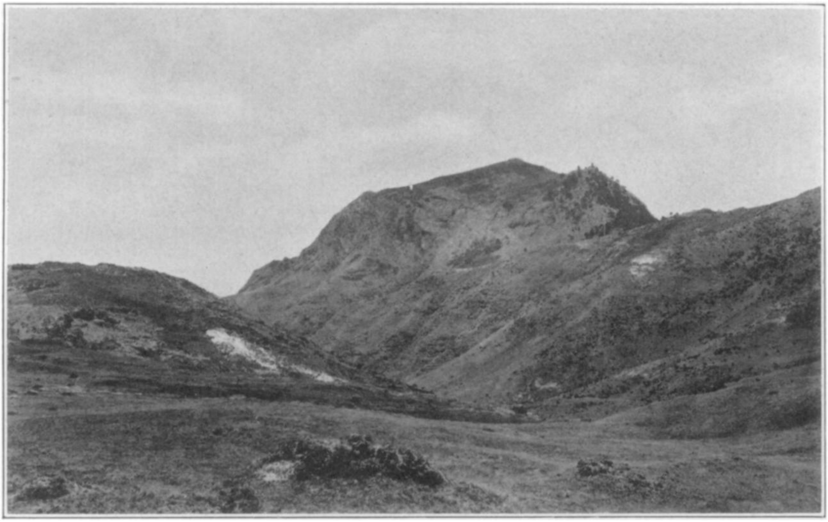

FIG. A

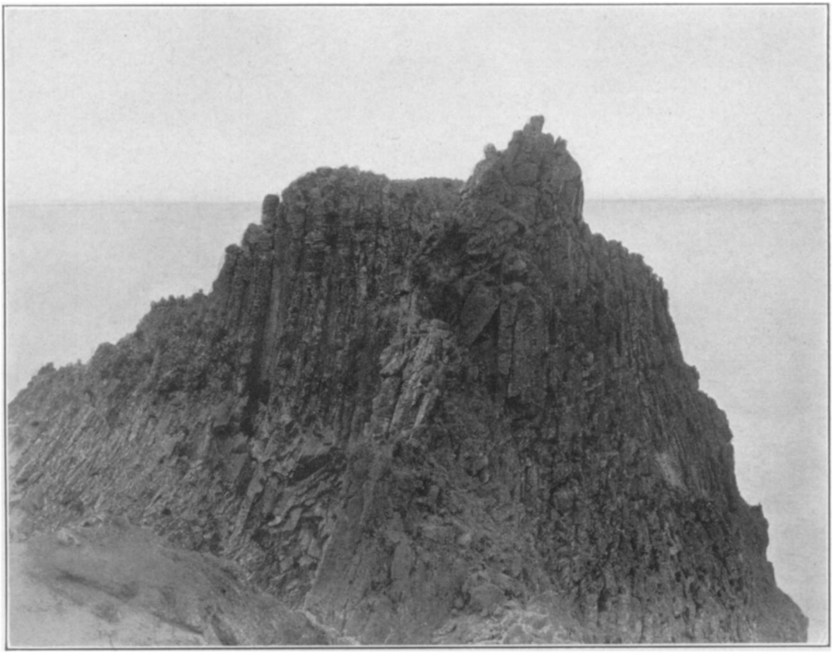

FIG. B

PLATE XI.

FIGURE *A*. Basaltic cliffs on the windward side of Saint Helena; looking eastward to Gill Point and Shore Island (basaltic) from the foot of Great Stone Top. The cliffs are 130–170 meters high. Note the absence of the "five-meter" bench, which has been eroded away on the windward side of the island.

FIGURE *B*. Lot's Wife, 1,516 feet high, an erosion remnant of a phonolitic neck, cutting the Sandy Bay Complex; looking west.

FIG. A

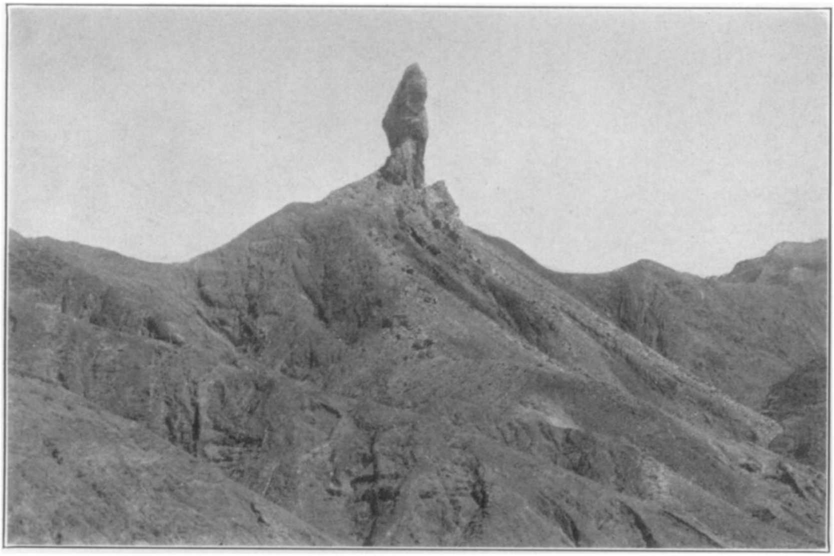

FIG. B

PLATE XII.

Looking west over "The Briars" in James Valley to the High Knoll (1,900 feet) neck of trachydoleritic basalt. The neck is the massive rock at the top of the cliff, crowned with a fort. The cliff shows the basaltic flows of the Main Massif, which are cut by the volcanic neck. The canyon wall is about 400 meters high; seventy different flows can be counted in it.

