Molokini

GEOLOGY OF MOLOKINI

By HAROLD S. PALMER

WITH

Notes on the Flora of Molokini

By EDWARD L. CAUM

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INTRODUCTION

Molokini is a small, crescent-shaped island, the remnant of the rim of a basalt tuff crater and lies in Alalakeiki Channel between the islands of Kahoolawe and Maui. The Molokini triangulation station of the Hawaiian Territorial Survey, a few feet east of the summit of the island, is in Lat. 20° 38′ 01.58″ N., and Long. 156° 30′ 00.24″ W. Hawaiian Datum. The center of the circle marked by the arcuate crest of the island may be taken as the position of the vent from which the tuff was ejected. This point is 18 statute miles S. 72° W. of the summit of Haleakala and 7 miles N. 48° E. of the summit of Kahoolawe.

Molokini has an area of 18.9 acres and a maximum elevation of 165 feet above mean lower low tide. Plate 1, A, taken from the northeast, shows the general shape of the island. The inner side of the west horn provides a good landing for small boats in almost all kinds of weather. Going along the rim or crest is easy and entirely safe. With a little care one can descend the inner slopes as far as the crest of the sea cliff, but the outer cliff-like slopes are for the most part inaccessible.

Very little has been written concerning Molokini. The Coast Pilot Notes [1] state correctly that it is a small, barren island of crescentic shape with the opening to the northwest, that a reef makes off about 300 yards from the northwesterly end of the island, and that there is deep water close to the island. Forbes [2] visited Molokini in 1913 and collected 15 species of plants. He states that the island is "the eroded remnant of an old tufa cone—the length along the ridge being about 1000 feet." His estimate of the length of the island is much too small; the crest measures about 3200 feet. Arago [3] passed Molokini en route from Kailua, Hawaii, to Lahaina, Maui, on August 15, 1819, and speaks of "the small rock of Morikini, from whose summit rises a lofty column of smoke, which would have induced us to suspect there was a volcano under it; the pilots on board assured us, however, that this was not the case." In view

[1] U. S. Coast and Geodetic Survey, Coast pilot notes on Hawaiian islands; 2nd Ed., p. 27, August 15, 1919.

[2] Forbes, C. N. Notes on the flora of Kahoolawe and Molokini, B. P. Bishop Mus., Occ. Papers, vol. 5, pp. 91-92, 1913.

[3] Arago, J. Narrative of a voyage around the world in the Uranie and Physicienne Corvettes, commanded by Capt. Freycinet, during the years 1817-1820, pt. II, p. 118, 1823.

of this statement search was made for relatively recent volcanic rocks on Molokini but none was found. The "column of smoke" may have been composed of wind-blown dust.

I am indebted to Mr. R. R. Tinkham, Superintendent of the 19th District of the United States Lighthouse Service, for the opportunity to visit Molokini under conditions most favorable for field work. Mr. Frederick A. Edgecomb, the engineer in charge of the construction work, and Mr. J. H. Jensen, who commanded the lighthouse tender *Kukui*, did me many favors. October 8, 9, and 10, 1925, were spent chiefly in making a contour map of the island. (See fig. 1.) October 12 was devoted to recording geologic data and collecting rock specimens. The morning of October 13 was spent collecting plants, which are discussed by Mr. Edward L. Caum on pages 15-18 of this paper.

In making the contour map a light plane table with telescopic alidade was used. Eleven stations were occupied, 28 points were located by stadia or by intersection, and 15 points on the inner shore and 5 points on the reef were located by depression angles. It was impracticable to sight points on the outer slopes, and the contours for this part of the island are based on profiles taken from photographs made while circumnavigating the island. The soundings, except the two at anchorages of the *Kukui*, were transferred from a blue print map in the Honolulu office of the Lighthouse Service, the original of which was made by the United States Coast and Geodetic Survey ship *Patterson*, in 1904. Certain checks show that the soundings were transferred to the present map with adequate accuracy. The submarine contour lines are only moderately accurate because they were not sketched in the field and because the number of soundings is not large. However, they represent the submarine topography well enough to allow of certain geologic deductions.

