MARQUESAN INSECTS: ENVIRONMENT

BY
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1. Marquesan Insects—I, Bulletin 98, 1932.
2. Check list of Tipulidae of Oceania, by Charles P. Alexander, Occasional Papers, vol. 9, no. 21, 1932.
3. Check list of the Elateridae of Oceania, by R. H. Van Zwaluwenburg, Occasional Papers, vol. 9, no. 23, 1932.
4. Fresh-water fishes from the Marquesas and Society Islands, by Henry W. Fowler, Occasional Papers, vol. 9, no. 35, 1932.
5. The lizards of the Marquesas Islands, by Karl P. Schmidt and Walter L. Necker, Occasional Papers, vol. 10, no. 2, 1933.
6. Society Islands Insects, Bulletin 113, 1935.
7. Marquesan Insects—II, Bulletin 114, 1935.
8. Marquesan Insects—III, Bulletin 142 (incomplete).

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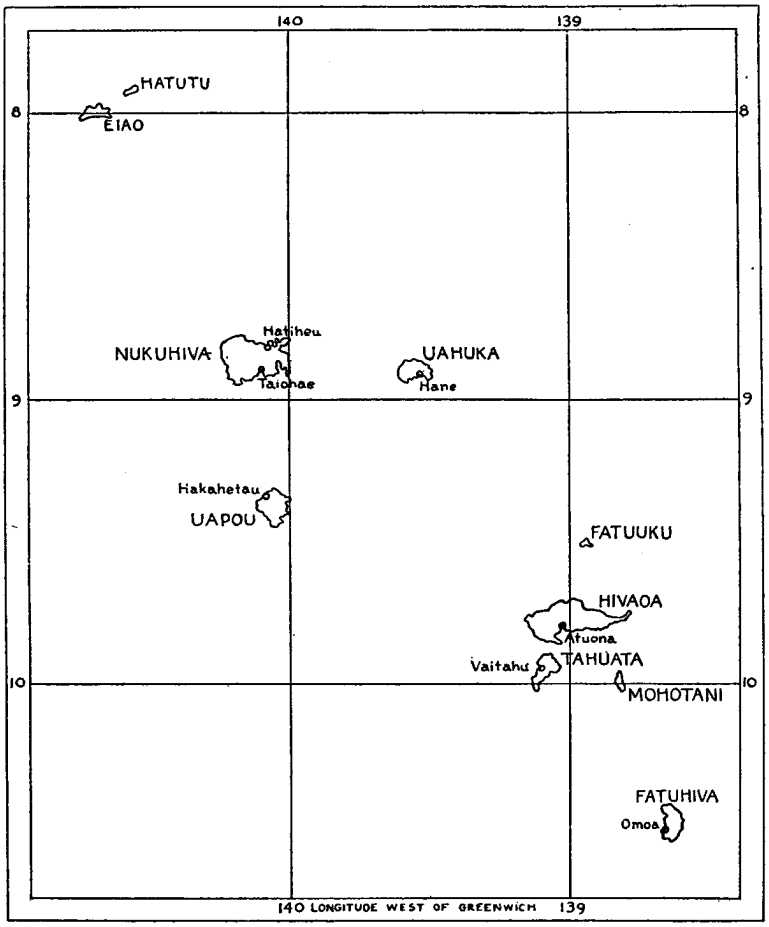
ILLUSTRATIONS



MAP OF THE MARQUESAS ISLANDS.

Marquesan Insects: Environment

By A. M. Adamson

INTRODUCTION

Scope

I have attempted here to describe the environment of the terrestrial and fresh-water fauna of the Marquesas Islands, and to discuss the geographical and geological problems that are of interest in connection with their origin. Some of these problems are difficult and highly controversial. I have little qualification for writing about them, but since they cannot be neglected by a student of the fauna of these islands I have tried to summarize what is known regarding them. This paper is based on personal observations on seven of the ten principal islands in the Marquesas and, like other publications of the Pacific Entomological Survey, to a considerable extent on the field notes and sketch maps prepared by Monsieur G. LeBronnec during his prolonged field work on all the islands except Fatuuku.

Acknowledgments

For permission to work in the Marquesas the Survey was indebted to Monsieur L. J. Bouge, then Governor of the Etablissements Français de l'Océanie, and for their hospitality and many other kindnesses to Monsieur A. Aumont, formerly Administrator of the Marquesas, and to Monsieur L. Rollin, his successor. Among the many Marquesan and other residents who helped us in our work, it is a pleasure to thank especially Monseigneur David Le Cadre, Père Siméon Delmas, Mme. M. Manlius, Messieurs Timo Vahatekua, Stanislas Taupotini, Samuel Kekela, G. LeBronnec, Mr. Robert MacKittrick, and Mr. Henry Lie.

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Field Work

E. P. Mumford, Director, and A. M. Adamson worked in the Marquesas from January 21, 1929 to April 10, 1930, and R. R. Whitten from December, 1929 to April 10, 1930. G. LeBronnec, who has been resident for many years in the islands, worked with us during the greater part of our visit,

and after our departure he continued field work until January 1932. H. Tauraa, of Tahiti, acted as field assistant from September 1929 to September 1931.

The headquarters of the Survey were at Atuona, Hivaoa, and on this island the most intensive work was done, from January 1929 to January 1932 intermittently, by all members of the field party. The principal collecting grounds were on the western mountains, culminating in Temetiu. These were reached from Atuona by the trail to Hanamenu, and from camps at Matauuna, an altitude of about 4,000 feet, north of Temetiu, and at Anatikaue and Anatuakina on the western slopes of the island. On the eastern central range a camp was made below the summit of Ootua, and collections were made also at Teava Uhia i te Kohu, near the eastern end of the range, which was reached by the trail from Puamau. LeBronnec, in 1931-32 collected along the high Kaava ridge, almost as far as Feani. Most of the work at intermediate levels, 1,000-2,500 feet, was done on the slopes of the western mountain range and on the central plateau northeast of Atuona, and at low levels at or near Atuona.

On Nukuhiva Mumford worked from September 3 to December 13, 1929, and Adamson from October 4 to December 4, 1929. LeBronnec and Tauraa assisted in 1929 and revisited the island May 9 to August 31, 1931. A camp at Tapuaooa, in western Tovii, served as a base for exceptionally rich collecting on the northeastern mountains. A trail was cut to the summit of Ooumu, at about 4,000 feet. A fauna nearly as abundant was found towards the southern end of the high western ridge, at Puokoke, which was reached from the western coast. Less time was spent on the northern and southern mountain ranges, where the fauna was less rich than near Ooumu, and on the plains of Tovii, where collecting was meager as compared to that on other regions of similar altitude. Most of the field work at low levels was done near Taiohae.

On Uapou most of Whitten's work was done, with Tauraa, December 1929 to March 1930. LeBronnec worked on this island in November and December 1931, and Adamson for a few days in December 1929. Hakahetau served as base, and most collecting at low and intermediate levels was done in the Pepehitoua Valley. From the head of this valley a trail was made to Teavatuhai, at about 3,000 feet on the central ridge. This is the highest collecting ground accessible on Uapou. LeBronnec collected also on the western side of the central range, ascending from Paaumea Valley.

On Uahuka LeBronnec and Tauraa had headquarters at Hane from February 22 to March 29, 1931. A trail was made from the head of Hane Valley to a camp at Penau, for collecting along the crest of the central ridge. Further field work extended to most parts of the island. Adamson collected

along the central ridge, from its western end to an altitude of about 2,500 feet, and in Vaipaee Valley, from September 19 to 25, 1929.

A comparatively small amount of work was done on Tahuata, from May 22 to August 8, 1930, intermittently, by LeBronnec and Tauraa. From headquarters at Tahuata a trail was cut to Amatea, where a camp was made for collecting trips by way of Vaitupaahei Valley to Haoipa and other points along the extreme crest of the central range. At low and intermediate levels they worked especially in Vaitahu, Hanamiai, and Hanateio Valleys and on the barren northern slopes.

On Fatuhiva less time was spent than on the other inhabited islands. LeBronnec, from August 15 to September 27, 1930, collected especially in Omoa and Hanavave Valleys and on the slopes above them, along the trail crossing the central range from Omoa to Uia, and along the crest of the southern half of this range.

On Mohotani LeBronnec and Tauraa collected from January 30 to February 5, 1931, and Adamson and LeBronnec for a single day, August 13, 1929. Collections were made over the islands generally, and especially in the forests of *Pisonia* and other trees towards the southern end.

Fatuuku was visited on November 19, 1930, by a party under Tauraa. At some risk an ascent was made to the summit of the island, where a few specimens were collected.

Eiao was worked more thoroughly than other uninhabited islands, by Adamson and Tauraa from September 28 to October 4, 1929, and LeBronnec and Tauraa April 12 to May 8, 1931. An abandoned settlement at Vaituha served as base, and during the dry weather of 1929 the only collecting grounds where moist conditions were found were along the small stream in Vaituha Valley. In the course of field work almost all parts of Eiao were reached.

To Hatutu two short visits were made in September 1929 by Adamson and Tauraa, who ascended the central range from near the middle of the northwestern coast, and in April 1931 by LeBronnec and Tauraa, who worked along the greater part of the crest of the central range from its southeastern end.

During the field work outlined above attention was devoted more or less equally to all kinds of invertebrate animals, except those of microscopic size. Most of the plants collected by the Survey, as hosts of insects and other animals, were obtained on Hivaoa, by Adamson, LeBronnec, Tauraa, and Marquesan assistants. A few plants of special interest were collected on other inhabited islands, and an attempt at a floral survey of Eiao, Hatutu, Mohotani, and Hatutu was made, especially by LeBronnec and Tauraa and assistants. For use in the field preliminary identifications of the host plants were made by Dr. Elmer D. Merrill, Consulting Botanist of Bernice P. Bishop Museum, then stationed at the University of California. As an aid

in preparing the present paper the Museum has provided specific determinations and made available the collections of previous expeditions to the Marquesas.

Note on Maps

The maps used in this report are reproduced from sketch maps made by G. LeBronnec, except that of Hivaoa, which was made by G. Bonno. In making these maps the coastlines of the six inhabited islands were taken from the United States Hydrographic Office charts, which differ little from the French charts made in 1881 and 1882. The maps of Fatuhiva and Uahuka are reproduced, with a few additions, from the published charts. Almost all details in the interior of Hivaoa, Tahuata, Nukuhiva, and Uapou are original. The maps of Mohotani, Eiao, and Hatutu are entirely original, for these uninhabited islands had not been previously surveyed. In preparation for the engraver the sketch maps by LeBronnec and Bonno were redrawn by E. Y. Hosaka and Arthur Soon.

On Hivaoa, Tahuata, Nukuhiva, and Uapou a theodolite was used, but the number of fixed points was small. On these islands, and on Fatuhiva and Uahuka, altitudes were determined with a Paulin altimeter, but without exact corrections for temperature and barometric pressure. The map of Mohotani was made with no instrument except an altimeter, those of Eiao and Hatutu without any instrument.

"Air-brush" maps of Tahuata and Nukuhiva (pls. 7, 8) were prepared by Messrs. Thomas Brothers, cartographers, and Frank W. Day, commercial artist, of Oakland, California, under my supervision. Obviously in the absence of adequate field data they are diagrammatic, and the limits of error are wide. They serve, however, to represent the major structures and the topographic pattern of the islands better than these features are shown on the previously constructed charts, on most of which the interior of the islands is not mapped.

The place names on the maps have been entered with great care; most of them represent a concensus of opinion of more than one Marquesan of standing. They include, with revision, the names used by the U. S. Hydrographic Office, by Linton, Handy, and Brown, and scores of names that have not heretofore appeared on published maps. Almost all the names of features in the interior of the islands are new. Many of them are known to a few older residents only.

GEOGRAPHY

Regional Relations

The Marquesas Islands lie on the eastern margin of Polynesia, almost exactly in the center of the Pacific Ocean, between latitudes 7° 50′ and 10° 35′ S. and longtitudes 138° 25′ and 140° 50′ W. To the south are the numerous atolls of the Tuamotu Archipelago, of which Pukapuka and Napuka, some 300 miles distant, are the nearest. To the west lie other scattered atolls, the nearest of which is Caroline Island, about 700 miles due west. To the north and east of the Marquesas lies a great expanse of unbroken ocean. The nearest high islands are the Society Islands, 850 miles to the southwest, and beyond these are the Austral, Cook, Samoan, and Tongan archipelagoes. Hawaii is 2,000 miles to the north-northwest.

With the exception of the small Mangareva Islands, the Marquesas are farther from a "continental" region than any other archipelago in the world. The coast of Mexico, which is the nearest part of a continent, is nearly 3,000 miles off, and Fiji is about 2,700 miles away.

In considering the degree of isolation of the Marquesas as compared with that of other high islands in the Pacific, I shall not attempt to discuss the possibility of past land connections within the Pacific basin; the presence of atolls is of little importance, because they may have played but a small part in the dispersal of the most characteristic members of the fauna and flora; and distances from the American continents are not considered, because the influence of these regions on Polynesia appears to be secondary. The main criteria, therefore, must be the distances from continental regions to the west, and from the nearest high islands. On this basis, Hawaii is clearly the most isolated in the Pacific, and indeed in the world, though such islands as Tristan da Cunha and New Amsterdam, in the South Atlantic and Indian Oceans, are farther from the nearest land than Hawaii is from some atolls. Easter Island ranks next in degree of isolation in the Pacific, and then the Marquesas. The distance from Hawaii to the nearest continental area to the west is nearly 3,000 miles, and to the nearest high islands—the Marquesas—2,000 miles; the corresponding figures for the Marquesas are 2,700 and 850 miles.