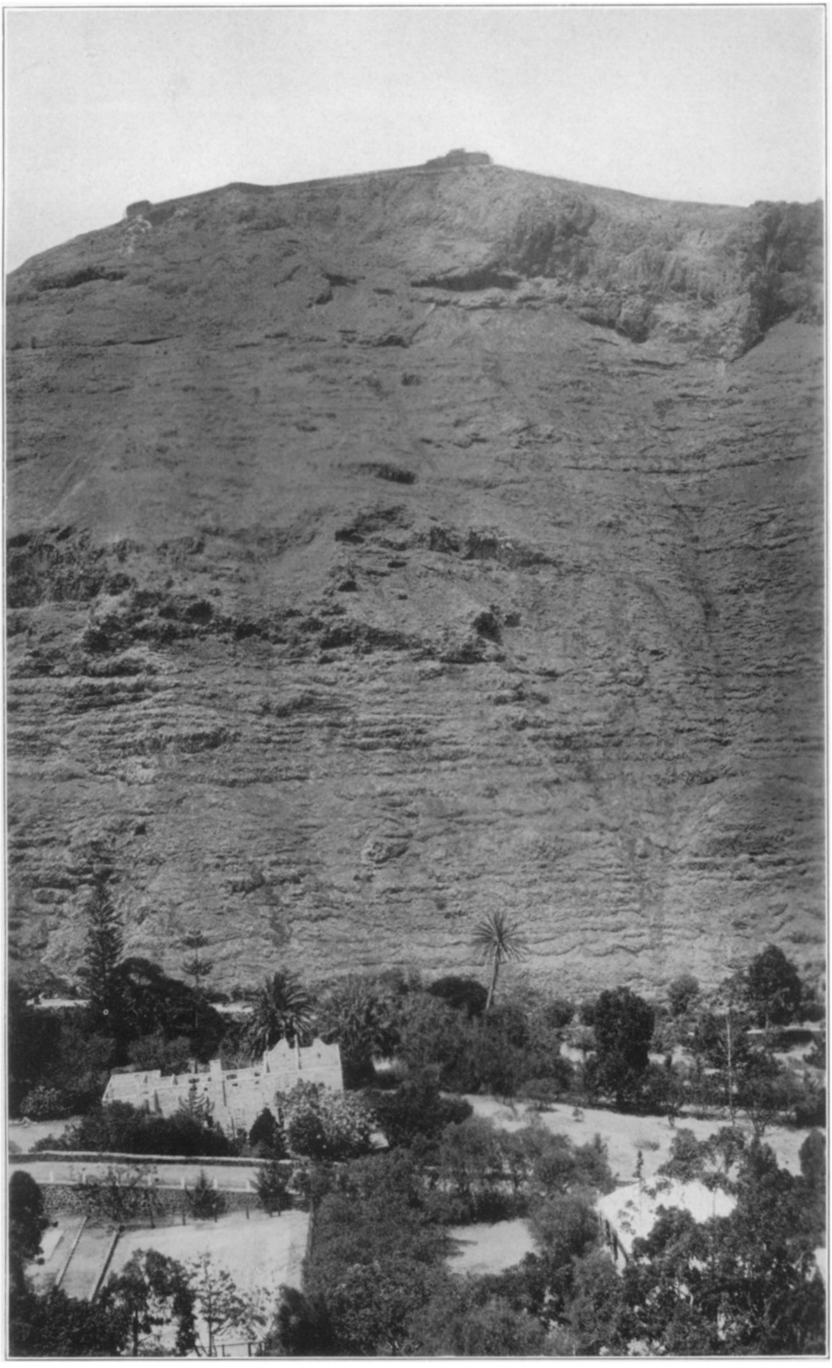

PLATE XIII.

FIGURE *A*. Phonolitic dome of Great Stone Top (1,620 feet high), effluent on gently dipping basaltic flows of the Main Massif; looking south from the southwest end of Bencoolen. The gorge of Sharks Valley is in the mid-ground.

FIGURE *B*. Phonolitic dome of Little Stone Top (1,550 feet high), extruded through basaltic flows. This view is continuous with *A*, on the right.

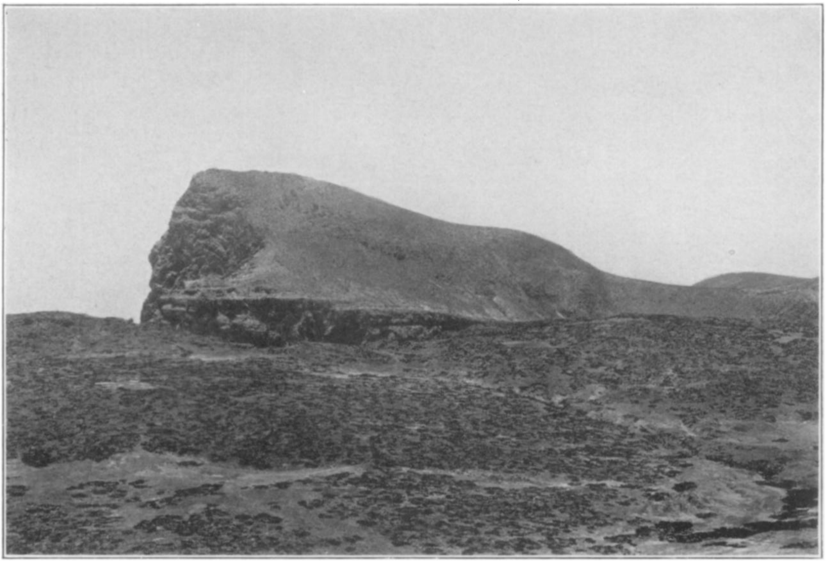

FIG. A

FIG. B

PLATE XIV.

Phonolitic dome of Great Stone Top (1,620 feet high), extruded through, and resting on, basaltic flows; looking northeast.