THE ROCKS

The most abundant rock on Molokini is tuff or cemented and altered volcanic ash. The weathered surfaces vary from yellow-brown to dark-brown in color, whereas the unweathered material is gray. Most of the tuff is fine grained, but in a few layers the particles are from one-fourth to one-half inch in diameter. The finer grained beds are firmly cemented but the coarser ones are only weakly cemented. No grains large enough for mineralogic identification

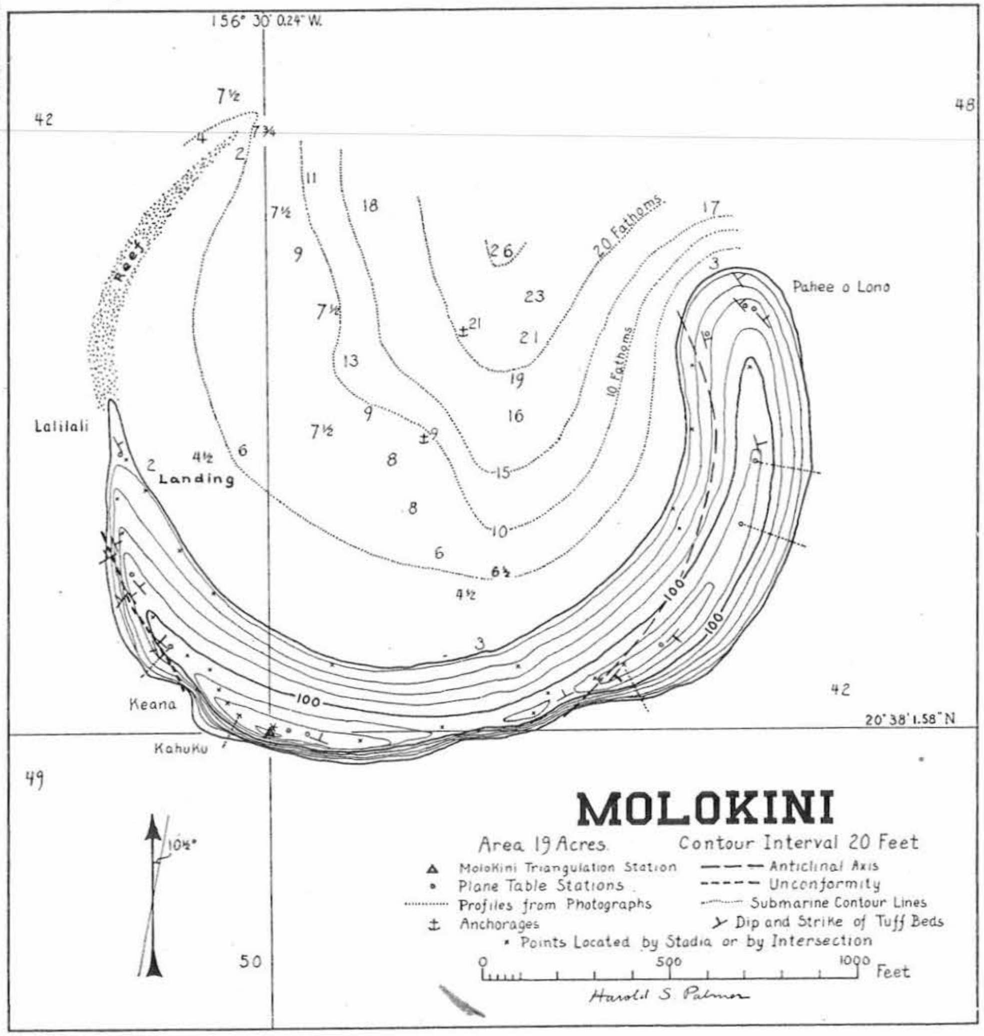


FIGURE 1—Map of Molokini Island

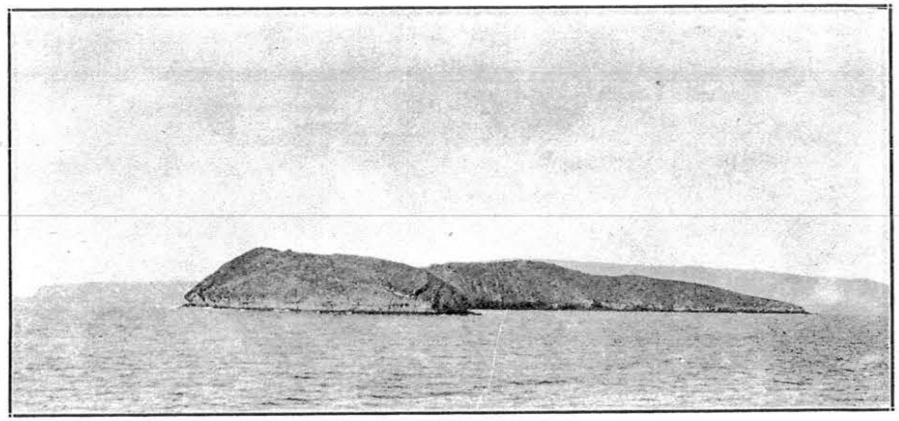
with a hand lens were found. It is reasonable to suppose that the tuff is of the same composition as the basalts which predominate on the other Hawaiian islands. This supposition was corroborated by grinding a portion of the tuff to a powder and examining the powder. With a microscope it was possible to identify a small amount of olivine, and a good deal of magnetite was separated from the powder with a horseshoe magnet. These two minerals are typical of rocks of basaltic composition. They occur in non-basaltic rocks but not in the rather large proportions found by this study.

Blocks of gray to black, vesicular, olivine-free basalt of common Hawaiian types are abundant in a few zones of the tuff. Most of the blocks are only two or three inches in diameter, but a single large one, a foot wide and five inches thick, was