In comparing the Marquesas with other high islands in central Polynesia, it may suffice to give the distances from the western margin of the Pacific basin—that is, from the eastern limit of islands that are believed to be the remnants of a former continental area. It is fairly generally agreed that the boundary is marked by a line drawn from New Zealand through the Kermadec Islands, Tonga, and Fiji, to New Hebrides and the Solomon Islands. The distances from this line are approximately as follows: for Mangareva 2,700, Marquesas 2,500, Society Islands 1,600, Austral Islands 1,500, Cook Islands

1,000, Samoa 500. These distances, however great, do not give a true picture of the actual isolation of these archipelagoes, because it must be remembered how minute the islands are in comparison with the vast expanses of ocean surrounding them. This has been emphasized by Buxton, who writes (8, p. 3)*: "According to Daly (1916), there are 73,000 square miles of land and 35,000,000 square miles of water in Oceania, so that the proportion of land to water is as one to five hundred; and yet Brigham's Index gives the names of 2,600 islands."

The form of the ocean floor in the region of the Marquesas is little known. About 170 miles north of the islands a depth of 2,475 fathoms is recorded by Agassiz (1, pl. 1) and of 2,456 fathoms as far to the southwest. A hundred miles to the west the charts record no bottom at 3,200 fathoms, nor at 3,000 fathoms some 200 miles to the east. I have not seen results of the *Dana,* which visited the Marquesas in 1928, equipped with modern sounding machines. There is little point in considering these depths further in relation to possible land connections, beyond stating that a hypothesis such as that of Meyrick (42, p. 490), who postulates a former land of "Palaeonesia," would probably involve vertical movements of as much as 3,000 fathoms if the Marquesas were to be included in it.

The Marquesas Islands are in the region of the southeast trade winds and near (but probably outside) the northern limit of the occasional hurricanes that are characteristic of the climate of the Tuamotus in the early months of the year. The Marquesas lie within the general ocean drift which sets westward across the wide area of the mid-Pacific; they are about 15 degrees south of the equatorial counter-current.

Interisland Relations

The islands of the Marquesas are distributed in an irregular chain about 50 miles wide, extending 230 miles southeast-northwest, about the same direction as that for the Tuamotu, Society, Austral, and Cook Islands. The arrangement is less regular than that of most of the archipelagoes to the southwest, which are characterized by arcuate forms, with the convexity towards the northwest. In the Marquesas the chain is approximately straight.

All the Marquesan islands are elongated in greater or less degree. The direction of elongation is approximately east-west or north-south, except for Eiao and Hatutu, where it is northeast-southwest. Chubb (14) has shown that these lines represent structural trends; the dominant lines are east and west, and north and south, with minor trends at an angle of 45 degrees to them.

The ten main islands are divisible into three groups, with intervening distances of about 60 miles: Fatuhiva, Mohotani, Tahuata, Hivaoa, and Fatuuku

* Numbers in parentheses refer to the Bibliography, pp. 71-73.

in the southeast; Uapou, Uahuka, and Nukuhiva in the center; and Eiao and Hatutu in the northwest.

The channel between Hivaoa and Tahuata is about 3 miles wide and between Eiao and Hatutu 3½ miles. Fatuhiva and the three central islands are each isolated by at least 25 miles of sea. Thomasset Rock in the southeast group and Motuiti in the central group are isolated rocky islets. Cotar Island (Coral Island, Îles de Sable) to the extreme northwest is a cluster of low islets of unknown origin. Of the few islets off the coasts of the main islands, the largest is Terihi, ¾ of a mile long, off the south end of Mohotani.

The depths of ocean separating the islands are almost unknown. On the published charts depths of 1,284 fathoms are recorded between Nukuhiva and Uapou and of 1,173 fathoms between Nukuhiva and Uahuka. According to the Pacific Islands Pilot (55, p. 228) a breaker was once observed in mid-channel between Eiao and Hatutu, though no signs of danger were recorded by some vessels that have passed through since then; I saw no breakers. The narrow channel—only 3 miles wide—which separates Hivaoa and Tahuata appears to be quite shallow; soundings of 37, 38, and 39 fathoms are recorded on the charts nearly 1 mile north of Tahuata and, according to Marquesans who have fished in these waters, depths of not more than 50 or 60 fathoms are found in mid-channel. In a large number of soundings the French surveys of 1881 and 1882 recorded no bottom at depths up to 164 and 178 fathoms round the islands of Mohotani, Tahuata, Hivaoa, and Fatuuku; to the southeast of Uahuka; and over a wide area to the north, east, and south of Eiao and Hatutu. Without further data, all that I need say here about the possibility of former connections between the islands is that an uplift of even 1,000 fathoms would probably leave the three central islands separate, and that a rise of as little as 50 or 60 fathoms would possibly unite Hivaoa and Tahuata.

It must be noted that Rollin (48, p. 27) gives a table of average depths of 273 to 328 meters between four pairs of islands, and that Brown (5, pt. 1, p. 17) states that an emergence of 400 meters "would unite or bring into close contact all land areas of the archipelago." Unless these writers based their conclusions on records unknown to me, and not shown on the United States, British, or French charts, it would appear that they had misconstrued the soundings at places where no bottom was found by the French surveyors.

The charts supply hardly any information regarding marine platforms around the islands. The only island around which many soundings have been made is Tahuata, where the bottom falls fairly uniformly to about 40 fathoms within about a mile from the shore, beyond which distance the soundings were not carried. According to Davis (20, p. 203) these soundings show that there is a well-defined bank around the greater part of Tahuata, and he infers,

from the few soundings, that there are similar platforms around the other islands.

A number of off-shore banks are known by name to the Marquesans. According to information given by them the banks surrounding Uahuka are larger and farther from shore than those known off the other islands. For instance, the shoal of Tehuemana, 4 miles east of Point Tehotepapa (Teohotepapa) is said to be only 70 fathoms deep, and the charts show a bank about 18 miles east of the island at only 35 fathoms. Apparently a slight lowering of sea level would considerably enlarge the island of Uahuka, especially on its eastern side.

Agassiz (1) figures a "Section across Marquesas Plateau." His term "plateau" is based on a single line of soundings, and its use does not seem to be justified.

Dimensions of the Islands

So little surveying has been done in the Marquesas that accurate figures for the dimensions of the islands are not available. The following table is based on all the information at my disposal. Most of the figures are estimates, and none are to be closely relied upon. Some of the figures are taken from Picquenot (44); the sources of most are from sketch maps and local records. (See pp. 43-70.)

	Area (square miles)	Length Maximum	Breadth Maximum	Greatest altitude	Area above 2,000 feet (square miles)
Fatuhiva	30.0	9.0	4.5	3670	5
Mohotani	6.0	5.0	1.5	1700	....
Tahuata	20.0	9.0	5.0	3280	2
Hivaoa	125.0	25.0	8.0	4130	25
Fatuuku	0.5	1.5	0.5	1180	....
Uapou	40.0	9.0	8.0	4040	3
Uahuka	30.0	9.0	5.0	2805	1
Nukuhiva	130.0	16.0	12.0	4000	30
Eiao	20.0	8.0	4.0	2000	....
Hatutu	7.0	5.0	2.0	1380	....

The total area of the Marquesas, according to these estimates, is about 400 square miles; Chubb (14) gives "about 500," and the figures 480 and 492 are given in many encyclopedias. The corresponding figures are 6,500 for the Hawaiian islands, 600 for the Society Islands, and 1,200 for Samoa. The greatest altitude in the Marquesas is slightly more than 4,000 feet, as compared with 13,825 on the island of Hawaii, 7,321 on Tahiti, and 6,094 on Savaii, Samoa. The Austral, Cook, Mangareva Islands, and Rapa are all considerably smaller and lower than the Marquesas.

Topography

Areal Features

All the Marquesan islands, with the doubtful exception of the "Coral Islands," are volcanic. Most of them are clearly the summits of large volcanoes. Their present topography is extremely rugged, as a result of erosion and also of faulting, which appears to have been much more active here than elsewhere in Polynesia. There are no true coastal plains in the Marquesas; the coastline is almost everywhere cliffed and in some places the precipices rise to more than 1,000 feet above the sea. On most of the islands there is a long central mountain range. There is no flat country above an altitude of about 1,000 feet, except in central Nukuhiva, where there are plains between 2,000 and 3,000 feet, and in some parts of Hivaoa, where there are plateaus up to 2,000 feet.

Three of the islands—Fatuhiva, Tahuata, and Uahuka (figs. 2, 3, 7)—are similar in structure and their topography may be described in comparatively simple terms. A high central ridge, approximately semicircular, extends along the greater part of the interior; the altitude of its crest is fairly uniform. On the innner side of the semicircle there are abrupt slopes into a few wide valleys, which have comparatively large streams. The outer slopes are more gradual and are dissected by numerous V-shaped valleys, with small, mostly intermittent streams. On Tahuata there are gentle outer slopes only in the northern half of the island. There are no extensive areas of level country above the floors of the valleys on any of these islands. According to Chubb (14) Fatuhiva and Tahuata are each the half of a volcanic cone, the other half of which has been lost by downfaulting, the crest of the central range representing the rim of the original crater. Whether or not this explanation applies to all three of the islands, it affords a clear and simple picture of their topography.

Each of the other three inhabited islands—Hivaoa, Nukuhiva, and Uapou (figs. 1, 5, 6)—has distinctive features. In outline Uapou is little elongated. The central range is short, about 3,000 feet high, and from it descends a series of secondary ridges. Striking and unique features of this island are the numerous lofty pinnacles that arise from the crests of the ridges. A great part of the interior of Nukuhiva is occupied by a wide central depression, with an average altitude slightly more than 2,500 feet, surrounded by high mountains except towards the east. Hivaoa has the most complex topography of all the islands; there are two separate mountain systems: a range with an approximately semicircular crest towards the west, culminating in Mount Temetiu at an altitude exceeding 4,000 feet, and a lower, central range along the narrow eastern half of the island. The western regions of

Hivaoa and Nukuhiva are long volcanic slopes, dissected by numerous deep valleys.

The comparatively low islands of Mohotani and Eiao differ from all the others in that the interior is more or less flat throughout. On both islands the uplands may be described as plateaus, between 1,000 and 2,000 feet high, sloping gently from east to west. Mohotani is inclined fairly evenly towards its low north end; on Eiao there is a slight inclination towards the southwest. The high interior of Hatutu slopes steeply towards the west; there are cliffs 500 to 1,380 feet high along the eastern side of the island, and less than 1,000 feet high on the west. Fatuuku is a rocky islet, with a flat summit in the western half.

Biologically the most important topographical feature is altitude, as it controls the two principal factors in the physical environment: rainfall and temperature. Regions above 2,000 to 3,000 feet constitute a cloud zone covered by rain forest, to which most of the endemic animals and plants are restricted. Nukuhiva has the largest area above 2,000 feet, but Hivaoa has more above 3,000. It is noteworthy that on Hivaoa alone there is a division of the cloud zone into two regions, western and eastern, separated by areas of much less than 2,000 feet. On Nukuhiva the mountains along the north, south, and west reach altitudes of 3,000 feet and more, but there are no areas of less than 2,000 feet between them. On Fatuhiva, Tahuata, Uapou, and Uahuka, only a small part of the central mountain range rises much above 2,000 feet. On the four uninhabited islands, Mohotani, Fatuuku, Eiao, and Hatutu, there is no region of sufficient elevation for the development of a cloud zone.

The soil on the greater part of the islands is red, reddish-brown, or yellow, porous and fertile. Different types of soil, whitish or greyish-white, very finely divided, less permeable, and infertile, are characteristic of Tovii and the mountains round Taiohae on Nukuhiva and of much of the island of Uapou. The relative sterility of Uapou, and of parts of Nukuhiva, may be due to the nature of the soil rather than to low rainfall.

COASTAL FEATURES

The coastline of all the islands except Mohotani, Fatuuku, and Hatutu is deeply embayed at the mouths of the valleys, especially on the windward, rainier, sides of the islands, where the valleys have been more deeply eroded. The lengths to which the sea has entered are remarkably uniform, relative to the size of the valleys and to the rainfall. To this embayment of the coast line are due such superb natural harbors as that of Taiohae.

The coasts are almost entirely unprotected by coral reefs. Crossland (17, pp. 551-552) records only 12 species of madreporarian corals (5 of

Pocillopora, 4 of *Porites,* and one each of *Psammocora, Montipora,* and *Fungia*) and though corals appear to grow all round the islands, so far as may be judged from the fragments on the beaches, only a few very small fringing reefs are present. Most of these are in the bays of northern Tahuata. The largest of them, which is described by Crossland, stretches across Hanahevane Bay where it is less than ½ mile wide. Unfortunately no thorough investigation appears to have been made of the "Coral Islands" to the north of Hatutu. Agassiz (1, p. 3) was informed by Marquesans that this was the only place in the Marquesas where corals grow in abundance, but Crossland (17, pp. 550-551), who was told by the captain of an island schooner that they were "mere sandbanks," concludes that the name "Îles de Sable" on the French charts is probably a correct description. No raised reefs are known in the Marquesas, though a few elevated beaches were observed.

This absence of large coral reefs in the Marquesas, in such striking contrast to the neighboring Tuamotus, was attributed by Dana (19, pp. 304, 325) to rapid subsidence. The main explanation advanced by Agassiz (1, p. 4) is that there are apparently no great platforms of erosion around the islands, on which reefs might grow. Crossland (17, p. 546) observed that "not only is the fauna restricted beyond all hope of normal reef formation, but also that half the fauna is here but a remnant struggling against adverse conditions" and moreover that "the same thing applies to the other groups of which collections were made." He concludes that the problem is ecological rather than geological, but is unable to offer a complete explanation in terms of adverse ecological conditions. He mentions the necessity of further observations on ocean temperatures around the Marquesas, because "an occasional fall might have the same effect upon corals as a permanent difference." This possibility is dealt with at length by Chubb (14, pp. 61-67) whose hypothesis of occasional extensions of the influence of the Peruvian current, sufficient to chill the waters round the Marquesas, is an attractive one, though admittedly almost entirely speculative. Gardiner (22, p. 166) accepts Chubb's hypothesis, and states: "The cold Peruvian current periodically laves the shores of the Marquesas . . . so that the present absence of coral formations is readily understandable." It is interesting to note the observations of Puls (45) and of Patterson and Smith (43) that an upwelling of relatively cool water occurs in the equatorial region of the Pacific, though perhaps this may never have chilled the waters surrounding the Marquesas below the limit for reef-building corals.