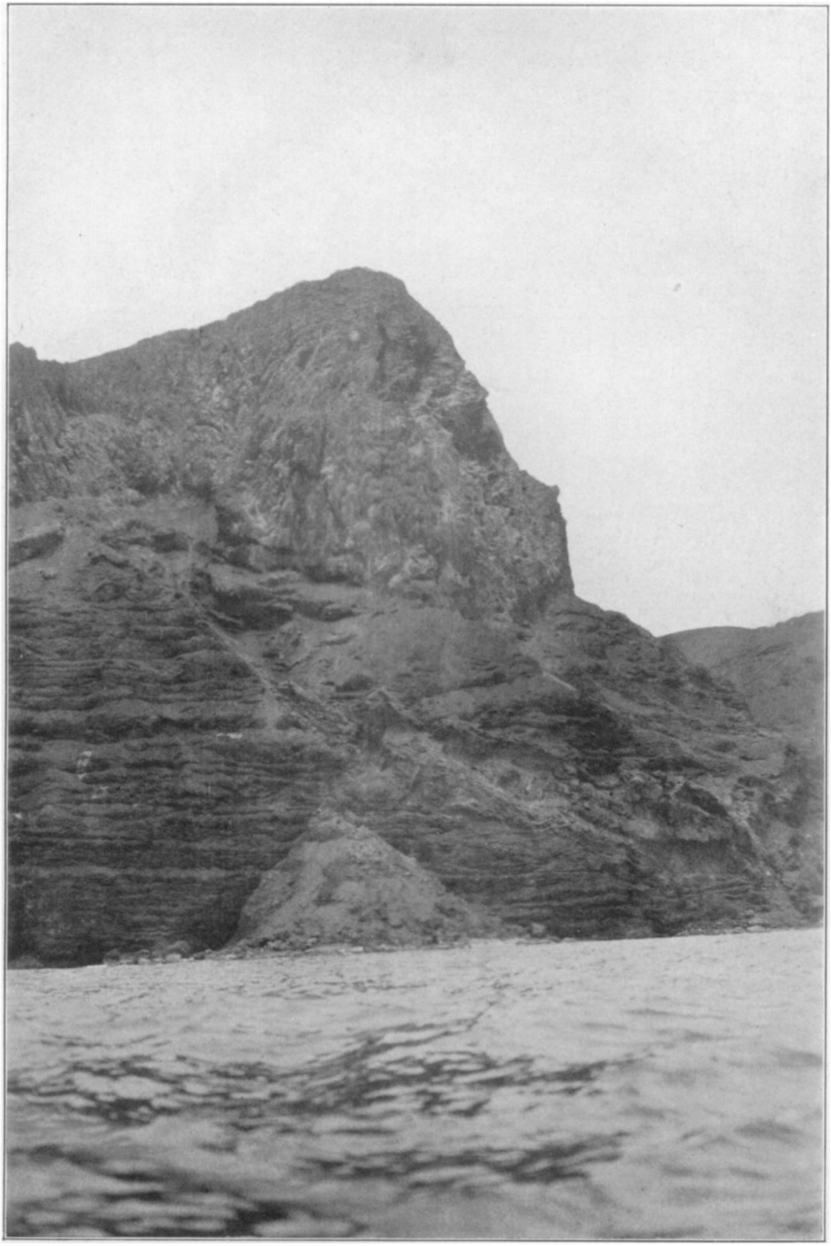

PLATE XV.

Looking north at the steep sea-cliffs of Great Stone Top (1,620 feet) on the right and of the pile of basaltic flows south of Little Stone Top. On the left at the sky-line in Boxwood Hill, the end of a phonolitic flow from the Little Stone Top vent. The paler-tinted mass in the sea-cliff is an intrusive, "chonolithic" body of rock, probably identical with that composing Little Stone Top. The arching and breaking of the basaltic flows by the intrusion can be observed.

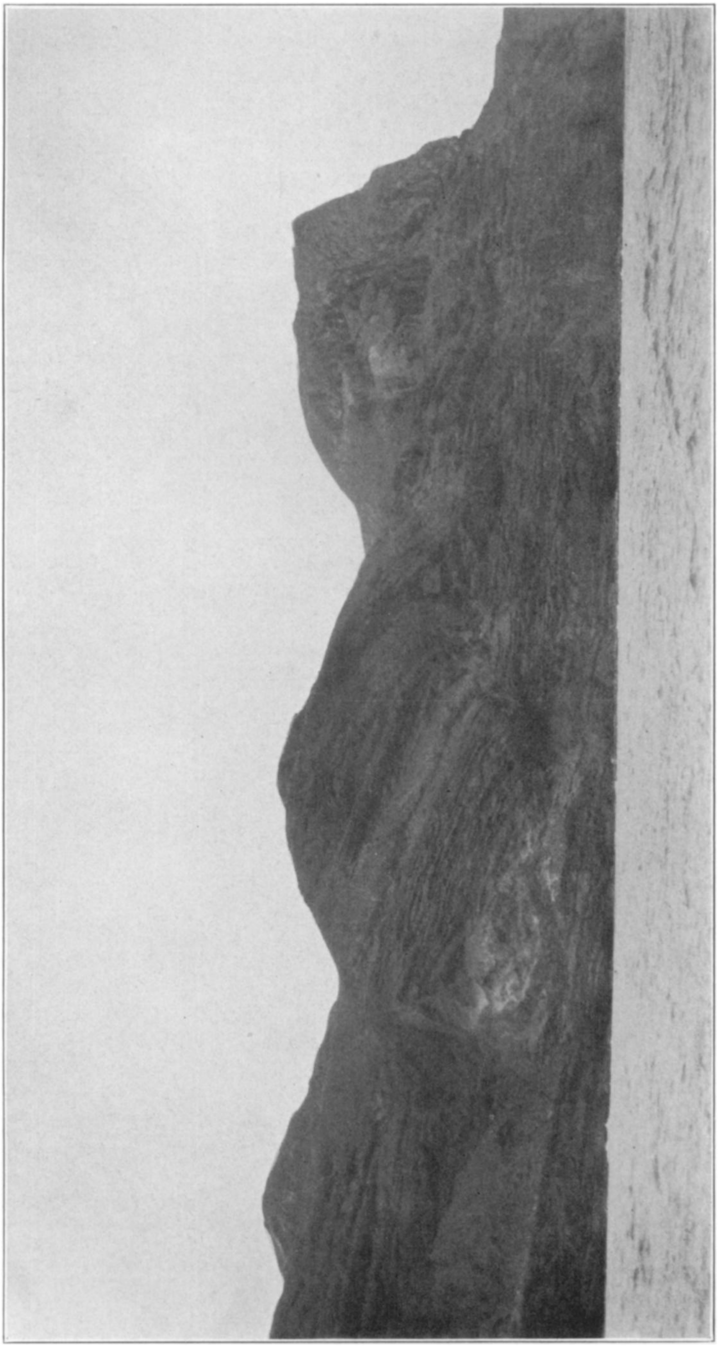

PLATE XVI.

Speery Islet, a jointed monolith of trachyte, covered with bird droppings. The jagged sea-stack on the right is a remnant of a wide basaltic dike. The Castle Rock pipe of phonolite is conspicuous in the background. Photograph by B. Grant.