found. Very few blocks of coral or other calcareous material were found embedded in the tuff, although search was made for them. The largest measures less than two inches in diameter, and in none could the nature of the original organism be determined. The blocks of lava and of calcium carbonate were undoubtedly torn from the walls of the volcanic conduit by the friction of swiftly ascending gas and lava. No olivine bombs, such as are found on other Hawaiian tuff cones, were discovered.

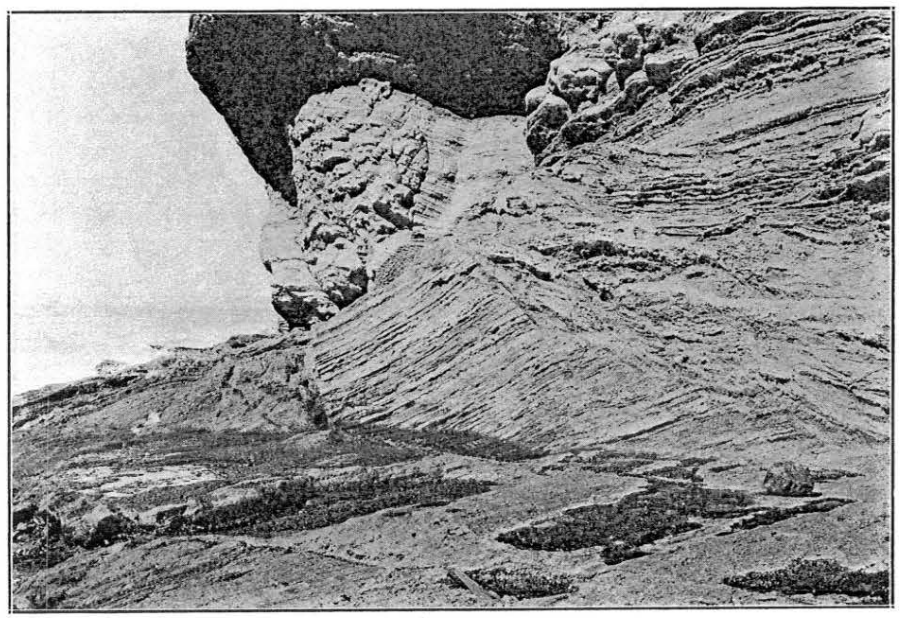
The tuff was undoubtedly ejected as a spray of lava droplets, the fluid lava being broken into droplets by the swift uprush of large amounts of gas, just as the Paris green solution is atomized by the current of air in a gardener's gun. When first broken into droplets the material would be in the molten, liquid state, but these droplets would freeze in the air and become solid before reaching the ground. Much of the gas must have been water vapor which became chilled by expansion so that it condensed as rain and fell with the solid particles making a shower of wet volcanic dust. The ejection was spasmodic rather than continuous so that the material fell in batches each of which made a separate tuff bed. (See Pls. I, B; II; III, A.) Layering would be further favored by gusts of wind which would drift the particles varying distances to leeward during their rise and fall.