The enormous cliffs round the coast are the most characteristic and spectacular feature of Marquesan topography (pl. 4, *B*). The line of cliffs or steep slopes is unbroken except at short stretches of beach along the heads of the bays, and in many parts of the coast the precipices rise vertically to heights

considerably more than 1,000 feet. The highest cliffs appear to have been formed by faulting; according to Crossland (17, p. 543), the smaller cliffs in parts of western Fatuhiva are due to marine erosion. All or most of the cliffs of Uapou, which are relatively low, may be due to marine erosion alone.

The shores of the islands are almost all rocky, with deep water at the base of the cliffs. A shore shelf, 3 to 8 feet above the level of high tides and in most places only a few feet wide, is a common feature. In some parts of the northwest coast of Eiao the shelf stands more than 10 feet above sea level (pl. 4, *C*). Small caves are common in the face of the cliffs behind these shelves. They are found in many other parts of the Pacific and there is but little doubt that they have been exposed by a recent general fall in sea level.

Beaches of sand and shingle are rare except at the heads of the bays; a notable exception is the white sandy shore on the exposed eastern coast of Eiao. Most of the beaches are of black sand or shingle, derived from volcanic rocks, with only small amounts of fragments of corals and shells (pl. 1, *B*). Where no permanent stream enters the sea, corals and shells may be preponderant, and the beach white. The contrast is clearly seen at the neighboring bays of Hakaui, at the mouth of one of the largest rivers in the Marquesas, and Hakaea, which is without a permanent stream.

According to Rollin (48) the average range of the tide at Taiohae, Nukuhiva, in 1924 was 1.45 meters. I know of no other data on the tide in the Marquesas.

VALLEYS AND STREAMS

The most characteristic valleys in the Marquesas are the magnificent amphitheaters, which have the appearance of parts of volcanic craters. Most of these valleys have small deltaic flats, only slightly higher than the beaches. Above the flats gentle slopes rise to the base of the surrounding mountains. There are six of these amphitheaters on Hivaoa and five on Nukuhiva, and one or more on all the islands except Mohotani, Fatuuku, and Hatutu. The greatest is at Atuona on Hivaoa; it is more than 2 miles wide, with sides as high as 4,000 feet.

The other large valleys are almost all narrow and deep enough to be termed canyons. Many of them have been sufficiently eroded to acquire flat floors; a rise in sea level of 100 feet would drown most of them to a distance of 1 to 2 miles from the shore.

Most of the Marquesan streams are of insignificant dimensions. Many of them are intermittent in their lower reaches, drying up completely in times of drought or continuing underground to the sea, appearing only here and there as springs. Thus on Tahuata there is only one stream, at Hanatetena, that flows permanently above ground to the sea. There are only three rivers in the Marquesas much more than 5 miles long; these enter the sea at Tahauku

on Hivaoa, at Taipivai and Hakaui on Nukuhiva. The river of Taipivai is the most voluminous in the islands. Mohotani and Eiao have each a single permanent stream and a few springs. No permanent sources of water are known on Hatutu, but on Fatuuku there is a spring which is said to persist through periods of drought. The beds of most of the Marquesan streams are stony; a bottom of sand or mud is uncommon, especially in the mountains.

There are no lakes in the Marquesas and in the high interior of the islands no permanent ponds of stagnant water were observed in the course of field work. When the mountain streams begin to dry up, small pools are isolated, but they are soon washed out when the streams are again flowing. The pool named Vaihakameama (Water-that-dances-by-moonlight) in Tovii, Nukuhiva, was the largest I saw in the interior or learned about from residents in the islands. In November 1929 its diameter was about 150 feet, its depth less than 3 feet, and the grass still rotting at the bottom showed that it was probably subject to occasional dessication. Brown (5, pt. 1) states that "several ponds or small lakes, 7 to 30 meters in length occur in the Tovii basin," but it seems certain that none of these is permanent. Marshy regions of small extent and probably subject to dessication appear in parts of Tovii on Nukuhiva. The term "swamp" is scarcely applicable to any of them.

At the mouths of many of the streams the sea has piled up bars of sand and shingle to form shallow lagoons of fresh or brackish water. After heavy rains the bar may be broken down and the pool washed out by the flood.

Habitats for fresh-water organisms are thus restricted in variety in the Marquesas, as they are in general on other oceanic islands in the Pacific. This is probably due to the porosity of the soil. In the interior of the Hawaiian islands there are no natural lakes worthy of that name, though true bog formations occur. On Tahiti there is a single lake, formed by landslides at the head of Vaihiria Valley. On Savaii, Samoa, there are some small crater lakes. But the absence of suitable habitats has probably had little relation to the extreme paucity of the fresh-water fauna in the Marquesas; few species have colonized the abundant streams, and many of these, like the Palaemonidae and the gobies, are the recent descendants of marine forms.

Climate

Meteorological records

The meteorology of the Marquesas Islands is very little known. Previous to 1929 the only observations listed (Reed, 46, p. 17) were broken records of rainfall from Fatuhiva and Nukuhiva, made between 1897 and 1903 by the anthropologist Von den Steinen and published by Hellmann (31). The meteorology of regions surrounding the Marquesas is likewise little known. There are some short records from Malden Island, a very few from the

Tuamotus, and some observations made over a fairly long period at Papeete, Tahiti. The nearest fully equipped meteorological station to the Marquesas is at Apia, in Samoa.

A series of observations which I started at Atuona, Hivaoa, in February 1929 was extended by enlisting the services of residents in the Marquesas so that continuous records of rainfall, temperature, humidity, and winds were made at Atuona since February 1929, and at Hatiheu, Nukuhiva, since February 1931, and at Taiohae, Nukuhiva, since October 1929. Aided by a grant from the National Research Council, observations at these stations were continued until recently. Unfortunately, it was practicable to make only a few measurements at high altitudes, but Mr. R. Klima kindly made observations at "Praha" at about 2,000 feet in central Nukuhiva from February to July 1930. At all stations observations have been made at 6, 12, and 18 hours. It must be admitted that the records were made by untrained observers, without the most refined instruments.

The meteorological data obtained at the various stations, with an account of the methods employed, were submitted for study to Professor J. B. Leighly of the University of California, who has presented and discussed the records for the three years 1929-1931 (38) so that little statistical material need be incorporated here. I am indebted to Professor Leighly for the use of tabular summaries and advice which he generously gave me for the preparation of this manuscript.

The following account of the climate of the Marquesas is not based solely on the short series of instrumental records obtained by the Pacific Entomological Survey, but also on information obtained from residents in the islands, mostly in the form of notes prepared by Monsieur LeBronnec. In the absence of further data, it must serve as a general picture of the climatic elements in the environment of the Marquesan fauna. Some comfort may be found in the thought that even data which may be adequate for the meterorologist fall far short of that which the biologist might wish to know about the intimate environment of any animal or plant.

RAINFALL

The total annual rainfall at stations in the Marquesas is shown in the following table:

	Millimeters	Inches
Atuona, south coast of Hivaoa, 1930	1375	54
Hatiheu, north coast of Nukuhiva (11 months) 1931	2889+	114+
Taiohae, south coast of Nukuhiva 1898 (from Hellmann)	1230+	48+
Taiohae, south coast of Nukuhiva 1902 (from Hellmann)	1470+	58+
Omoa, west coast of Fatuhiva 1900 (from Hellmann)	2972	117

The most striking feature of the climate of the Marquesas is the great variation in annual rainfall. So far as may be judged by the opinion of resi-

dents in the islands, the year 1930 at Atuona was moderately rainy; the figures for a dry year would probably be much less than 1,000 mm. At Hatiheu, 1931 was probably typical of wet years. The heaviest monthly total in the records in 1930 and 1931 was 538 mm (21 inches) at Hatiheu, in February, 1931. Hellmann (31) records 596 mm in December, 1900, at Omoa, and during a "Zyklon" at Taiohae on January 15, 1930, the rainfall for one day was 170 mm. At Atuona in 1930 there were 107 days with measurable rain; at Hatiheu in 1931 there were 134 in the 334 days covered by the record. Hellmann records 255 days of measurable rainfall at Omoa in 1900.

According to residents in the islands, there has been an alternation of cycles of wet and dry years during the last thirty years somewhat as follows: 1903-1906, wet years; 1908-1910, dry; 1911-1917, wet; 1918-1928, dry; 1929-1931, wet; at the end of 1931 a dry cycle began. In the absence of exact records, the degree of drought in dry years may be judged by the effect on the flora. During the dry period from 1918 to 1928 conditions of extreme aridity prevailed at low levels; the herbaceous covering of exposed regions withered away; the production of copra was greatly diminished and many young coconut palms and vanilla plants were killed; in the western region of Uahuka many semi-wild horses perished. In the days of a large population, famine resulting from drought was not unknown; it is mentioned by many writers on the Marquesas, though not, so far as I have been able to discover, in much precise detail. During wet cycles rain may fall at sea level nearly every day for months on end, the rivers being almost constantly in a state of flood. The contrast between conditions in dry and wet years may be illustrated by observations on the island of Eiao. When visited by LeBronnec in 1921 and by me in 1929, the island had been almost completely denuded of herbaceous vegetation, as a result of drought combined with destruction by sheep and other herbivores. In 1931, LeBronnec reported that a wet year had restored a thick herbaceous covering over the greater part of the island.

Seasonal variations in rainfall are not sharply defined, and are probably of much less importance biologically than the variations from year to year. The available records cover so short a period that no conclusions as to seasonal variations may be based upon them. All that can be stated here is the opinion of residents in the Marquesas, who recognize, in years of transition between cycles of wet and dry years, a dry season from October to April, and a rainy season from May to September. These seasons are very irregular, both in time and in amount of precipitation, and it would be difficult to correlate many biological phenomena with them. Little is known about seasonal variations in the rainfall of the cloud zone.

In most if not all other central Pacific islands there are well-defined wet and dry seasons. The insignificance of seasonal variations in rainfall in com-

parison with variations from year to year in the Marquesas is therefore exceptional and extremely interesting.

The records show slightly higher rainfall in the central islands than in the southeastern group. This is probably exceptional; in the opinion of residents the reverse is the rule. Fatuhiva is considered to be the rainiest island in the Marquesas, and this is borne out by the luxuriance of the vegetation in Omoa and Hanavave Valleys, where the mountain flora descends to lower levels than elsewhere in the islands. It is to be expected that in the mountains precipitation is greatest on Hivaoa and Nukuhiva, which are the only islands with large areas above 3,000 feet. On Uapou most of the land lies below 3,000 feet and the pinnacles which attain heights of up to 4,000 feet probably have little influence on precipitation. Handy (30, p. 7) considers Uapou to be the most arid of the inhabited islands; this may be due to the sterility of the soil more than to a relatively low rainfall. Uahuka, the lowest of the six inhabited islands, is probably the driest.

On the uninhabited islands, which do not rise above 2,000 feet, precipitation is probably only a little higher than over the surrounding ocean. The entire islands are subject to prolonged drought.

Within the period 1929-31 Professor Leighly finds that the variation in the amounts of precipitation from month to month correspond fairly closely at the different stations, so that the factors causing these variations do not appear to be localized.

Local variations in rainfall, with respect to exposure to the trade winds, are well marked. The western, leeward, sides of Hivaoa, Nukuhiva, and Uahuka receive a much diminished rainfall and the lower slopes, having been largely deforested by goats and cattle, constitute barren regions known locally as *terres désertes,* in Marquesan *fenua ataha.* The vegetation is xerophytic, the invertebrate fauna very meager, and none of the valleys in these regions inhabited at the present time. There is similar barren land on northern Tahuata and northwestern Uapou. On Fatuhiva, which is elongated approximately at right angles to the trade winds, the valleys on the western side are sufficiently near the central crest to receive much rain from the air cooled by ascending it; the windward, eastern, slopes suffer from low rainfall, while Omoa and Hanavave, on the leeward side, are wet. In the same way, the valleys of Vaitahu, Anapoo, and Hapatoni, on western Tahuata, are relatively wet. The distribution of rainfall on Fatuhiva and Tahuata, however, is probably not so simple as I have indicated. On the uninhabited islands local variations in rainfall are presumably small.

Variations of rainfall with altitude are, of course, very great. Records from "Praha," at an altitude of about 2,000 feet on Nukuhiva, show 1 to 2 times as much rain as at stations at sea level. Above 2,000-2,500 feet, within the cloud zone, precipitation is probably abundant everywhere and at all

seasons; damp conditions prevail, and the vegetation may be described as rain forest.

Thunder and lightning are rare in the Marquesas. From January 1929 to April 1930 I experienced only one prolonged thunderstorm of much intensity, on January 26, 1929. Electric disturbances are frequent in the Tuamotus and in the Society Islands in the early months of the year.

CLOUDINESS AND HUMIDITY

At Atuona in 1930 the average of the monthly means of cloudiness, expressed as tenths of the sky covered, was 3.3; at Hatiheu in 1931 the average for 11 months was 5.6. On the six higher islands there are almost always clouds over the mountains, which are frequently enveloped in cloud from their summits to 3,000 feet or lower. At sea level the sky is seldom completely overcast.

The relative humidity during the period covered by the records was constantly high, seldom falling much below 80 percent, and at night, so far as could be judged without measurement, often approaching 100 percent. The mean annual relative humidity at Atuona in 1930 was 83.8 percent. No observations were made at high altitudes, but as rain is abundant there at all times, it may be assumed that the humidity is always high, especially in the dense vegetation among which insects and other animals live. On the uninhabited islands it probably varies little from the humidity over the surrounding ocean.

Several writers on the Marquesas have said that the Marquesan climate is not humid. Though strictly incorrect—the atmosphere in mid-Pacific being always moisture-laden—this opinion is true in a sense. The humidity of the air is unpleasant only when the trade winds fail, and the atmosphere in the mountains is always fresh and invigorating.