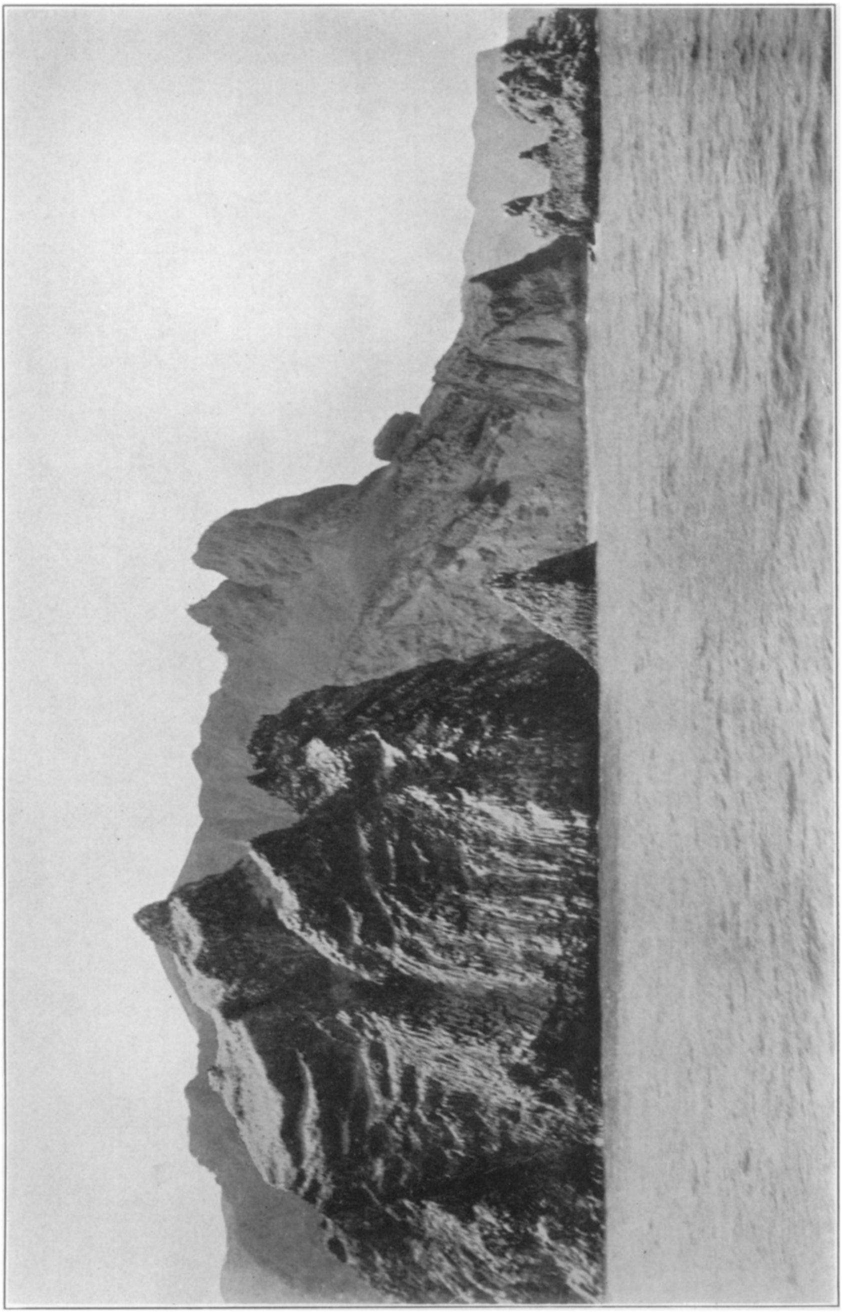

PLATE XVII.

The Barn (2,019 feet); looking north over the Knotty Ridge Complex of the midground. Note the relative uniformity of the Complex with respect to its degree of resistance to erosive agents, in spite of the existence of many narrow basaltic dikes in the friable Complex The massive flows of The Barn dip 15 to 30 degrees toward the background. Dikes are comparatively rare in this thick mantle of flows.