STRUCTURE

If just a single lot of particles were ejected they would fall back to the ground forming a simple, conical mound. But if there were



A



B

PLATE I—Views of Molokini: *A*, from the Northeast, Island of Kahoolawe in the distance; *B*, wave-cut terrace, showing bedding of tuff, unconformity between two series of beds, and a fault in the lower series.

successive blasts the later ones would clear away the central part of the mound and scatter it laterally, thus making a depression or crater surrounded by a rim. The later layers would fall onto the rim and conform to its slopes, both outer and inner. Thus the parts of the layers nearest the vent would slope downward and inward, the parts falling on top of the rim would be nearly horizontal, and the more distant parts of the layers would slope downward and outward. Thus the rim tends to form an anticline or arch of beds. The crest of the anticline and the crest of the rim would coincide except where erosion has attacked one side more than the other. This has happened at Molokini. On the east horn of the island, the anticlinal crest lies a little west of the ridge crest, about a thousand feet east of the lighthouse. Looking eastward toward the point where the anticlinal crest crosses the ridge crest, the beds in the foreground are seen to dip to the left or inward. Below the crag are beds which dip to the right or outward from the center of the crater. The transition by way of horizontal beds from inward to outward dipping beds can be seen. (See Pl. II, A.)

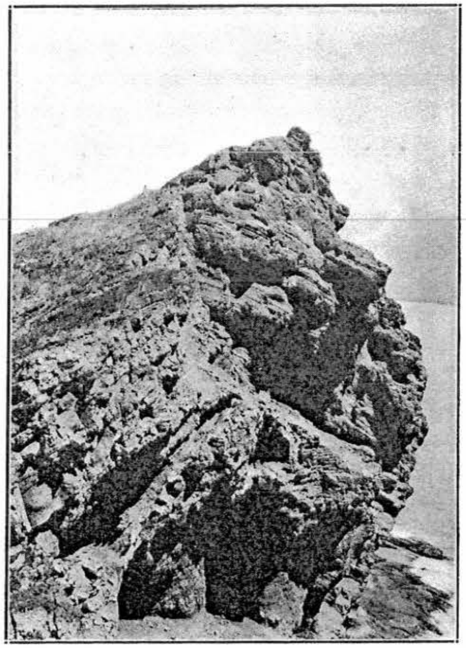
North of Keana (fig.1) there is a different relationship between two sets of beds. On the outer side of the island are beds which dip west or northwest. If this were one flank of an anticline the beds on the inner side should dip in the opposite direction, that is, east or southeast. As a matter of fact they dip to the northeast. Moreover, there is no transition by way of horizontal beds from the outer to the inner set of beds. The beds of the inner slope lie unconformably on those of the outer slope; the positions of the two sets do not conform to one another and the beds of the inner slope follow closely a surface cut across the bevelled edges of the beds of the outer slope. (See Pl. II, B.) The unconformity is also seen in Plate I, B where it separates the beds sloping to the left (west) from those sloping to the right (east). The lower beds are obviously the older. Moreover, the inward dipping beds must have had a foundation under them when they were deposited. It is clear that the eruptions which built Molokini came in two epochs.

It is possible that the interval between the two series of eruptions was very short and that the island formed by the first series was suddenly destroyed by a violent eruption which began the second series. On this assumption considerable amounts of coarse tuff and many large blocks of lava, which had been torn from the walls of the conduit should be found embedded in the lower layers of the second series. Also some blocks of tuff of the first series should be embedded in the tuff of the second series. None of these is found. The extremely infrequent occurrence of excessively violent eruptions in Hawaii also makes it improbable that the interval was short. It seems more probable that the interval was long enough to permit erosion by waves and wind to reduce greatly the size of the island made by the first series of eruptions. The beds made by the second series have encased and in some measure protected a remnant of the earlier island. The attitude of the beds of the first series suggests that the vent, from which the material was ejected, lay a little south of the point at which the later activity centered. Perhaps part of the earlier beds lay above the later vent and were violently removed, whereas the rest of the destructive work done on the earlier island was by slower erosion.

The continuity of the beds is broken in many places by joints or fractures most of which are nearly vertical in position. The joints constitute channels down which water percolates readily and therefore the rock next them weathers more quickly and is more liable to be eroded away. As viewed from a distance the weathered joints make narrow, vertical shadows and broad shadows appear where blocks bounded by joints have fallen out. (See Pl. III, A.) On the inner side of the island, where cliffs are replaced by slopes of 25 to 30 degrees, the weathered rock has yielded less to erosion. It forms bands of soil which are marked by richer vegetation than in neighboring areas. The strips of grass and herbs give evidence of the joints in the rock below.