TEMPERATURE

Daily means of temperature were computed according to the formula

$$\text{Mean} = \tfrac{1}{4}\,[t_6 + t_{12} + 2\,(t_{18})]$$

in which t_6, t_{12} and t_{18} represent the readings at these hours. This formula was found by Leighly (38) to give a close approximation to the means of a 72-hours series of half-hourly observations made at Taiohae; the method compensates, at least in part, for the lack of night readings.

The mean annual temperature of the record at Atuona in 1930 was 25.8°C, the mean maximum 31.9°, the mean minimum 22.4°. For the hottest month, November, the monthly mean was 27.0°, the mean maximum 33.1°, the mean minimum 22.7°; the corresponding figures for the coldest month, August,

were 24.9°, 31.7° and 22.1°. The "mean annual range" (the difference between the monthly means for the hottest and coldest months) was 2.1°.

Within this narrow range of temperature seasonal variations are of relatively little account; on human beings the effects of variations in relative humidity and wind velocity are of much greater significance. The annual curve of temperature follows fairly closely the curve of insolation, the hottest months being usually March and April, the coolest August and September. The central islands showed slightly higher means of temperature than the southeastern islands, due to the small difference in latitude.

Mean monthly temperatures at "Praha," at 2,000 feet on Nukuhiva, were 5 to 6 degrees lower than those at sea level. Few records were obtained at higher altitudes; in addition to the effect of altitude, the mean maximum must be greatly reduced by freer circulation, reduction of insolation by the clouds which overhang the mountains for a great part of each day, and by evaporation from the almost constantly damp surfaces of the vegetation. In the cloud zone, the climate is temperate rather than tropical.

When the humidity is high and when the trade winds fail, the climate in the villages situated in deep valleys is unpleasantly warm and damp, but there is some relief in the cool land breeze which descends the valleys between midnight and sunrise.

WIND

The trade winds blow with great regularity, both in direction and velocity; calms are relatively infrequent, and high winds rarely occur. The direction of the trades varies between northeast and southeast. Seasonal variations are irregular, but in general it may be said that from April to October the direction of the trade winds varies between east and southeast, and for the rest of the year between east and northeast. The southeast trades are the stronger and more regular, and bring the most agreeable weather. When to the north of east the winds are less strong and less regular, and days of calm, with consequent rise in temperature, are more frequent.

Very high winds, which generally come from the north or northwest, are extremely rare. During 15 months in the islands I hardly ever observed a wind of velocity above 6 or 7 on Beaufort's scale, even at high altitudes, and only once a gale. This was in March 1930, when the wind blew from the northwest for about four days, with sufficient force to blow down breadfruit trees. It did not attain the velocity of a hurricane, yet within the last thirty years residents in the Marquesas recall only two other storms as severe as this, about 1903 and 1905. Visher (56) gives no definite record of hurricanes in the Marquesas, which is at least an indication of their infrequency. It appears that these islands are near the northern limit of the hurricanes which occasionally pass through the Tuamotus from the north.

Without entering into a discussion of wind as an agent in dispersal, it may be noted here that both the prevailing winds and most of the infrequent gales reach the Marquesas from directions in which the nearest land is thousands of miles off, but that both blow in directions which would favor the dispersal of life from one Marquesan island to another. Attention should be drawn, also, to the westerly winds in the upper air. According to Thomson (54), the vertical thickness of the trades in latitude 15° S. varies between 0.5 to 3 kilometers. Above them is a mixing layer, 2-4 km thick, moving from the east. From about 5 km and upwards there is a westerly wind stratum; at Apia, Samoa, its maximum velocity is 10.5 m.p.s at 11.5 km. There is thus far no evidence of a high easterly trade wind over the Pacific. Many writers have given much attention to tropical hurricanes as a factor in the dispersal of life from west to east across the Pacific. Since they blow steadily, the high westerly trades may be as effective as occasional hurricanes.

"TIDAL" WAVES

In 1902 or 1903 a series of about 12 "tidal" waves reached the south coast of Hivaoa. Tahauku Valley was flooded for about ½ mile inland, and some houses were destroyed. Such occurrences are very rare, but the Marquesans have a name—*taitoko*—for "tidal" waves, which shows they are not unknown.

SUMMARY

The little that is known of the climatic environment of the Marquesan fauna may be summarized as follows. The greater part of the endemic fauna, being now restricted to high altitudes, has a physical environment which is remarkably constant in all respects, with very moist conditions, and a climate that is temperate rather than tropical. At low and intermediate levels on the higher islands, and everywhere on the lower islands, the climate is tropical, but without extremely high temperatures. Periods of several years of abundant rain alternate with periods of prolonged drought; on the leeward sides of the higher islands, and in all parts of the lower islands, the drought may amount to extreme dessication and cause the withering of most of the herbaceous vegetation. Fatuhiva appears to be rainier, relatively to its altitude, than the other islands. All elements other than precipitation vary within very narrow limits. Seasonal variations in most climatic elements are irregular and of small degree. Diversity of habitat, in comparison with conditions on many other oceanic islands in the Pacific, is great with respect to rainfall and small with respect to temperature.

GEOLOGY

General Features

The geology of the Marquesas Islands is very incompletely known and information is especially inadequate for the biologist, who wants to know the habitable age of the archipelago as a whole and of its individual islands, and the possibility of former land connections. Chubb (14) has written a most interesting and suggestive account of the geological history of the Marquesas, and Williams (57) has studied the data and specimens collected during the course of the field work on which the present report is based, especially that done by Monsieur G. LeBronnec.

Chubb describes three phases of volcanism in the Marquesas. During the first phase, fissures were produced on the ocean floor and along these a number of volcanoes rose far above the sea, chiefly by the outpouring of lava. After a period of quiescence, there followed a series of explosions, forming ash cones, and varied by an occasional flow of lava. Differentiation of pyroclastic rocks proceeded further in the northern than in the southern islands. Tahuata was perhaps formed during this second phase; and also Mohotani, so far as Chubb could judge of the nature of its rocks by viewing this island from the sea. The third phase of volcanism was characterized by the extrusion of dykes and sills. Then, "faulting took place along some of the fissures, with the result that the south and east sides of Nukuhiva, parts of the south and north of Hivaoa, the southeast side of Tahuata, and the west side of Fatuhiva were submerged."

The remainder of Chubb's account is for the most part highly hypothetical. On the inference that coral reefs were absent, as they now are, he suggests that during a long stationary period wave erosion proceeded far enough to reduce the large islands to low ridges, and to truncate completely the smaller islands. Elevation is said to have followed, of probably more than 2,000 feet in the southeastern islands and 3,000 feet on Nukuhiva. Tahuata was thus joined to Hivaoa. New cliffs of marine erosion were formed. Subsidence then ensued, as shown by the embayment of the coast line and amounting to at least 600 feet on Hivaoa. The last change in level was a minor one, due to a general fall of sea level of 6 to 8 feet.

The petrography of the islands is better known than other aspects of Marquesan geology. The exposed rocks are mostly basaltic lavas. It is highly probable that no "continental" rocks occur here, and no plutonic rocks have been found. Fragmental volcanic ejecta are relatively insignificant in quantity. Chubb (14, pp. 4, 47) states that "apart from recent alluvial deposits, beaches, and a few tiny coral reefs, rocks of sedimentary origin are extremely rare. . . . The predominant rock types throughout the group are labradorite

basalts with phenocrysts of olivine and augite, and trachy-basalts, the latter including the andesine basalts and andesine andesites of Lacroix." The known rocks of all the islands are in the "série sans néphéline" of Lacroix, with the exception of those that constitute the remarkable pinnacles on the island of Uapou, which Lacroix (36, p. 111) writes "sont constitués par des *phonolites* très néphéliniques, dont quilques-unes renferment de la *leucite;* c'est le seul exemple d'une telle composition dans le Pacifique." Lacroix (37) decides in favor of the hypothesis that among the Marquesan islands, "Uapou constituerait un centre éruptif distinct, alimenté par un magma un peu spécial."

The Marquesan volcanoes have been extinct for a long period, though two small volcanic cones on Uahuka and one on Nukuhiva may have erupted in recent times. At one point near Tehutu, on the southern coast of Hivaoa, Chubb (14, p. 16) found "an emanation of sulphuretted hydrogen and sulphurous deposits," and Rollin (48) mentions a few mineral springs. Earthquakes are unknown in the Marquesas Islands.

Vertical Movements and Land Connections

Evidence of Uplift

Chubb has advanced the hypothesis that there has been an elevation of as much as 2,000 feet on Hivaoa and 3,000 feet on Nukuhiva. He was influenced by the statements of Jardin (34), who incorrectly described the wide hollow of Tovii as "le point culminant" of Nukuhiva, as well as by the sketch of Nukuhiva on the British Admiralty chart (14, fig. 10), which gives a totally misleading impression of a flattened summit.

As direct evidence of uplift on Nukuhiva, Chubb records "an outcrop of limestone 6 to 8 feet thick about 1,000 feet above sea level," on the trail between Taiohae and Hakaui on Nukuhiva. He had not been able to visit the locality, but had examined a specimen which was presented to the St. George expedition. Before the appearance of Chubb's paper, I had observed what was almost certainly the outcrop mentioned. Because of its bright white color, it would be difficult to confuse it with any other outcrop along this trail, and I was therefore able to ask Mr. Robert MacKittrick of Taiohae to obtain samples from it. Père Siméon Delmas also was kind enough to send a specimen. These samples were submitted to Williams, who reported (57, p. 83) that the material was "a decomposition product of some volcanic rock." Since the above paragraph was written, Chubb has made it clear that the specimen of limestone described by him had been incorrectly labeled before it came into his hands.

In the interior of Hivaoa, at altitudes of 1,300 to 2,000 feet, there are plateaus with remarkably level surfaces. The largest of these is near the

asserts that his estimate of a subsidence of Hivaoa by 600 feet is "more likely to be an under- than an over-estimate."

Antevs (2) has estimated that if the periods of maximum Pleistocene glaciation were synchronous in the northern and southern hemispheres there must have been a fall of ocean level of 305 feet; if the maximum glaciations were only partly contemporanous there may have been a fall of 290 feet. It is possible that such a change in sea level may have united Hivaoa and Tahuata. There is no reason for believing that it united any of the other islands, so far as I can judge from the soundings that have been made between them.

H. E. Gregory (24) gives 1,000 feet as the extreme range of oscillation that may be assumed for the Marquesas. This figure is somewhat in excess of the total movement indicated in the foregoing discussion. Even the subsidence of somewhat more than 600 feet, required by Chubb for the drowned valleys of Hivaoa, would probably not have united any of the islands except perhaps Hivaoa and Tahuata. A fall of ocean level in the Pleistocene, according to Antevs' figures, may have failed to unite even these two islands. It appears, then, that there is as yet no conclusive geological evidence for past connections between any of the islands; what evidence there is would suggest a connection between only two islands, Hivaoa and Tahuata.

Brown (6, 4) believed that the Marquesas have subsided 4,000 to 6,000 feet, because he regarded some of the high mountain plants as the remnant of a "cold-climate vegetation" that once flourished at much higher altitudes. To carry weight, such an argument would need to be supported by very forceful evidence; yet each of the four genera of cold-climate plants mentioned (6), *Reynoldsia, Cheirodendron, Cyathodes* (*Styphelia*), and *Vaccinium,* may be found in Hawaii as low down as in the Marquesas. The presence of these genera in the Marquesas demands no such explanation as Brown has advanced, especially since it has not been shown that their occurrence at similar levels in Hawaii also is due to subsidence.

The high degree of island endemism in the Marquesan fauna shows that the individual islands have been separate for a long time. There is some indication of a close affinity between the faunas of Hivaoa and Tahuata, but the distance between these islands is only about 3 miles and it may be unnecessary to assume a connection between them. Mohotani appears to have few species of the genera that have undergone the most evolution in the Marquesas. There is therefore reason to believe that it has not been connected to other islands—unless, of course, its original fauna was destroyed by submergence or by volcanism.

I should be glad to pass by the broader question of subsidence in the Pacific area as a whole, as it is one on which the authorities disagree. I do not wish to discuss the biological evidence for and against the former existence

of large land masses until all the existing collections have been studied. The geological evidence was concisely stated by the late J. W. Gregory (25), who recognized great vertical movements in the Pacific. He was satisfied that the geological evidence was fully consistent with biological evidence and sufficient to meet the demands of some biologists for "extensive Pacific lands on which developed a Eu-Pacific fauna and flora." He wrote that: "Lands survived across the central Pacific apparently until the Lower Kainozoic. . . . Darwin's theory of coral islands. . . implies the sinking of a belt across the southern Pacific during the Upper Kainozoic." It should be noted that J. W. Gregory cited "the botanical evidence from the Marquesas of their subsidence for thousands of feet" among the arguments on which he regarded Darwin's theory as "now established."

The opposite view has been set forth by H. E. Gregory (24), who describes the Pacific Depression as an area of remarkable stability, within which the extreme range of known oscillation is about 1,200 feet. No recent vertical movements of greater extent appear to have been recorded within this area. Marshall (40), for example, has shown that in the Cook Islands a still-stand has lasted over a long period, and Chubb (15-a) states that he found no evidence of uplift or subsidence on Easter Island. Williams (57), in writing on the geology of the Society Islands, states, "The islands of the South Central Pacific as a whole seem to indicate a vast region of comparative stability"; he finds no evidence of folding of the ocean floor, and believes that the Society Islands, for example, may just as well have arisen on a flat ocean bottom.

It is clear that the biologist who demands extensive lands in the history of the central Pacific finds little or no support from geology. The most he can expect is that the geologists will not veto the deductions that he feels justified in making from biological evidence, and in that matter the geologists are divided. It is perhaps safe to conclude that their opinion is predominantly against the existence of past land connections between the central Pacific islands, at least since the beginning of the Tertiary.