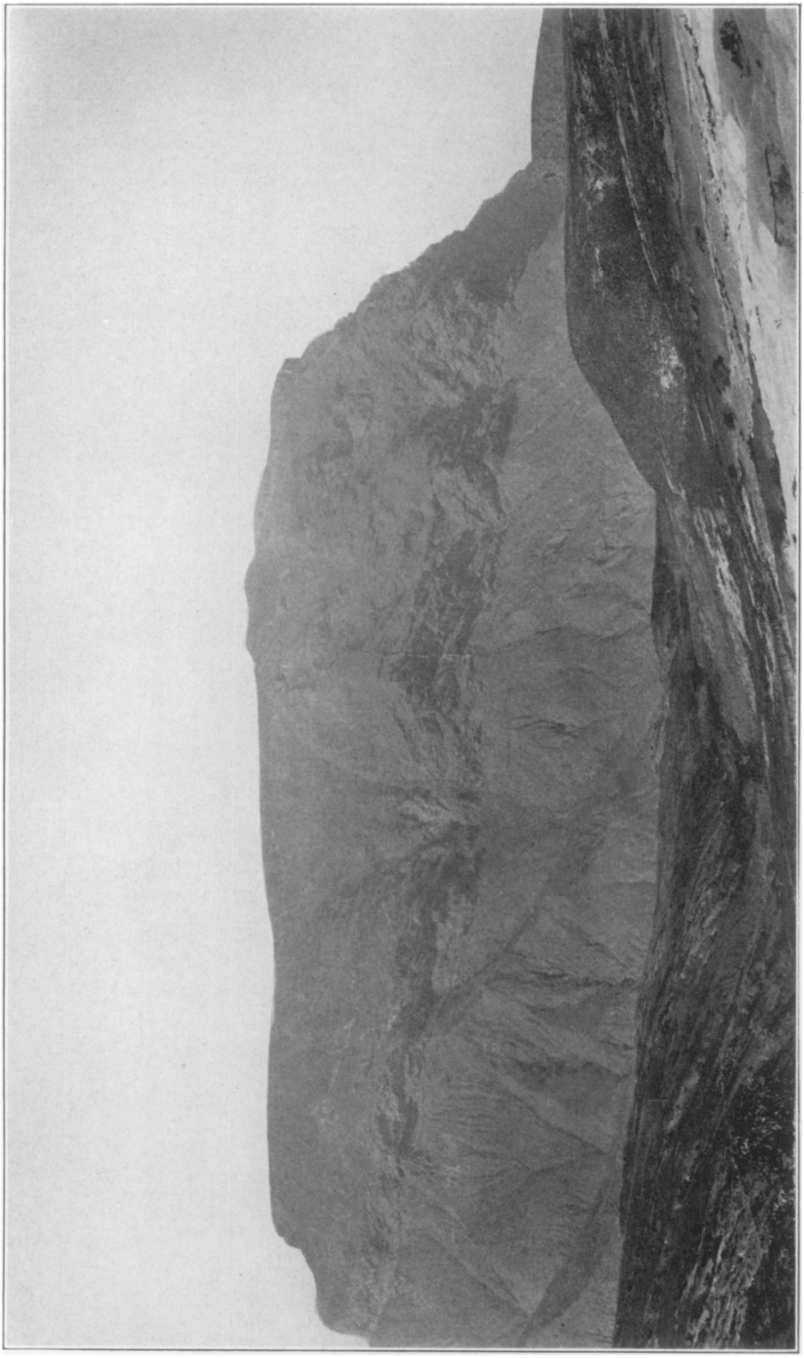

PLATE XVIII.

Typical view of the deeply eroded Knotty Ridge Complex; looking north-east to the western end of the Barn. Knotty Ridge is in the left foreground.

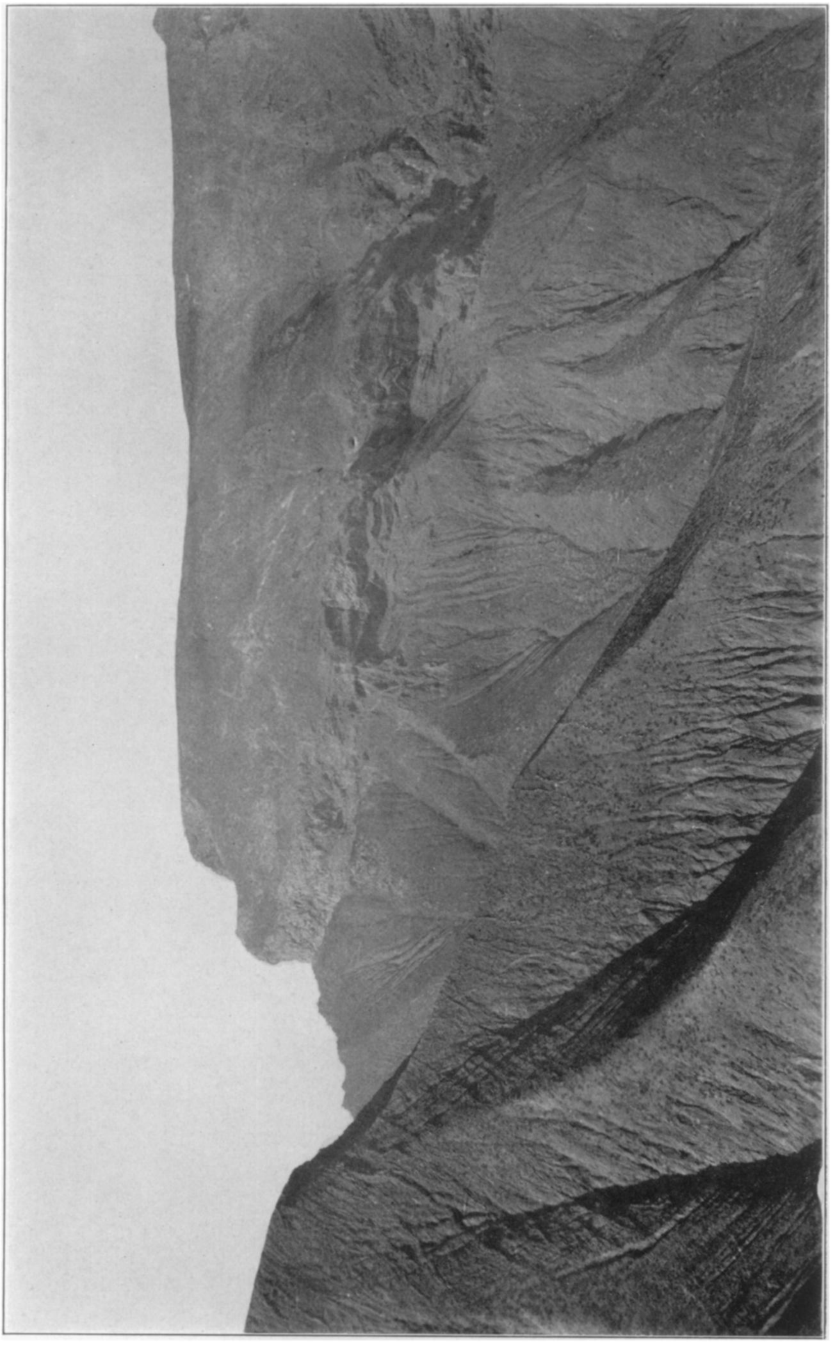

PLATE XIX.

FIGURE *A*. Deep lateritization of the basaltic flows of the Main Massif; looking northeast from a point north of Warren's Gut to Flagstaff Hill (2,275 feet high), left, and The Barn (2,019 feet high), right. Longwood Plain, in profile, tops the eroded, lateritized slope.

FIGURE *B*. Steep dips of the thin basaltic flows from the eruptive center of the Northeastern Massif; looking northeast across Rupert Valley to the high Deadwood Plain.