Most of the joints are mere cracks separating blocks of tuff which have not been offset. Some of the joints have been changed to faults of small throw as the beds on opposite sides of the fracture have been slightly offset. The offsetting probably occurred as slumping before the beds had become well hardened. At a point on the west coast of the island a fault of several feet throw cuts the older (lower) beds in the miniature cliff (Pl. I, B).

The tentative submarine contour lines (fig.1) indicate that the crater-rim never was a complete circle, but that the crater opened to the north. Consider the area bounded by the circle that would be



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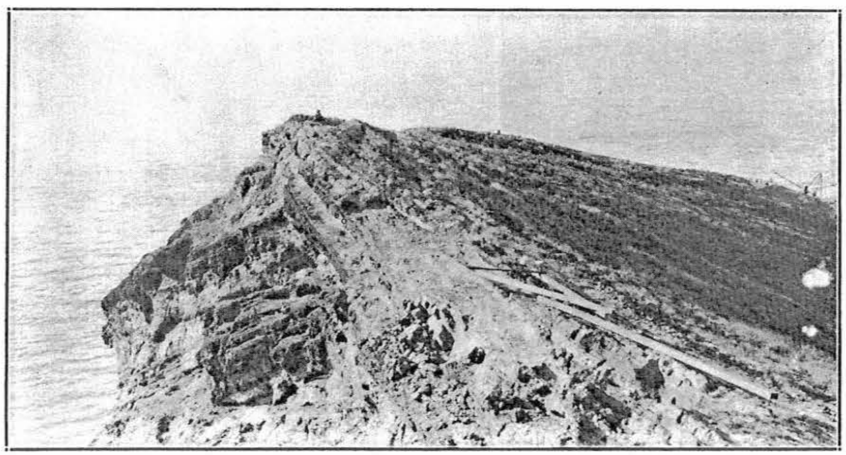


B

PLATE II—Views of Molokini: *A*, looking East along the south rim, showing crest of the depositional anticline; *B*, looking North along the west horn, showing unconformity between two series of tuff beds.

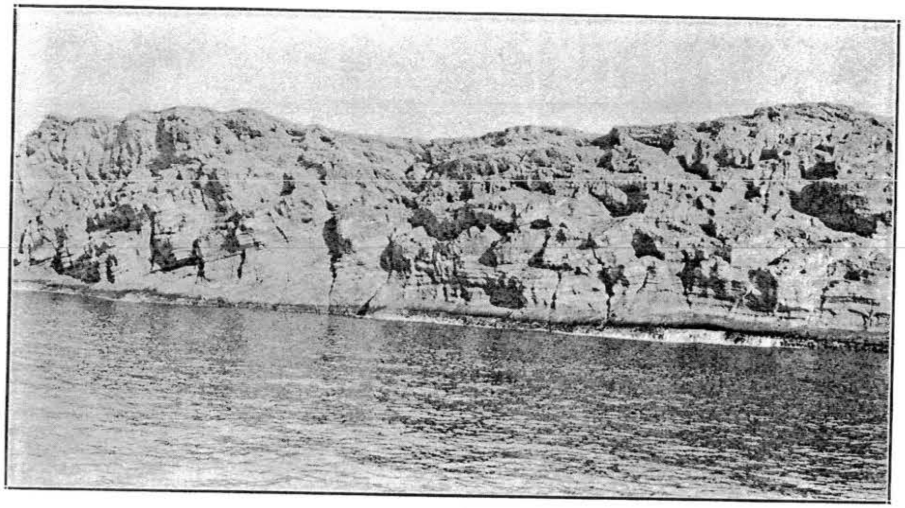
made by continuing the present rim until it closed on itself. The deepest sounding within this area is 26 fathoms and is very close to the north edge of such a circle. If there were a complete submarine rim shallower water would be found in going northward, or in any other direction, from the center of this circle. Instead of this, the water is found to be deeper. Molokini is like many other tuff and ash craters and cones in Hawaii in that the prevailing trade winds drifted a large part of the ejecta southwest or south giving rise to unsymmetrical forms by depositing the ejecta unevenly.