Age

As Gregory (24) has said, the rocks of the central Pacific islands tell little about their age and the best guide is probably their physiographic form. So far as I know, no writer on the Pacific islands has attempted to give a precise estimation of the age of the Marquesas. Schuchert (49) states that "the Hawaiian volcanoes appear to have arisen in early Cretaceous time." Williams (57), on the evidence of erosion, believes that none of the Society Islands date back farther than the Pliocene, that the major activity was perhaps in the Pleistocene, and the last eruptions of Tahiti and Meetia

FLORA

General Features

In the present consideration of the Marquesan flora, I have attempted to draw attention to facts that should be kept in mind by a student of the fauna.

In making the field records on which the discussion is based I received much assistance from Monsieur G. LeBronnec, who has an intimate knowledge of the native flora. I have made use, also, of the field notes prepared by him after my departure from the Marquesas. I am greatly indebted to Dr. F. B. H. Brown, Mr. O. H. Swezey, and Dr. Harold St. John for reading and criticizing parts of the manuscript; to Dr. E. D. Merrill, Dr. E. B. Copeland, Dr. F. B. H. Brown, Miss Marie C. Neal, and Mr. E. H. Bryan, Jr., for the time they have generously devoted to the identification of plants collected by the Pacific Entomological Survey. I have not been able to survey the literature on the botany of the central Pacific islands published since 1933, the year in which the manuscript of these pages was prepared.

Until recently Drake del Castillo (21) was the principal authority on the Marquesan flora. The standard work is now the "Flora of southeastern Polynesia," by F. B. H. and E. D. W. Brown (4, 5), which deals with the vascular plants of the Marquesas, including some of those collected by the Pacific Entomological Survey. In these pages I have followed the botanical nomenclature adopted by Brown and have therefore dispensed with authors' names following the specific names of plants.

Jardin (34) lists 20 species of mosses for the Marquesas as a whole, 20 of fungi, 54 of lichens, and 49 species of algae, most of which are marine. Merrill (41) lists some other papers on the Thallophyta, but these lower plants are in fact little known in the Marquesas.

Brown (4, 5) lists 72 species of pteridophytes, 98 of monocotyledons, and 287 species of dicotyledons in the Marquesas. Of these 457 species, about 20 percent are endemic, 30 percent are indigenous but grow naturally elsewhere, 20 percent are regarded as aboriginal introductions, and 30 percent are regarded as probable arrivals since the discovery of the Marquesas by Mendaña in 1595. The plants considered to have been brought by the Polynesians form a very important element in the flora. They include even such species as *Gleichenia linearis,* which perhaps occupies as much of the area of the islands as any individual species of plant.

The Marquesan flora is very much less rich than the Hawaiian. Christensen (11) lists 154 indigenous species of pteridophytes in Hawaii, and according to a list drawn up by Mr. E. H. Bryan, Jr., and quoted by Campbell (10), there are 163 indigenous Hawaiian monocotyledons, as compared with 69 and

46 in the Marquesas. In the Society Islands, Copeland (16) estimates the number of known species of pteridophytes as 164. Conclusive figures for the monocotyledons collected in the Society Islands cannot be given for comparison here, pending the publication of the results of recent field work by M. L. Grant (23) and others for Bernice P. Bishop Museum.

Cyrtandroidea, an interesting and primitive lobelioid, is the only endemic genus known in the Marquesas. The degree of endemism among the species of the pteridophytes and monocotyledons in the Marquesas is about 25 percent as compared with about 70 percent for Hawaiian pteridophytes (11), about 70 percent for Hawaiian monocotyledons (10), and about 30 percent for the pteridophytes of the Society Islands (16). Brown (5) believes that the degree of endemism in the monocotyledons of the Marquesas and Society Islands is approximately the same. Buxton (8) states that about 30 percent of the vascular plants of Samoa are endemic.

A large number of endemic varieties are described by Brown (4, 5), whose figures for the degree of endemism in "species and varieties," excluding varieties produced by cultivation by the Marquesans, are 49 percent for the pteridophytes, 84 percent for the monocotyledons, and 64 percent for the dicotyledons.

Affinities and Origin

A study of the literature on the Marquesas and other central Pacific islands leads to few satisfying conclusions regarding the origin of their floras. How complex the problem is, and how conflicting the opinions of the botanists are, may be gathered from Skottsberg's "Juan Fernandez and Hawaii: a phytogeographical discussion" (52). Rock (47), Brown (7), and Guillaumin (26) have emphasized the American affinities in the Hawaiian flora, Guillaumin going so far as to state that "le domaine hawaïen devrait être exclu de la région malayo-pacifique pour être rattaché . . . . . à la région mexicaine," while Campbell (9) writes of "the overwhelming preponderance of Malayan and Australian types in the Hawaiian flora." Skottsberg (51) cannot agree with Guillaumin's view and affirms that "his statement that [the Hawaiian flora] almost entirely lacks all Australian, New Zealand and Polynesian elements is not correct." The elaborate theory set forth by Guppy (28), involving successive and distinct waves of dispersal, with migratory birds as important agents, has not met with general acceptance. However valuable his discussions may be, they do not seem to have brought a solution of the problem within sight. F. B. H. and E. D. W. Brown (3) have stated that dispersal of plants across the central Pacific has been from east to west.

For the pteridophytes of the Marquesas, F. B. H. and E. D. W. Brown (4) find "a primary affinity with the Society Islands and a secondary one

with Hawaii." E. D. W. Brown (4) writes that 80 percent of the non-endemics find their closest relatives in Indo-Malaya, 6 in America, 8 in Australia, and 6 in Antarctica. By extending the statistical method of determining the direction of migration, namely, by determining "the probable center of origin of each species as indicated by the grouping of all of its relatives," Brown asserts that probably 82 percent of the non-endemics are of American origin, 13 "Indo-Malayan or Asiatic," 2 Australian, and 2 Antarctic. Substantially the same relations are found by F. B. H. Brown (5) to prevail in the dicotyledons of southeastern Polynesia. He writes that 82 percent of the dicotyledons are probably of American origin; 12 percent of Indo-Malayan origin, and 6 percent of Australian origin. In the indigenous Marquesan monocotyledons, Brown (5) finds that "33 percent of the species and varieties" have "close allies in the Society Islands, 29 percent in Hawaii, and 26 percent in America. A slight affinity is indicated with Antarctica, New Zealand, Rapa, and Fiji."

Brown (5) states that the Marquesan dicotyledons have immediate affinities "primarily with the Society Islands and secondarily with Hawaii."

Setchell had no data from the Marquesas except those in Drake del Castillo (21), which included only 138 indigenous species of vascular plants from the Marquesas, but it is worth while to repeat some of Setchell's conclusions (50) regarding the floras of the eastern archipelagoes in the central Pacific:

1. There is a definite representation of an old Pacific element in these groups.
2. The overwhelming relationship, so far as identity of species or specific affinity is concerned, is with the Indo-Malayan region.
3. There is possibly an Australio-Polynesian element, but it is not readily separable from the foregoing.
4. There is possibly a slight Neotropic element in the indigenous floras.
5. There is a distinct Subantarctic element, especially in the flora of Tahiti.
6. The Boreal element is slight, possibly under revision will be found wanting.

Copeland's study of the Tahitian ferns (16) has lead him to conclusions similar to those of Setchell.

As shown by Brown (4, 5), the Hawaiian affinities in the Marquesan flora are numerous and important. My impression is that they are more general and amount to much more than the affinities so far discovered between the faunas of the two archipelagoes. The affinities in the faunas are apparent in only a few isolated—though none the less striking—examples.

On the vexed problem of the past distribution of land in the central Pacific, the botanists are in as difficult a situation as the zoologists, as the briefest survey of the literature shows. Campbell (9), for example, demands land connections for the Indo-Malayan and Australian elements in the Hawaiian flora. Setchell (50) finds that in a broad view such hypotheses raise more difficulties than they solve, and he is prepared to dispense with such connections in the eastern central Pacific. Hillebrand (32) regarded the

Hawaiian flora as oceanic, and Buxton (8) writes: "Our knowledge of the flora is consistent with the view that Samoa is an oceanic archipelago." Guppy (27) regarded the issues as to whether various islands are oceanic or continental as "dead not living issues," being satisfied that the continental islands end with Fiji and the large islands to the west and south of Fiji.

Floras of the Individual Islands

In comparing the faunas of the several islands in the Marquesas, it is important to know the relative richness of their floras. Many species of insects are restricted to single species of plants, and a large amount of species-formation in the flora of an island is likely to result in an increase in the number of species of insects. It is also of interest to the zoologist to know whether there is a high degree of island endemism in the flora, as there is in the fauna. Unfortunately these questions—especially that of island endemism—cannot be answered with assurance in the present state of knowledge of the Marquesan flora. A significant number of species have been recorded from only one island; but little is known about the distribution of many of them and their absence on all islands save one is not established.

Something may be said, however, regarding the relative richness of the floras. The four uninhabited islands may be separated at once from the others, as they are too low for a cloud zone and have therefore relatively meager floras. Of the six inhabited islands, it appears to be certain that Uahuka has the least varied flora. Of the remaining five islands, the flora of Uapou impresses the field worker as being considerably less rich in species than those of Hivaoa and Nukuhiva; and judging by its topography and by LeBronnec's field notes, I imagine that the flora of Tahuata is similar to that of Uapou or rather less rich. As for Hivaoa and Nukuhiva, the two islands with the largest region in the cloud zone as well as the greatest total area, I know of no sure indications that one has a richer flora than the other. My general impression gained during field work on these islands was that their floras are similar in variety. Fatuhiva is much smaller and lower than Hivaoa and Nukuhiva, but its relatively heavy rainfall has made the flora very luxuriant and may have endowed it with a larger number of species than Uapou and Tahuata. Possibly Fatuhiva has almost as many species of plants as Hivaoa and Nukuhiva. According to these general impressions, the six highest islands may be tentatively placed in the following order with respect to the number of species in their floras: Hivaoa and Nukuhiva, Fatuhiva, Uapou and Tahuata, Uahuka.

The flora of Uahuka, the lowest of the inhabited islands, is probably very much less rich than those of those of the other five inhabited islands. Judging only by field observations, I should not hazard an opinion regarding

the absence on Uahuka of any genus of the Marquesan flora; but I think that most of the following characteristic genera, which flourish in the highest altitudes of the other islands, may be absent from Uahuka or form, as a whole, a small and inconspicuous part of its flora: *Reynoldsia, Cheirodendron, Cyrtandra, Rapanea, Ilex, Scaevola,* and *Sclerotheca.* It is important for the entomologist to note that *Metrosideros* and *Weinmannia,* the two trees on which more insects were collected than on any others, occur on Uahuka in very small numbers, not forming a large element in the forests as they do on other islands.

The flora of the four uninhabited islands is relatively meager in number of species and it was possible in the course of field work to make representative collections of plants on all of them. The lists prepared from these collections and from observations, with the addition of some of the species recorded by Brown (4, 5), include about 80 species of vascular plants from Mohotani, about 90 from Eiao, 22 from Hatutu, and 17 from Fatuuku. Though of course incomplete, these numbers afford an adequate basis for comparing the floras of these and other islands.

A large proportion of the species on Eiao, Mohotani, and Fatuuku, and all of those on Hatutu, are xerophytes. Only five species of ferns were seen on Mohotani, three on Eiao, and only one (*Polypodium phymatodes*) on Hatutu and Fatuuku. Very few of the plants on these uninhabited islands are endemic to the Marquesas; an undescribed species of *Ficus* on Eiao is the only endemic tree known. Of great importance to the zoologist is the complete absence on these low islands of the trees that were found on the higher islands to support the largest insect faunas. On Eiao and Hatutu many such insects as *Rhyncogonus* and *Germalus* are thus present without any of the food plants on which species of these genera were most commonly found on the higher islands.

The lists show little difference between the number of species in the floras of Eiao and Mohotani. The fauna of Eiao, so far as the collections have been determined, is much richer than that of Mohotani, and a similar relation in the floras might have been expected. Possibly the flora of Eiao has been so much reduced by the sheep that many of its original features have been lost. There are many differences, moreover, between some of the general characters of the vegetation of the two islands, in spite of the similarity in their topography and climate, and analysis may show that the flora of Eiao is older than that of Mohotani. More species of plants were collected on Hatutu than on Fatuuku, but more time was spent on Hatutu. Only one genus of tree, *Pisonia* (*Ceodes*), was seen on Hatutu, whereas *Pisonia, Sapindus, Thespesia,* and *Hibiscus* were found on Fatuuku. The flora of Hatutu is more xerophytic than that of Fatuuku.

Zones of Vegetation

Brown (4) distinguishes the following five zones of vegetation in the Marquesas: "high altitude, cold climate vegetation," "rain forest," "mesophytic forest," "semiarid forest," "arid and semiarid grassland associations." For the present purpose it will be sufficient to distinguish the following main divisions: 1, The rain forest of the cloud zone, with a lower limit at about 2,000 to 2,500 feet and extending to the highest altitudes; 2, intermediate levels of moderately heavy rainfall, between 1,000 and 2,000 to 2,500 feet; 3, low levels, below 1,000 to 1,500 feet, and regions of low rainfall from sea level to about 2,000 feet. Though these divisions are not made from a strictly botanical point of view, they will serve for a very general description of the vegetation. Most of what follows applies especially to the two largest islands, Hivaoa and Nukuhiva, and not at all to the uninhabited islands, where the range in altitude is only 2,000 feet or less.

RAIN FOREST

In the rain-forest zone there is always heavy precipitation and a luxuriant vegetation. In the upper regions, above about 3,000 feet, the flora is a dense growth of small and medium-sized trees in sheltered places, and of low shrubs on many of the wind-swept ridges and slopes. Among the dominant trees are *Metrosideros collina, Weinmannia, Crossostyles biflora, Cyrtandra, Sclerotheca, Cheirodendron,* and *Reynoldsia,* and tall tree ferns of the genus *Cyathea.* The undergrowth in sheltered places consists mainly of *Freycinetia* and a great many species of ferns, and is usually very dense. The branches of the trees are almost everywhere covered by a thick epiphytic growth of mosses, ferns—especially the filmy ferns, *Hymenophyllum* and *Trichomanes,* and the bird's nest fern (*Asplenium nidus*)—and here and there *Lycopodium phlegmaria, Selaginella,* and *Procris pedunculata.* The only native orchid seen was *Liparis clypeolum*; three other species are recorded by Brown.