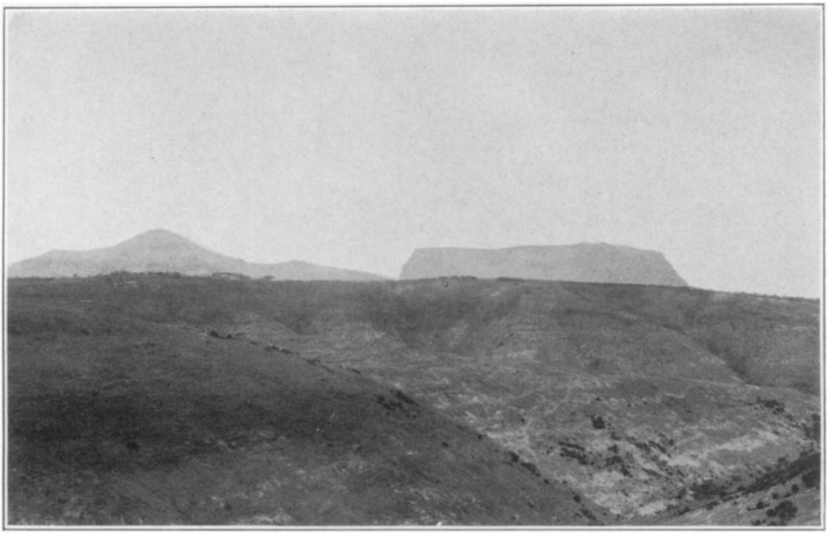

FIG. A

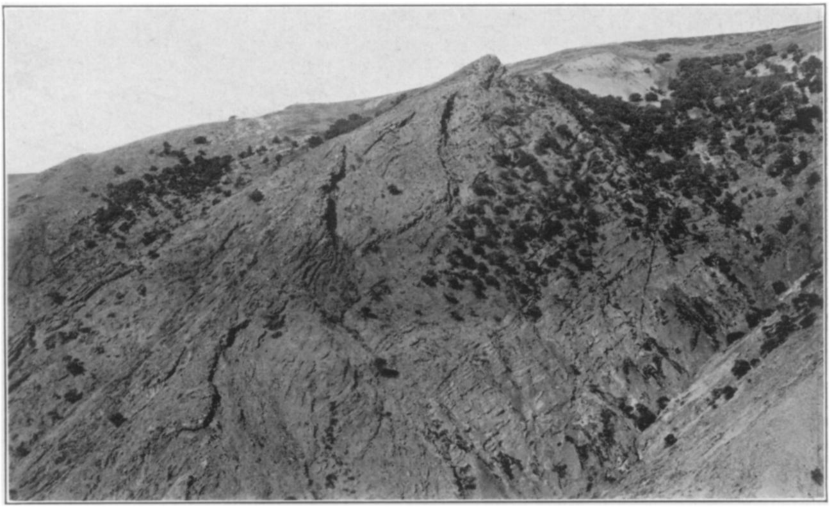

FIG. B

PLATE XX.

FIGURE *A*. Looking northeast from Boxwood Hill, past the slope of Little Stone Top (right), over Sharks Valley, to Bencoolen, an erosion remnant of a thick trachytic flow from the Little Stone Top vent. Sharks Valley of the foreground has been cut through this flow into the underlying basaltic flows of the Main Massif.

FIGURE *B*. Looking southwest from Longwood Plain over the deeply lateritized basaltic flows of the Main Massif to Bencoolen ridge (left), Great Stone Top (center), and Little Stone Top (sharp peak on the right).

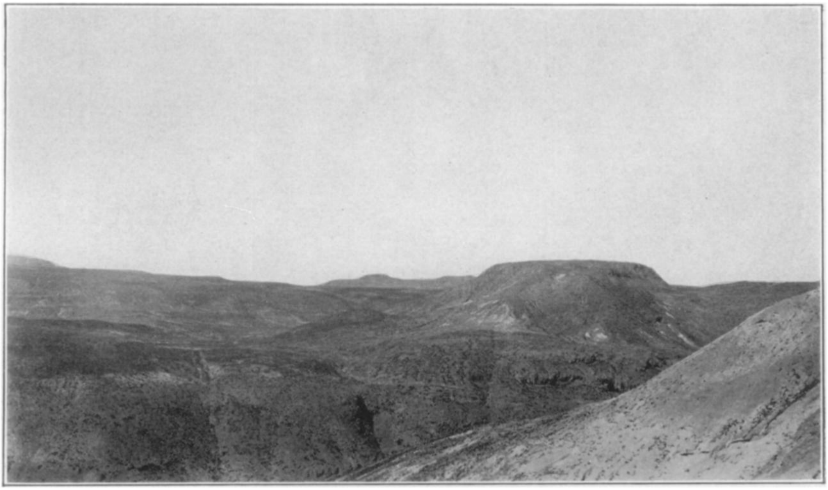

FIG. A

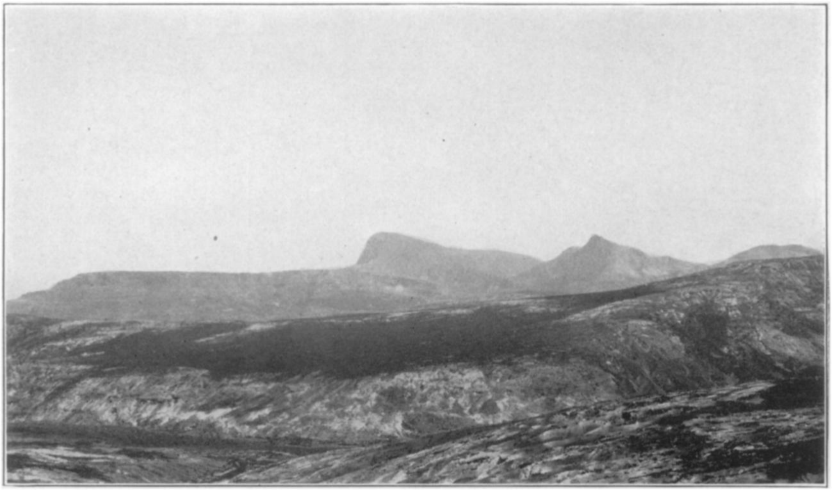

FIG. B

PLATE XXI.

Characteristic basaltic dikes of the northeast-southwest system, cutting basaltic flows of the Main Massif; looking eastward from Crown Point (Sandy Bay) to the Sandy Bay Barn sea-cliff (1,413 feet high). Note the absence of a well defined 3–5 meter sea bench on this windward side of the island.