As suggested by Brigham[4] Molokini is a satellite of the great volcano of Haleakala rather than an independent center of eruption. As the 100-fathom line around Haleakala includes Molokini there is no great depth of water between the two. The symmetry of the cone of Haleakala is broken by various irregularities, one of the most conspicuous of which may be called the "Ulupalakua Ridge." It extends west-southwest from the summit as a ridge or protuberance built up by excessive extrusion of lava and ash from numerous minor craters arranged along this line. From the summit to about the 5,000-foot contour line the row of craters bears S. 60°W., which is the direction toward the center of the island of Kahoolawe. At Puu Makua the line forks. The southerly branch bears S. 50°W. and terminates at Puu Kanaloa near the shore, but if it were continued it would pass south of the south side of Kahoolawe. The northerly branch bears S. 80°W. and has Molokini as its most westerly visible point. If continued westerly it would pass well to the north of Kahoolawe. Olai Hill, a cinder cone across the channel from Molokini, is the last center of volcanic action of this branch on Maui.

TOPOGRAPHIC FEATURES

The inner slopes of Molokini are for the most part the original slopes made by the tuff as it fell. In places slabs of tuff have split off along bedding planes and fallen bodily from the lower slopes or have been eroded bit by bit. Erosion has modified the eastern inner slopes much more than the western inner slopes. The original crest has been removed and the present crest lies to the east or outside of the anticlinal crest. Three layers of tuff have evidently been more resistant to erosion than the others and have made step-like interrup-

[4] Brigham, W. T., Notes on the volcanoes of the Hawaiian islands: Boston Soc. Nat Hist., Mem., Vol. 1, 1868.



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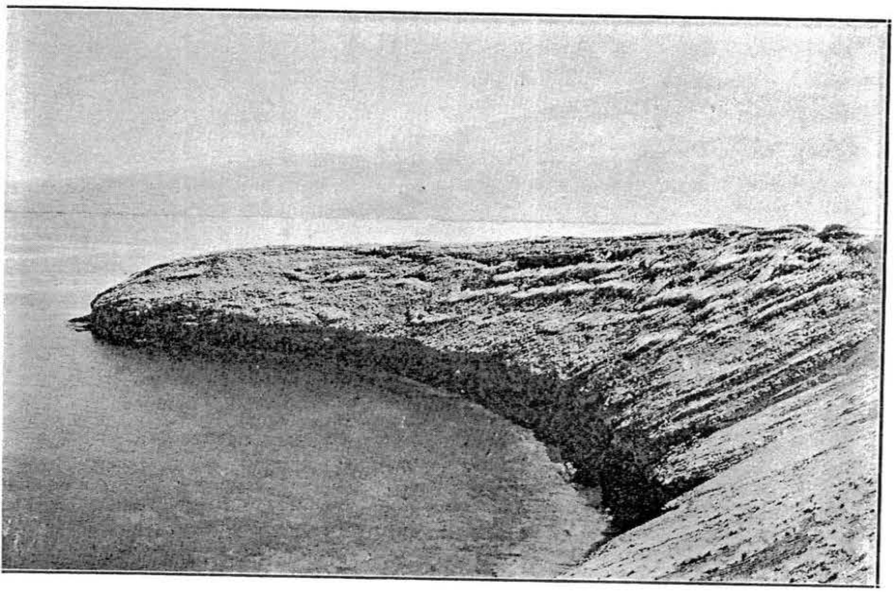

B

PLATE III—Views of Molokini: *A*, cliffs on the south coast, showing wind-eroded surfaces and joints; *B*, the east horn as seen from near the summit of the island, showing soil bands marked by vegetation along weathered edges of tuff beds.

tions in an otherwise smooth slope. Above the edges of these layers a moderate amount of soil has accumulated, distributed as bands which are made prominent by a decidedly more vigorous growth of grass and herbs (Pl. III, B.).