On wind-swept ridges and slopes, the forest in many places is reduced to a low, dense scrub of stunted *Metrosideros, Cyathea, Freycinetia,* and *Sclerotheca. Vaccinium,* sedges of several kinds, and many ferns are abundant. On an exposed slope north of the summit of Mt. Temetiu, at altitudes of 3,000 to 3,500 feet, there is a remarkable association composed almost entirely of pteridophytes: a few species of ferns and *Lycopodium cernuum.* In the cloud zone the staghorn fern (*Gleichenia linearis*) is not so abundant as at lower altitudes, but in restricted areas it is dominant.

In some of the deep gulches, and the heads of valleys that reach the cloud zone, there are groves of *fe'i* (*Musa fehi*). These are most numerous on Fatuhiva; on the other islands they are said to be diminishing in extent, possibly because of the banana-borer (*Cosmopolites sordida*), which is com-

mon in the Marquesas. Setchell (50) attributes the decrease of the *fe'i* in Tahiti to its overgrowth by *Freycinetia.* It seems more plausible to blame the introduced borer, which is present also in Tahiti; *Freycinetia* is native in the Marquesas and Society Islands and the *fe'i* is probably an aboriginal introduction, so that competition between these plants has had a long time in which to reach a balance. In the Marquesas Islands that I visited there are no groves of *fe'i* so extensive as one that covers a hillside above Lake Vaihiria in Tahiti.

There are few tall trees in the rain forest of the Marquesas. Many tree ferns, which do not greatly exceed 50 feet in height, stand out above the rest of the forest. *Metrosideros* reaches a height of 100 feet in Hawaii, but I rarely saw any in the Marquesas more than 30 or 40 feet high. There are also few pure stands of any large tree, except *Hibiscus tiliaceus* near the lower limit of the cloud zone; in Hawaii *Metrosideros* alone occupies many large areas.

Many genera and species of plants are restricted to the upper regions of the cloud zone, being rarely seen below 3,000 feet. The most conspicuous of these are *Cheirodendron* and *Reynoldsia.* Most of the species in the cloud zone do not grow at lower levels, a condition general in the Pacific islands. Most of the endemic plants, and many indigenous species of long standing, are confined to the cloud zone. Brown (5), however, has emphasized the fact that there is still a considerable number of endemic species of monocotyledons at low altitudes.

Very few recently introduced plants are established in the rain forest. Some species of aboriginal introduction are important in the lower parts of the cloud zone, notably the bamboo, banana, and *Gleichenia linearis.* Of recent arrivals there are some grasses, especially *Paspalum conjugatum. Commelina nudiflora* forms a thick carpet at the foot of some deep gulches as high up as 3,500 feet; and there are a few introduced stragglers such as the almost ubiquitous guava, *Ageratum conyzoides,* and some planted mangoes. In general it may be said that the habitats of a great proportion of the present native fauna, which is largely restricted to high altitudes, have so far suffered little direct alteration by the introduction of plants into the Marquesas.

INTERMEDIATE ZONE

The characters and vertical limits of the intermediate zone cannot be sharply defined. At its upper limit, 2,000-2,500 or even 3,000 feet, it gives place without abrupt change to the true rain forest. Its lower limit in wet regions may be below 1,000 feet, but in most places it is slightly higher. On the dry leeward slopes there may be scarcely any intermediate forest zone between the barren regions and the lower limit of the cloud zone. The

greatest development of forest of intermediate character is found on the plateaus west and east of Mt. Ootua on Hivaoa, and over most of central Nukuhiva.

The forest may be termed mesophytic. Its flora is characterized by the dominance of *Hibiscus tiliaceus,* and the abundance of such trees and shrubs as *Piper latifolium, Wickstroemia foetida, Canthium barbatum, Glochidion ramiflorum, Pandanus,* and *Cordyline terminalis.* Most forests of these species are fairly dense, and there is a luxuriant undergrowth of *Freycinetia,* grasses, and ferns. On the plateau northeast of Atuona, not far west of Mount Ootua, a species of *Alphitonia* is abundant; it is characteristic of this zone and largely confined to it.

Towards the upper limit of the intermediate zone, many species of the rain forest appear in considerable numbers. On much of Tovii, Nukuhiva, and on the top of the central range of eastern Hivaoa, *Metrosideros* and *Weinmannia* are abundant. On western Tovii they are the dominant trees, along with *Wickstroemia foetida,* in a very open forest with wide expanses of grassland and *Gleichenia.* In the denser forests, from 2,000 feet upwards, the large ferns of the family Marattiaceae are conspicuous; *Asplenium nidus* is common and *Freycinetia* very abundant.

In this zone many open spaces are occupied by *Gleichenia linearis* or by such grasses as *Paspalum conjugatum.* These are doubtless secondary associations, following deforestation.

The flora of the intermediate zone is rich and varied, especially at its upper limits, and provides good collecting of all kinds. It is characterized, however, by the absence of many of the most interesting trees of the Marquesan flora, and some of the most important as hosts of insects. There is also a large element of introduced plants, such as guava and *Paspalum conjugatum.*

LOW LEVELS

Brown (5) makes the interesting statement with regard to the Marquesan monocotyledons that the "littoral vegetation is not cosmopolitan in distribution; on the contrary, its percentage of endemism is nearly as high as that of the upland vegetation." But the flora from sea level to about 1,000 feet, taken as a whole, is characterized by an overwhelming predominance of species that are very widely distributed, by natural or by human agencies.

In the strand flora *Thespesia populnea, Hibiscus tiliaceus,* and *Cordia subcordata* are the most prominent trees, and *Ipomaea pes-caprae* the most conspicuous herb along the beaches.

In the well-watered valleys the dominant tree is *Hibiscus tiliaceus,* with many others such as *Inocarpus edulis, Pandanus, Ficus,* guava, and *Aleurites moluccana*; in addition, of course, there are planted coconuts and breadfruit,

and many imported trees here and there in the villages. The undergrowth in these valleys is high and dense where the rainfall is sufficient. It is composed of many species of shrubs, such as *Nothopanax,* and of herbs which are almost entirely introduced species. There are few ferns, except *Nephrolepis hirsutula,* which is very abundant. *Commelina nudiflora* covers the banks of many streams and other moist ground. There are many grasses, most of them, I think, introduced. There are some tall trees, such as *Inocarpus edulis,* in this forest, which may be fairly dense, especially where *Hibiscus tiliaceus* forms a tangled growth of branches spreading horizontally.

On the lower slopes (pl. 1, *A*) the following trees are characteristic: *Sapindus, Casuarina, Xylosma, Pandanus, Premna,* guava, *Ficus,* and *Morinda citrifolia.* Such forests are in most places rather open, and the undergrowth consists mainly of grasses, such introduced herbs as *Sida* and *Cassia occidentalis,* and some malvaceous shrubs.

In the barren, deforested regions of leeward Hivaoa, Nukuhiva, and Uahuka, eastern Fatuhiva, and northern and northwestern Tahuata and Uapou (pl. 3, *A*) the vegetation is very meager from sea level up to 2,000 feet or more, where the rain forest begins with scarcely any intermediate zone. Before the introduction of grazing animals, much of these regions was doubtless forested. At present the trees are few and scattered on the slopes; *Casuarina, Pisonia,* and *Ficus* are characteristic. A low scrub of guava and xerophytic shrubs occupies many of the slopes. Wide areas, especially on western Uahuka, are covered by the tall grass *Miscanthus japonicus*; whether or not these are secondary formations following deforestation, I do not know. There is much grassland; on the slopes of western Nukuhiva, according to Brown (5), *Pennisetum, Eragrostis,* and *Aristida subspicata* predominate in this association. In many places, especially above 1,000 feet, all other vegetation is replaced by *Gleichenia linearis.*

Some forest persists in the dry valleys of the *fenua ataha.* It may reach considerable size, as in Hanauaua Valley, Hivaoa, where there are fairly tall trees such as *Xylosma suaveolens* and *Sapindus saponaria.* The undergrowth is usually meager or absent.

The most desolate regions of denudation by herbivorous animals, such as parts of the *fenua ataha* of northwestern Uapou, support hardly any permanent vegetation. In dry weather a few scattered herbs, such as *Cassia occidentalis,* scarcely make any impression on a landscape of bare, stony earth.

Recent Changes in the Flora

Much vegetation has been destroyed by introduced grazing animals and by the grass *Paspalum conjugatum.* Sheep, pigs, cattle, and donkeys on Eiao (pl. 5) and sheep on Mohotani have greatly reduced the vegetation, and

if their ravages continue uncontrolled, they may soon bring about a complete denudation of these islands and the extermination of almost the entire land fauna. There has probably been very little change, as a result of human activities, in the floras of the other two uninhabited islands, Hatutu and Fatuuku.

On the six inhabited islands, especially in the leeward *fenua ataha* (pl. 3, *A*) the goats have destroyed the flora on many steep slopes above the sea and far removed from the villages. Farther inland cattle and pigs have brough about much deforestation. The cattle are destructive even up to the lower limits of the cloud zone, and the pigs higher still. Donkeys are numerous on only one of the inhabited islands, Uapou, where they have been the chief agents in the denudation of the northwestern corner of the island.

For the present, the deforestation by these animals on the inhabited islands is not serious economically, because it is limited to uninhabited regions; it may, however, have reduced the water supply in some cultivated valleys. Nor is this destruction of the flora on these islands a matter of great immediate concern to the zoologist, because it is restricted to regions which support a meager fauna even where some forest remains. I do not think that the cattle and pigs have had much effect on the rain forest, though the cattle, if allowed to multiply freely, would soon become a menace to it, especially on central Hivaoa and Nukuhiva.

Paspalum conjugatum (pl. 2, *B*), a recent immigrant in the Marquesas, has not yet caused much deforestation. But it is the dominant undergrowth in many places, especially on Hivaoa, Nukuhiva, and Fatuhiva, up to 2,000 feet and more. It has begun to invade the rain forest; it is well established all along the trail on the eastern central range of Hivaoa, and appears to be spreading rapidly into the forest on each side of the trail. This grass can kill trees in a short time; if it continues to spread as rapidly as it appears to be spreading now, it will destroy much of the forest. Whether or not its "biotic potential" will be reduced in some way, after a more prolonged existence in the Marquesas and before much deforestation is accomplished, I do not know.

Gleichenia linearis, by occupying deforested areas, prevents the return of the original vegetation. As this fern supports hardly any fauna, its increase is all the more undesirable.

Deforestation, of course, is only a part of a wider subject: the effect on the native flora of all immigrants, plant and animal. The subject is too large and complex to be discussed in any detail here. Attention need merely be drawn to one general result, that the flora below about 2,000 feet has been profoundly changed since the arrival of the human race. Below 1,000

feet the native plants have been replaced, to a very large extent, by immigrants.

Food Plants of Marquesan Insects

The following remarks are based largely on general observations in the field. A more detailed and comprehensive discussion of the relations between insects and their food plants in the Marquesas is not attempted, for two reasons. Firstly, the food plant has yet been established for only a small proportion of the endemic insects. Time was not available for the rearing of many insects, and few of the larvae and nymphs that were collected can be determined as to species. Records of imagoes taken by beating and sweeping, even though the genus or species of plant was generally carefully noted, do not often establish the host plant, but provide a basis for only general conclusions. Secondly, all the families of plant-feeding insects collected have not yet been determined.

Aside from economic plants, which are not included in this paper, the two plants that support the largest insect fauna in the Marquesas are *Metrosideros collina* and *Weinmannia marquesana*. Beating on these trees, in the cloud zone, always yields large numbers of insects, especially Hemiptera-Heteroptera (Lygaeidae, Caspidae, and Nabidae), Hemiptera-Homoptera (Jassidae, Cixiidae, Delphacidae, and Chermidae), weevils (especially the Cryptorrhynchinae), and parasitic Hymenoptera. I do not know which of these plants supports the larger insect fauna, but it seems certain that both genera have been in the Marquesas for a long time. *Weinmannia marquesana* is an endemic species, with more than one variety; *Metrosideros collina* is widely distributed in Polynesia, but it has evolved a number of endemic varieties in the Marquesas.

Many species of insects were taken on the following, among other genera of flowering plants in the cloud zone: *Crossostyles, Cyrtandra, Ilex, Sclerotheca, Vaccinium,* and an undetermined genus tentatively referred to the family Myrsineaceae. *Crossostyles* is represented in the Marquesas by one species, *C. biflora,* which is restricted to central Polynesia; the other genera named have endemic species in these islands.

The following genera of flowering plants, on which a search for insects was frequently made, yielded relatively few species, even in the cloud zone: *Cheirodendron, Reynoldsia, Freycinetia, Glochidion, Wickstroemia, Zingiber, Cordyline, Bambusa.* The species of the first three of these genera are endemic to the Marquesas. *Glochidion* is represented by *G. ramiflorum,* which occurs from Samoa to the Marquesas, *G. tahitense,* known also in the Society Islands and Pitcairn, and *G. marchionicum,* which is endemic. The last four genera are represented by species of fairly wide distribution.

The araliaceous genera *Cheirodendron* and *Reynoldsia,* though apparently supporting a relatively meager insect fauna, are commonly affected by a scale-insect (*Lepidosaphes,* new species?) that was not found on other plants. An endemic thrips (*Isoneurothrips brevicornis* Moulton and Steinweden), collected once on *Reynoldsia,* may be restricted to it.