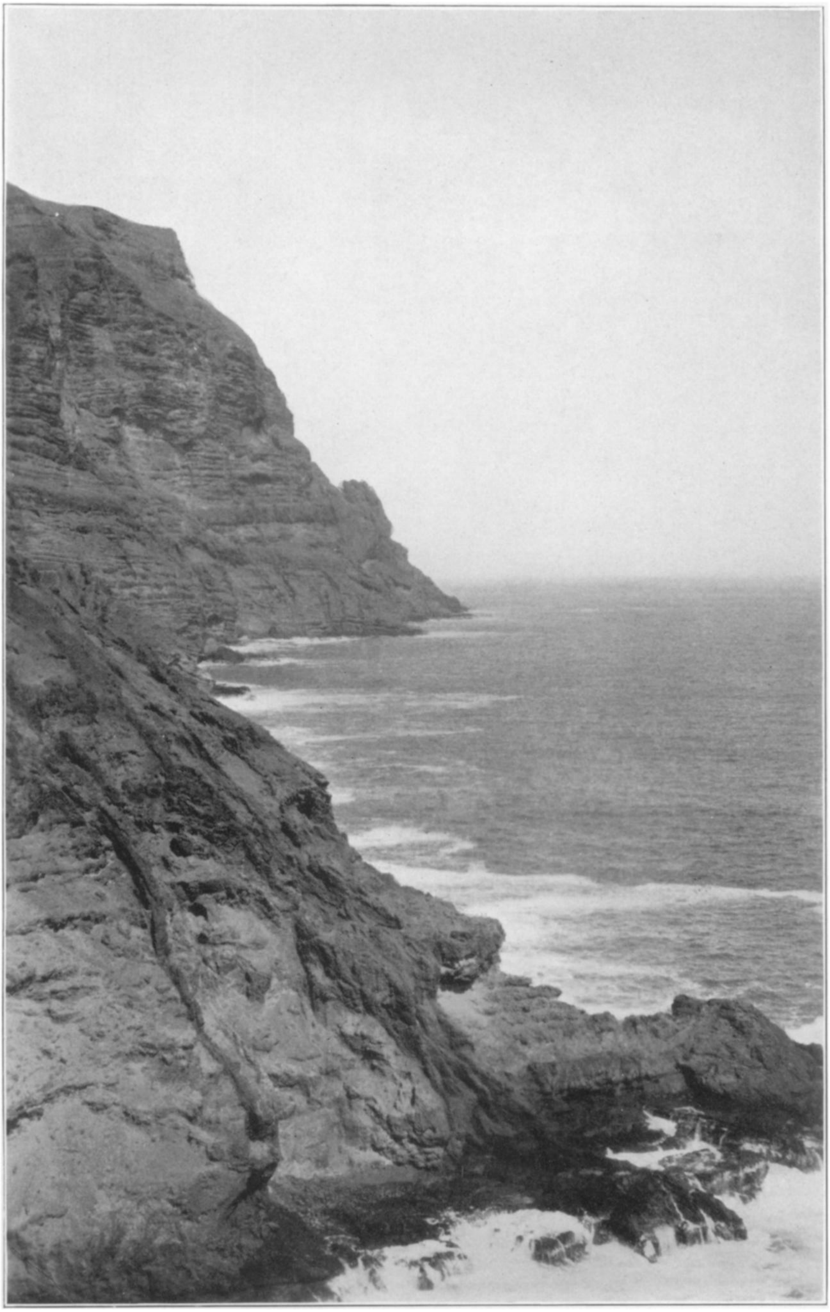

PLATE XXII.

FIGURE *A*. Sea-cliffs at and southwest of Jamestown. The rock bench cut before the recent five-meter emergence is visible; also the down-dip truncation of the centrifugally sloping flows of basalt, Main Massif. A part of the famous stairway, called "The Ladder," appears on the left.

FIGURE *B*. The rock bench cut before the five-meter emergence; looking southwest across Rupert's Bay to Munden's Point.

FIG. A

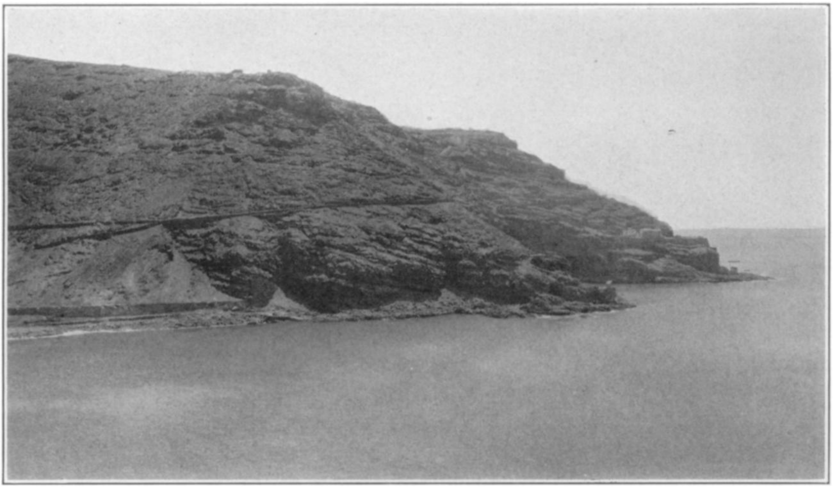

FIG. B

PLATE XXIII.

Figure *A*. Sea-cave now being cut in the basalts, southwest of Jamestown. The lip of the cave is well below low-tide level.

Figure *B*. Sea-cave near Hickshall Point (mouth of Breakneck Valley). This cave was cut before the five-meter emergence. At its mouth it is eight meters high, from floor to roof, and the floor is three to four meters above high tide. The depth of the cave is about thirty-five meters.