In general, the outer slope of the east horn of Molokini follows the slope of the tuff beds, but one very extensive slab has sloughed off after being undermined by the cliffs below. (See Pl. I, A.) Small parts of the outer slope of the west horn have been made by clearing off weaker tuff down to a more resistant bed. The rest of the outer west side and all of the outer south side are very irregular cliffs. (See Pl. III, A.) The fantastic details of rock sculpturing are due to the peculiar ability of wind to remove the weaker portions of the rock regardless of position. Undermining and quarrying of joint-bounded blocks by waves has been another factor in causing the ruggedness of these cliffs. A striking, topographic feature of Molokini is the wave eroded terrace which extends along nearly the whole shoreline. (See Pls. I, II, III.) I traversed the terrace in the counter-clockwise direction from the landing to Keana. Mr. Theodore Dranga, of Bishop Museum, informs me that he has traversed the terrace in the opposite direction from the landing along the inner curve and along the outer eastern and south sides to a point about below the summit. At a comparatively recent time the sea stood about fifteen feet higher than its present level and the horizontally directed attack of the waves cut laterally into the island. The first effect was the cutting of a notch like that seen on the east side of the island (Pl. I, A) except that the flat surface was a few feet below sea level where the waves worked most effectively. As the notch was cut in farther the overhanging part became so undermined that its support was inadequate and it fell, making a cliff. By repetition of the process the cliff was forced to recede, especially on the south side of the island. Molokini is so situated that the strongest and most effective waves come from the south as this side is most open to the sea. The waves from this direction are infrequent, as the prevailing winds are the northeast trade winds, but their infrequency is more than compensated for by their greater strength. Therefore the boldest and highest cliffs are found on the south side of the island, despite the fact that it is usually the lee. The lowest cliffs, only 20 to 30 feet high, are on the inner side of the crescent.

GEOLOGIC HISTORY

The following stages in the geologic history of Molokini may be deduced.

1. Building of the great dome of Haleakala, partly above and partly below sea level, until the depth at the future site of Molokini was reduced to 100 fathoms or a little less.

2. Eruption from the west end of the Ulupalakua Rift Line of an older series of tuff beds forming a cone or crater of unknown shape and size, but reaching at least 100 feet above sea level.

3. Partial destruction of the cone or crater, largely by wind and wave erosion with possibly the aid of a violently explosive eruption. During this interval a few corals or other lime-secreting organisms lived on the sea-bottom.

4. Eruption of a younger series of tuff beds in which are embedded fragments of lava and a few fragments of carbonate of lime—torn from the walls of the conduit through which the volcanic matter ascended. These beds covered and in part protected the older beds. They made an island much like the present Molokini in shape except that the middle or southern portion of the crescent was wider, the outer slopes smooth and sloping about 30° outward, and the horns, especially the west horn, extended farther north.

5. Erosion of the island, chiefly by waves which made the cliffs and the wave-cut terraces.

6. Falling of sea level so as to expose the wave-cut terrace and the base of the cliffs behind the terrace. [The interpretation of these wave-cut benches as having been made at a time of higher sea-level is being questioned by some geologists, who ascribe these features to the cutting of storm-waves at the present sea-level.]

7. Renewed erosion which has accomplished little work as yet compared to that done prior to the falling of sea level.

NOTES ON THE FLORA OF MOLOKINI

By Edward L. Caum

As far as available records show, there have been only two botanical surveys made of Molokini. Mr. Charles N. Forbes, a botanist on the staff of the Bishop Museum, spent part of a day on the islet on February 10, 1913, and Dr. Harold S. Palmer, Professor of Geology at the University of Hawaii, collected as well as circumstances permitted on October 13, 1925. A comparison of Palmer's collection with the list published by Forbes[5] is rather interesting. Forbes lists 15 species of plants from Molokini, whereas Palmer collected 17, only 10 of which appear in the earlier list. The number of species common to the two lists should be increased by one, however. Forbes records *Jacquemontia sandwicensis*, while Palmer's plant is much nearer to the variety *tomentosa*, noted by Hillebrand[6] as occurring on the south shore of Molokai. A comparison of Palmer's plant with the specimens collected by Forbes shows them to be undoubtedly the same, and it is of interest to note that Forbes altered his determination subsequent to the publication of his list, as the sheet in the Museum herbarium bears the penciled emendation "var. tomentosa Hbd." in Forbes' handwriting. The plant is not typical of the variety *tomentosa*, as the peduncles are much shorter and the flowers smaller than those of the Molokai specimens, but it is much nearer to the variety than to the species, and further study may show it to be worthy of varietal distinction. All together twenty-one species of plants were collected or observed on the islet in these two surveys.

The following list combines the two collections and shows the total number of plant species reported from Molokini. The initials following the names indicate the collector; F, Forbes; P, Palmer.

PORTULACACEAE
- Portulaca lutea Solander .... (F; P)
- Portulaca oleracea Linnaeus .... (F; P)
- Portulaca sclerocarpa Gray .... (F; P)

MALVACEAE
- Sida fallax Walpers .... (F; P)

STERCULIACEAE
- Waltheria americana Linnaeus .... (F; P)

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[5] Forbes, C. N., Notes on the flora of Kahoolawe and Molokini: B. P. Bishop Mus., Occ. Papers, vol. 5, pp. 91-92, 1913.