Piper latifolium, which is restricted to Polynesia and is abundant in mesophytic forest up to about 3,000 feet in the Marquesas, appears to have few insects dependent upon it. But it is one of the principal food plants of the large weevils of the genus *Rhyncogonus,* which are almost always to be found in great numbers feeding on the leaves of this plant, wherever it grows within the range of the beetles. Of the 23 species of *Rhyncogonus,* 9 were taken on *Piper latifolium,* though none of them may be restricted to it, as these beetles seem to have a wide range of food plants. The habits of their larvae in the Marquesas are unknown.

Many insects inhabit the dead petioles of ferns, especially the tree ferns (*Cyathea*) and *Histiopteris incisa.* Several species of weevils of the subfamily Cossoninae appear to be restricted to these host plants. There is a rich and varied fauna in the rotting petioles of the large ferns *Angiopteris* and *Marattia;* most of the insects are probably not restricted to these plants, but frequent them as do the centipedes, amphipods, and isopods. Few insects were found feeding on the living parts of any species of fern.

In Hawaii the plants that have the largest number of insects dependent upon them are arranged by Swezey (53) in the following order: "*Acacia koa, Metrosideros collina polymorpha, Pipturus albidus, Pelea* spp. and *Euphorbia* spp." *Acacia* is not represented in the indigenous Marquesan flora. It is interesting that *Metrosideros* should be among the two most important host plants in both archipelagoes. The insect faunas of indigenous species of *Pipturus, Pelea,* and *Euphorbia* in the Marquesas were not investigated. Some native insects were taken on *Boehmeria,* which is related to *Pipturus.*

The following genera, which Swezey finds to have only a small native insect fauna in Hawaii, are present also in the Marquesas: *Santalum, Xylosma, Byronia* (*Ilex*), *Wickstroemia, Scaevola, Sapindus, Pritchardia,* and *Hibiscus* (*H. tiliaceus*). Swezey states that *Aleurites moluccana, Eugenia malaccensis, Calophyllum inophyllum, Thespesia populnea, Cordyline terminalis,* and *Artocarpus incisa,* all of which grow also in the Marquesas, have no native insects attached to them in Hawaii. So far as my observations go, I think that Swezey's statements apply in greater or less degree to most of these plants in the Marquesas. *Hibiscus tiliaceus* may be the most important exception; this species is believed to be an aboriginal introduction in Polynesia, but there are at least two varieties peculiar to the Marquesas. The genus *Ilex* may have more endemic insects attached to it in the Marquesas than in Hawaii.

Summary

Specific endemism in the Marquesan flora is high, probably similar to that of the Society Islands and Samoa, but much lower than that of Hawaii. Only one endemic genus of vascular plant is known in the Marquesas.

The Marquesan flora is closely allied to that of the Society Islands. There are secondary, but numerous and striking, affinities with Hawaii. I think that most botanists would regard the Marquesan flora as predominantly Indo-Malayan in affinity and origin, but with several other elements of considerable importance.

With respect to the relative number of species in their floras, as estimated on the basis of observations in the field, I have very tentatively placed the individual islands in the Marquesas in the following order: Hivaoa and Nukuhiva, Fatuhiva, Uapou and Tahuata, Uahuka; Eiao and Mohotani, Fatuuku and Hatutu. The floras of the last four islands, on which there is no cloud zone, are relatively meager in numbers of species.

Three vertical zones of distribution on individual islands are distinguished: 1, rain forest, composed almost entirely of indigenous species and including the most important food plants of native insects; 2, an intermediate zone composed chiefly of mesophytic forest and including many introduced species; 3, lowland zone with a preponderance of introduced and other widely distributed species.

Grazing animals may soon bring about the denudation of Eiao and Mohotani. On the six larger islands, deforestation, though extensive, has been most active in dry regions that naturally support a meager fauna. The destructive grass, *Paspalum conjugatum,* is now widespread, and apparently becoming a serious agent of deforestation. The native flora below 1,000 feet has been replaced in large measure by immigrants, and to a considerable extent up to 2,500 feet. There has probably been little recent change in the floras of Hatutu and Fatuuku.

Metrosideros collina and *Weinmannia marquesana* appear to support the largest numbers of native insects in the Marquesas. Many native insects were taken on *Crossostyles, Cyrtandra, Ilex, Sclerotheca, Vaccinium* and *Cyathea,* and relatively few on such genera as *Cheirodendron, Reynoldsia, Freycinetia, Glochidion, Wickstroemia, Zingiber, Cordyline* and *Bambusa.*

NOTES ON THE INDIVIDUAL ISLANDS

HIVAOA

In many respects Hivaoa is the most important of the Marquesan islands. It has the largest region above an altitude of 3,000 feet and its total area (125 square miles) is only slightly less than that of Nukuhiva. Hivaoa has the largest population in the islands and according to Handy (30) it may have been the first island to be settled by the Polynesians. In recent years the seat of the French government has been at Atuona on its southern coast, where the principal headquarters of the Pacific Entomological Survey were made. More time was spent in field work on Hivaoa than on any other island.

There are two main mountain systems on Hivaoa: a high western mass, culminating in Mount Temetiu, with long volcanic slopes to the west and northwest, and a lower central range forming the narrow eastern half of the island. They are separated by the deep valleys of Tahauku and Hanaiapa and a small area of remarkably flat country at medium elevations. (See fig. 1.)

The western system has a well-defined, approximately semicircular, crest. From its southern end at Teaehoa Point, it rises gradually to an altitude of 3,000 feet above Taaoa Valley, and then abruptly to the imposing summit of Mount Temetiu (pl. 2, *A*), the highest point on the island and perhaps in the Marquesas. The peak that bears this name on the U. S. Hydrographic Office charts is marked 3,576 feet; southwest of it is an unnamed point at 3,904 feet. These data are so obviously irreconcilable with the actual topography of this region that it seems best to disregard them. Picquenot (44) gives 1,260 meters or 4,133 feet for the highest point on Hivaoa. When LeBronnec made the ascent of Temetiu in 1932 his altimeter gave a reading of 4,162 feet. With all due allowance for temperature and for changes in barometric pressure between readings, it seems safe to conclude that the altitude of Temetiu is well over 4,000 feet.

North of the summit of Temetiu the altitude drops to slightly less than 4,000 feet, and continues with little change for about 2 miles along the crest to the summit of Feani, at about 4,000 feet. The crest of the range continues northeast as the long Kaava Ridge, which descends gradually to an altitude of about 1,600 feet near the head of Hanaiapa Valley.

On the inner, southern and eastern, sides of this range the land drops abruptly from its crest, into the caldera-like amphitheaters surrounding Taaoa and Atuona. Here the mountain sides are everywhere very steep and in many places vertical. Above Taaoa there is a great impassable wall, though it is not too steep to be partially forested. The side of Temetiu above Tohuto is a tremendous vertical cliff of almost bare rock, several thousand feet high. Most of the upper slopes surrounding Atuona Valley are precipitous and the inland trail from Atuona to Hanamenu winds up them with innumerable bends. A number of short, buttress-like ridges, some of them with knife-edged crests, descend from these slopes, between short, deep valleys.

The outer sides of the western range, to the west and north of Taaoa and Atuona, are fairly gradual, presumably volcanic, slopes, dissected by numerous valleys. The highest parts of Hivaoa are extremely rugged country, deep gulches alternating with knife-edged ridges. Farther down the western slopes the valleys widen out and the ridges between are rounded or even flat along the top. Still farther down, extensive plateaus, nearly level, or inclined at a slight angle, stand at altitudes between 500 and 1,000 feet, and are separated by the deep valleys. The widest of these plateaus are at Tupeka, Tuohoa, and Pahuta to the east of Hanamenu, and Motutapu and Ahau to the south. They constitute one of the largest areas of open country in the Marquesas. Along the southwest coast is a high ridge, rising to nearly 2,500 feet at Mt. Pouoanuu, with steep slopes to the top of the cliffs along the sea.

The mountains east of Atuona Valley are much lower than those on the west, not greatly exceeding 2,000 feet. They are cut away on the east by the deeply eroded valleys of Tahauku and Vaipae, and their inner slopes into Atuona Valley are abrupt.

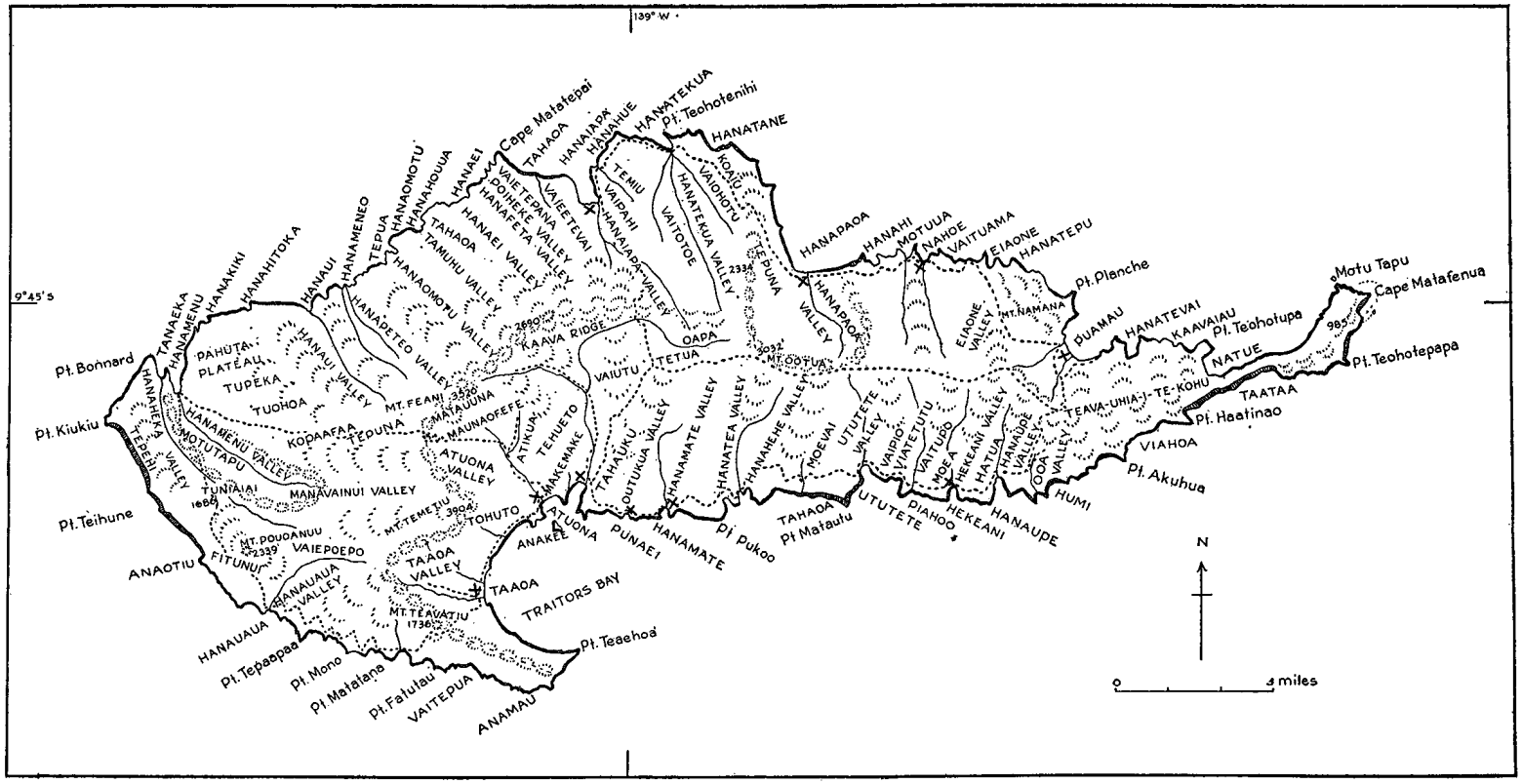

FIGURE 1.—Sketch map of Hivaoa based on a survey by G. Bonno.

Kaava Ridge presents a magnificent appearance when viewed from the plateau between Atuona and Hanaiapa. Its inner, southern, sides are steep but not precipitous and are dissected by numerous V-shaped ravines in very regular series. East of Mt. Feani, precipices along the foot of this ridge overlook the deep valley of Vaipae. The northern sides of Kaava Ridge, which I have not seen, probably represent the outer slopes of a volcano.

Northeast of Atuona is a dissected plateau, considered by Chubb to have been formed by marine planation. It is traversed by the trail from Atuona to Hanaipa, which, after climbing the steep slopes east of Tahauku Bay, reaches a remarkably level area at about 1,300 feet; thence the trail continues north with only a slight rise in altitude to the head of Hanaiapa Valley. The plateau is bounded on the west by abrupt slopes into Tahauku Valley, on the north by Kaava Ridge. Near the middle of the plateau a trail branches off to the east; along it the altitude rises gradually to slightly over 2,000 feet, below Mt. Ootua.

The eastern mountain range is continuous from the plateau northeast of Atuona to the end of the narrow eastern peninsula at Cape Matafenua. The only outstanding peak is Ootua (3,032 feet), which is the culminating point of the high ridge west of Hanapaoa Valley. Viewed from the south, Ootua has the appearance of a small cone, with a rounded top 500 to 600 feet above the trail below, from which it is easily ascended. A short distance east of Ootua there is a steep descent to about 2,000 feet near the heads of Hanahi and Ututete Valleys, whence the trail continues along the range at altitudes of 2,000 feet and slightly higher. In some parts the top of the ridge is knife-edged, between the heads of deep valleys. Other parts of it are remarkably flat, resembling on a small scale the plateau northeast of Atuona. Some of the ridges between the valleys on each side of this range end abruptly in high cliffs above the sea; some of them are cut off at a short distance from the coast.

The system of drainage on Hivaoa is fairly simple, most of the streams pursuing more or less straight courses to the sea. There is only one long river, which enters the sea at Tahauku. Its tributaries receive all the water from the southern side of Kaava Ridge, from the west side of Ootua and from much of the plateau northeast of Atuona.