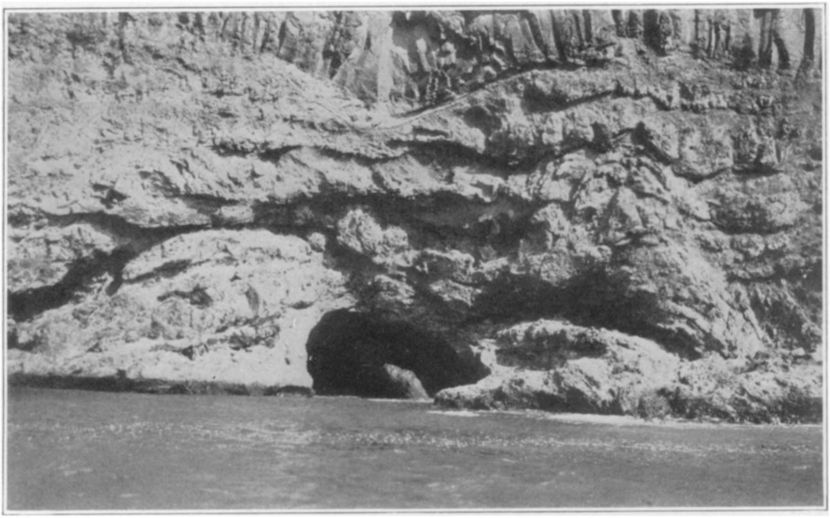

FIG. A

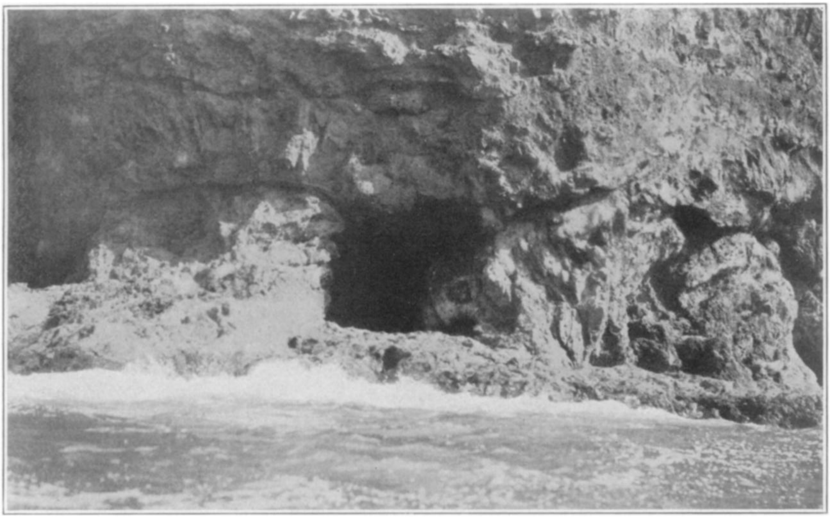

PLATE XXIV.

Rock bench cut in the horizontal Table Mountain Sandstone at the Cape of Good Hope; looking east. At the base of the cliff, behind the man, is a dry sea-cave, similar to that shown in Plate XXV. Both caves were cut in granite, on which the sandstone rests unconformably. The white patches on the bench are composed of sea-salt, evaporated from the spray. The bench is three to five meters above high-tide level.

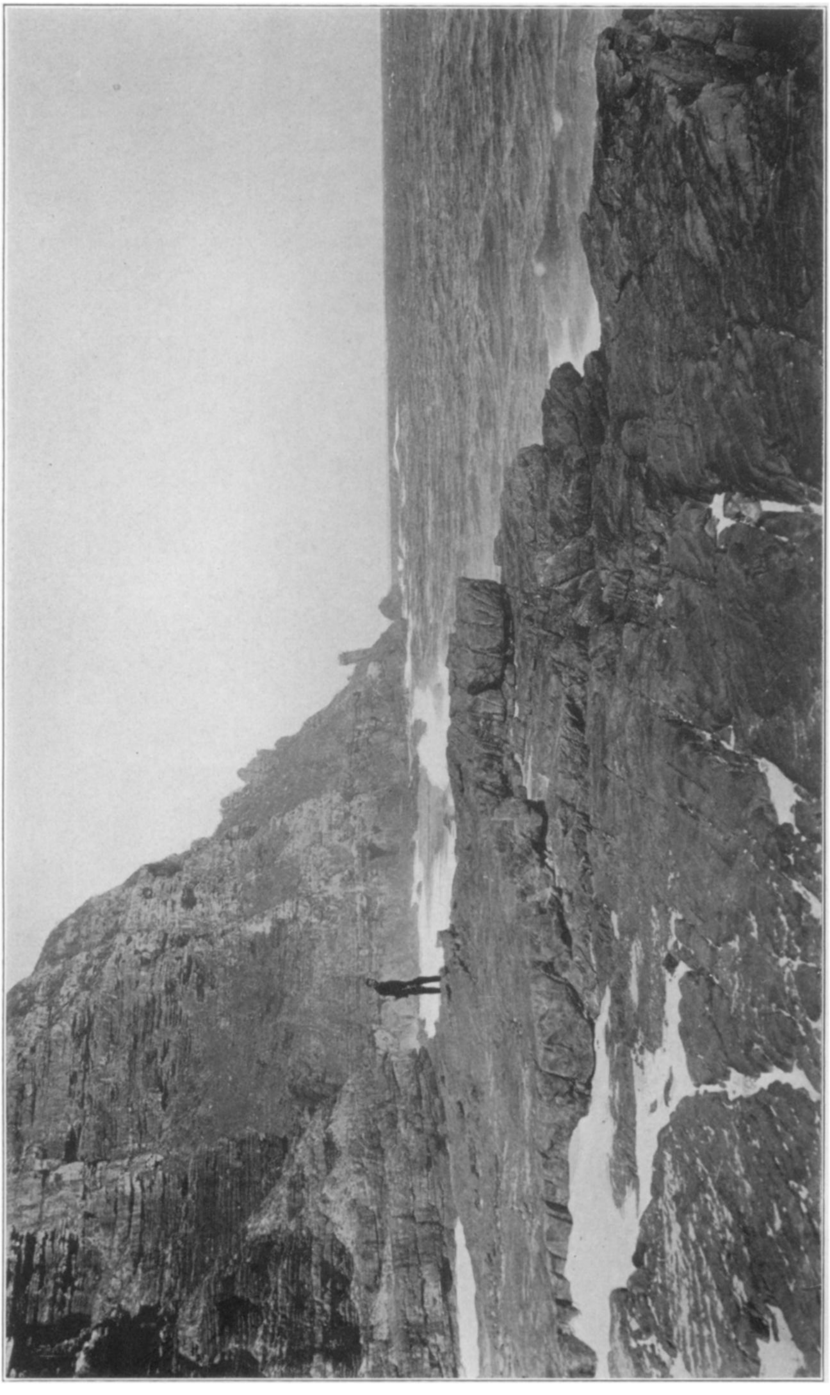

PLATE XXV.

Sea-cave, cut in granite which is unconformably overlain by the Table Mountain Sandstone, at the Cape of Good Hope. The cave is ten meters high and about 40 meters deep. At the opening, its floor is about 3 meters above high-tide level. The cave was cut before the five-meter emergence of this coast.