[6] Hillebrand, William, Flora of the Hawaiian Islands, p. 318, 1888.

ZYGOPHYLLACEAE
Tribulus cistoides Linnaeus....(F; P)
LEGUMINOSAE
Meibomia uncinata (Jacquin) Kuntze....(F)
Hedysarum uncinatum Jacquin
Desmodium uncinatum (Jacquin) DeCandolle
Leucaena glauca Bentham....(P)
CACTACEAE
Opuntia megacantha Salm-Dyck....(P)
COMPOSITAE
Lipochaeta lavarum DeCandolle....(F; P)
SOLANACEAE
Lycium sandwicense Gray....(F)
CONVOLVULACEAE
Jacquemontia sandwicensis Gray....(F)
Jacquemontia sandwicensis tomentosa Hillebrand....(P)
Cuscuta sandwichiana Choisy....(P)
VERBENACEAE
Lantana camara Linnaeus....(F; P)
NYCTAGINACEAE
Boerhaavia diffusa Linnaeus....(F; P)
CHENOPODIACEAE
Atriplex semibaccata R. Brown....(P)
CYPERACEAE
Cyperus sp. indet....(F)
GRAMINEAE
Heteropogon contortus (Linnaeus) Beauvois....(F; P)
Andropogon contortus Linnaeus
Panicum pellitum Trinius....(P)
Syntherisma sanguinalis (Linnaeus) Dulac....(P)
Panicum sanguinale Linnaeus
Digitaria sanguinalis (Linnaeus) Scopoli
FILICES
Doryopteris decipiens (Hooker) J. Smith....(F)
Pteris decipiens Hooker

The change in the number of species from 1913 to 1925 may be explained in several ways. Great changes may occur in the floral population of a small, rugged island like Molokini in a period of almost thirteen years. There are no data as to the relative abundance of the different species in 1913 as Forbes merely states that "they form a fairly good vegetable covering over the island." It is certain, however, that a count of individual plants would show an overwhelming preponderance of not more than a half dozen species, while the

other species would be represented by very few individuals. Palmer's field notes show that the grasses and *Sida* far exceeded any of the other species in number of individuals, and that *Lantana* is of intermediate abundance. One species, *Leucaena glauca*, was represented by a single plant.

In the vicissitudes of life on a tiny, rugged, wind-swept islet with thin or pockety soil some poorly established species might readily become extinct. On the other hand, the wind and visiting birds might easily bring the seeds of other species some of which falling in favored spots might grow and establish new members of the plant population.

Conditions of life are further changed from season to season by the varying weather. The plants observed on Molokini are all species which normally live in open dry situations. Toward the end of the summer many of them die back and become dormant until revived by the winter rains. In the quiescent state they might readily be overlooked. In this way one could account for the omission from the second (October, 1925) list of some of the species which appear in the first (February, 1913) list, such as *Meibomia* and *Doryopteris*. Consideration of the species omitted from the first but appearing in the second list shows conclusively that some of them at least must be comparatively recent immigrants. The two new grasses are both common species on one or more neighboring islands, and *Atriplex* has been rather extensively planted within recent years on the nearby islands of Lanai and Kahoolawe. *Leucaena* and *Opuntia* almost certainly are new as it is most improbable that Forbes would have overlooked plants as conspicuous and distinctive as these. Moreover, Palmer found only a single individual of *Leucaena* although *Opuntia* was fairly abundant on the east end of the crescent. As *Opuntia* spreads very rapidly wherever it becomes established, it seems that it has not been established on Molokini long enough to allow of its spreading to the center and west end of the island. Moreover, none of the individuals of *Opuntia* is large. *Cuscuta*, also might well be a recent introduction as it is a common beach plant on other islands although not at all common on Molokini. Its yellow stems, matted together and tangled over and around the other vegetation, make it rather conspicuous and unlikely to have been overlooked in the first survey.

Any attempt to explain the differences between the lists of plants from these two surveys is of necessity speculative. In view of the fact that the small size of Molokini makes a complete census of its growing plant species a possibility, a comparison of the two lists, made several years apart and at different seasons of the year, affords interesting material for speculation.