Five of the principal valleys of Hivaoa are magnificent amphitheaters. These are the valleys of Taaoa, Atuona, Puamau, Hanapaoa, and, according to LeBronnec's notes, Ututete. On the extreme northeast, the small valley of Natue, which I have not seen, is probably another amphitheater. All these valleys have the appearance of remnants of volcanic craters and this was Chubb's interpretation of the two valleys that he studied, Taaoa and Atuona. All of them except Natue have abundant streams. The other large valleys are long and narrow. Many of them have been extensively eroded, sloping so gradually from the shore that an altitude of 100 feet is not reached within a distance of one or two miles upstream. The principal valleys of this type are Tahauku, Hanaiapa, Hanamenu, Manavainui, and Hanaheka on the northwest.

Atuona Valley is perhaps the greatest valley in the Marquesas, the amphitheater being more than 2 miles wide, with surrounding mountains 4,000 feet high. Behind the beach is a small deltaic flat, above which there is a gentle slope to the foot of the surrounding precipices. The head of the valley is divided by short ridges into three main branches. The streams from these unite in a small river; a lagoon some 50 feet wide has been formed at its mouth by a rampart of sand and shingle above the beach.

Taaoa Valley is smaller and relatively wider than Atuona, and its floor rises more steeply. Numerous streams descend from the mountains above it, entering the sea at several points.

Between Atuona and Taaoa is the small valley of Tohuto, below the great vertical side of Mount Temetiu. It contains a small permanent stream, but its bed has not been cut down to sea level.

Tahauku Valley is one of the most extensively eroded in the Marquesas, and one of the widest of its kind on Hivaoa. Its river, the largest on the island, is formed by two main tributaries. One of these has its source on the western side of Mt. Ootua, whence it crosses the central plateau, disappearing in dry weather and reappearing farther west

to enter the head of Tahauku Valley in a series of waterfalls. The other main tributary has excavated the very deep valley of Vaipae, in which there are waterfalls several hundred feet high. In Tahauku Valley the incline is very slight, not attaining an altitude of 100 feet until about 2 miles inland. The largest lagoon on the island is at the mouth of Tahauku river. The "tidal" wave of 1922 cut off a second lagoon to the west, into which water filters from the river through the bank of sand.

Ututete Valley, according to LeBronnec's field notes, has the form of part of a small crater, with a fairly flat floor for over a mile inland. It has a permanent stream. The other valleys along the south coast are short canyons, and most of their streams are intermittent. The largest are Hanamate and Hekeani, the floors of which do not reach 100 feet for at least a mile upstream. On each side of Ututete Bay the hanging valleys, Moevai, Vaipio, Kaavaioa, and Vaitupo, are occupied by small, mostly intermittent streams, the beds of which are still far above sea level.

Puamau Valley is a superb amphitheater, of symmetrical form, on a smaller scale than Atuona and somewhat resembling Taaoa. Most of the floor of the crater which it apparently represents is below the sea, and the present floor of the valley begins to rise steeply about 1 mile inland. It has several permanent streams. Hanapaoa Valley, also an amphitheater, has a small stream; its floor slopes gradually from the sea.

Hanaiapa Valley is the widest of its kind on Hivaoa—that is, excepting those valleys that presumably occupy former craters. Its steep sides rise above an almost flat floor. There is a fairly large lagoon at its mouth. Between Paumau and Hanapaoa the valleys of Eiaone, Nahoe, and Motuua are deeply excavated and have fairly flat floors for a mile or two inland. The floor of Hanahi Valley has a steep slope to the sea. These four valleys have small or intermittent streams.

The western and northwestern slopes of the eastern mountain range are dissected by numerous valleys. On the long slopes west of Temetiu they are deeply excavated and a rise of 100 feet in sea level would drown those of Hanamenu and its branch Manavainui for over 2 miles inland, and those of Hanaheka and Hanaui for about 1 mile. There is a lagoon at the north of Hanamenu Bay; the river enters the sea at the eastern side of the beach, and at the west there is an abundant spring of excellent water, which has been drawn upon by whalers and other vessels.

Along the southwest coast the valleys are very short and their streams are all of insignificant dimensions. The largest valley on this side is Hanauaua, which receives a stream from the heights above Taaoa, over a waterfall several hundreds of feet high.

The coast line of Hivaoa is extensively cliffed. On the southwest, from Point Kiukiu to Anaotiu, there is a great vertical wall over 1,000 feet high, the most magnificent of its kind in the islands. Along most of the north coast, many of the spurs between the valleys end in headlands rising to over 500 feet above the sea. The eastern promontory is cliffed throughout. On the south coast the cliffs at Point Matautu exceed 1,000 feet, and at a few other points they are over 500 feet high. A raised shore shelf of the characteristic form is present all round the island, so far as I know. The widest shelf of this kind seen in the Marquesas is around Anakee Islet, near Atuona. Almost all the beaches of Hivaoa are of black sand or shingle. Indeed the only large beach of white sand observed was at Hanaheka Bay. The Pacific Islands Pilot (55) mentions a white sandy beach on the north coast west of Cape Matafenua.

Anakee, near Atuona, with steep sides a few hundred feet high, is the only prominent islet round the coast of Hivaoa, the others being merely small rocks.

Most of the exposed rocks of Hivaoa are black lavas, with beds of ash between them in some places. They decompose to a characteristic red, porous soil. Summarizing his own findings and those of Chubb, Lacroix (36) states that on Hivaoa the only known rocks are basalts, andesites, and a large dyke of gabbro. The exposed rocks near Mount Ootua are of different composition from those of other parts of the island, being whitish and disposed in rectangular blocks, and along the trail south of the summit of Ootua, a white soil, like clay, replaces the red earth of other regions. At Tohuto, near the trail from Atuona to Puamau, there is evidence of solphataric activity.

Chubb, in interpreting the original structure of Hivaoa, considered it likely that the valleys of Taaoa and Atuona and the arc of Kaava Ridge are "the eroded remnants of craters." If this interpretation be correct, it may apply also to Ututete, Puamau, and Hanapaoa Valleys, and possibly to Natue Valley. The inner slopes of Kaava Ridge bear a striking resemblance to those of the Tunoa-Pahuhituone Ridge on Nukuhiva, which on Chubb's interpretation are the inner sides of a major crater. The distinctive nature of the rocks and soil at Ootua is suggestive of an independent origin, possibly later than in other regions.

The cloud zone of Hivaoa occupies the entire western mountain system from above Taaoa to the end of Kaava Ridge, and from about 2,000 feet on the eastern side to slightly over that altitude on the west. This is the largest area of cloud zone country in the Marquesas. From slightly west of Ootua, along the central range almost to its eastern end, there is a much smaller region of cloud zone.

On the slopes above Atuona Valley, the change from intermediate levels to the cloud zone is well defined at about 2,000 feet. Below that level the forest in exposed places gives way to grass and *Gleichenia linearis,* and here there is a scanty fauna. At Mounaofefe (2,000 feet) the trail enters a region where *Piper latifolium, Boehmeria,* and many ferns are abundant and where *Partula* and *Rhyncogonus* appear. At about 2,500 feet the fauna and flora of the cloud zone are well developed, *Crossostylus biflora* being characteristic from this point upward and the land snails of the genus *Vitrina.* Down the leeward western side, the cloud zone ends at a higher altitude than on the east. At Kopaafaa (2,800 feet) there is still a heavy rainfall, mountain forest, and a rich fauna, but not far below this point the rainfall is low. At Anatikaue, nearly 2,000 feet high on these western slopes, the characteristic vegetation of the ridges is *Gleichenia linearis,* and even in the valleys there is a meager flora and fauna. At the southwestern end of the main range the rain forest ends a little below Vaiepoepo (altitude 2,300 feet). The extreme southwestern ridge, even at the summit of Mt. Pouoanuu (2,339 feet), is dry and barren.

At the summit of Ootua (3,032 feet) there is a heavy rainfall; *Cheirodendron* and *Reynoldsia* flourish and land snails such as *Vitrina* are abundant. But the fauna and flora are less profuse than on Mount Temetiu and it is likely that many species of the high western mountains are altogether absent from Ootua. The slopes west of Ootua, above the central plateau, and the top of the central range towards the east, are also to be included within the cloud zone. Between Ootua and the heights above Puamau no collections were made, but judging by the flora one would expect the fauna to be rich. The altitude is too low for *Cheirodendron* and *Reynoldsia,* but tree ferns, *Metrosideros,* and *Weinmannia* are abundant, and the branches of the trees are overgrown by epiphytes, including *Lycopodium phlegmaria* and *Procris pedunculata,* which are characteristic of the rain forest. At Teava Uhia i te Kohu (Pass Hidden in the Mist), towards the eastern end of the range, there is exceptionally rich collecting in the forests of tree ferns, *Metrosideros,* and *Weinmannia.* I do not know how much farther east the rain forest extends; it probably ends above Natue Valley.

On the plateau northeast of Atuona there is a fairly heavy rainfall, but this region is hardly to be included in the cloud zone. At the southern side of the plateau there are many open spaces, covered only by *Gleichenia,* and where forests occur the dominant trees are *Hibiscus tiliaceus, Piper latifolium, Wickstroemia,* and *Pandanus.* Few *Partulae* were seen here but towards the northern side of the plateau, above the head of Hanaiapa Valley, zonitids of the genera *Microscystis* and *Trochonanina* were found in great numbers. Few insects of the mountain fauna were seen in this region.

The lower slopes of middle and eastern Hivaoa, below 1,500 to 1,000 feet, are subject to dessication, and much of the flora is xerophytic. *Casuarina, Xylosma suaveolens, Sapindus saponaria,* and a few *Cerbera manghas* are characteristic trees, and there are extensive areas with only a scrub of guava and xerophytic shrubs. Goats have denuded several regions, especially the hills east of Puamau. Between Hanatekua and Hanaiapa, on the north coast, the slopes are covered mainly by short grass, with here and there patches of *Miscanthus japonicus.*

The middle and upper parts of the valleys eastward from Taaoa on the south and Hanaiapa on the north are well forested and apparently not subject to dessication. *Hibiscus tiliaceus* forms dense forest on the floors of the valleys, with such other trees as *Inocarpus edulis, Aleurites moluccana,* and many introduced species, both trees and herbs.

Western Hivaoa from Hanaiapa round by way of Hanamenu to Point Teaehoa is a dry region, the *terre déserte* or *fenua ataha.* Precipitation is low because of its leeward relation to the mountain range which cuts off its rain. Added to this is the extensive deforestation by goats along the cliffs, and by cattle, horses, and pigs farther inland. Characteristic trees are *Casuarina, Ficus,* and *Pisonia* on the slopes and *Xylosma, Sapindus,* and *Thespesia* in the valleys. In favored spots in the valleys, where the ground is kept damp by the streams, there are some thickets of *Hibiscus tiliaceus* and even—in Hanaheka Valley, for example, at 1,100 feet—of bamboo. Extensive areas of open country are covered only by low grass, replaced higher up by *Gleichenia,* and by a low scrub of guava and xerophytic shrubs. There is much bare earth where the surface soil has been exposed and eroded. The fauna is as meager as might be expected. It is not until an altitude of nearly 2,500 feet is reached that the mountain fauna and flora begin. The scenery of this region is, however, magnificent. From the tops of the long, gently sloping ridges there are clear views over the open landscape to the sea, and inland to the green, cloud-capped mountains above. The spectacular nature of the landscape is increased by the numerous wild horses, cattle, goats, pigs, and even wild dogs. In contrast to the close valleys where the villages lie and the rain-soaked forests on the high mountains, the air at 2,000 feet here seems dry and invigorating.

Some of the best collecting grounds on Hivaoa can be reached by trail, and they are much more accessible than on Nukuhiva. The inland trail from Atuona to Hanamenu crosses the ridge north of Mount Temetiu, passing through extensive rain forests on both sides of the ridge and along its crest. This trail was passable for horses when Hanamenu was inhabited, but it is now falling into disrepair. The ascent of Mount Temetiu is difficult, because of the dense scrub through which a passage must be cut. The mountains above Taaoa are easily reached from the southwest, through open country along the ridge past Mount Pouoanuu, and then by pig trails in the lower parts of the rain forest. The crest of Kaava Ridge may be followed from its western end above the head of Hanaiapa Valley. The trail along the middle of the eastern half of the island passes below Mount Ootua through rain forest at about 2,500 feet altitude. There is rich collecting at Teava Uhia i te Kohu, at about 2,000 feet, within less than 2 hours' journey from Puamau.

The population of Hivaoa is about 600. Atuona is the present capital of the Marquesas. It is the best base for biological field work in the Marquesas, being only two or three hours' journey by trail from the crest, nearly 4,000 feet high, north of Mt. Temetiu. The other principal villages on Hivaoa are Taaoa on the south coast and Hanaiapa and Puamau on the north. There are a few families at Tohuto, Tahauku, Punaei, Hanamate, and Hekeani on the southern coast, and at Nahoe and Hanapaoa on the north. The entire western region from Hanaiapa to Taaoa is uninhabited. There is a hamlet on the southern slopes of Hivaoa at Moea, the only settlement in the Marquesas at the present time that is not situated in a valley. The term "Inhabited Plateau" applied to the uplands in the eastern half of Hivaoa on the United States Hydrographic Office chart appears to be a mis-translation of the French *Plateau Inhabité.*

Tahuata

Most of the following account of Tahuata is based on the field notes and sketch map made by Monsieur G. LeBronnec in 1930. I did not visit the island.

Tahuata is about 9 miles long and 5 miles wide. Its area is about 20 square miles. Its topography is relatively simple. From a semicircular central ridge steep slopes descend east and west into deep valleys separated by short buttresslike ridges, and a slightly dissected volcanic slope descends north. (See fig. 2.) The crest of the central

range is everywhere above 1,000 feet high; not far from the southern end it reaches 2,000 feet and it exceeds 2,000 feet from Tupahoehou to the beginning of the northern volcanic slope. Along Uuao Ridge for a distance of about one mile the altitude is slightly over 3,000 feet.

The valleys of Vaitahu and Hapatoni on the west and Hanatetena on the east are short and wide and surrounded at their heads by abrupt slopes to the crest of the central

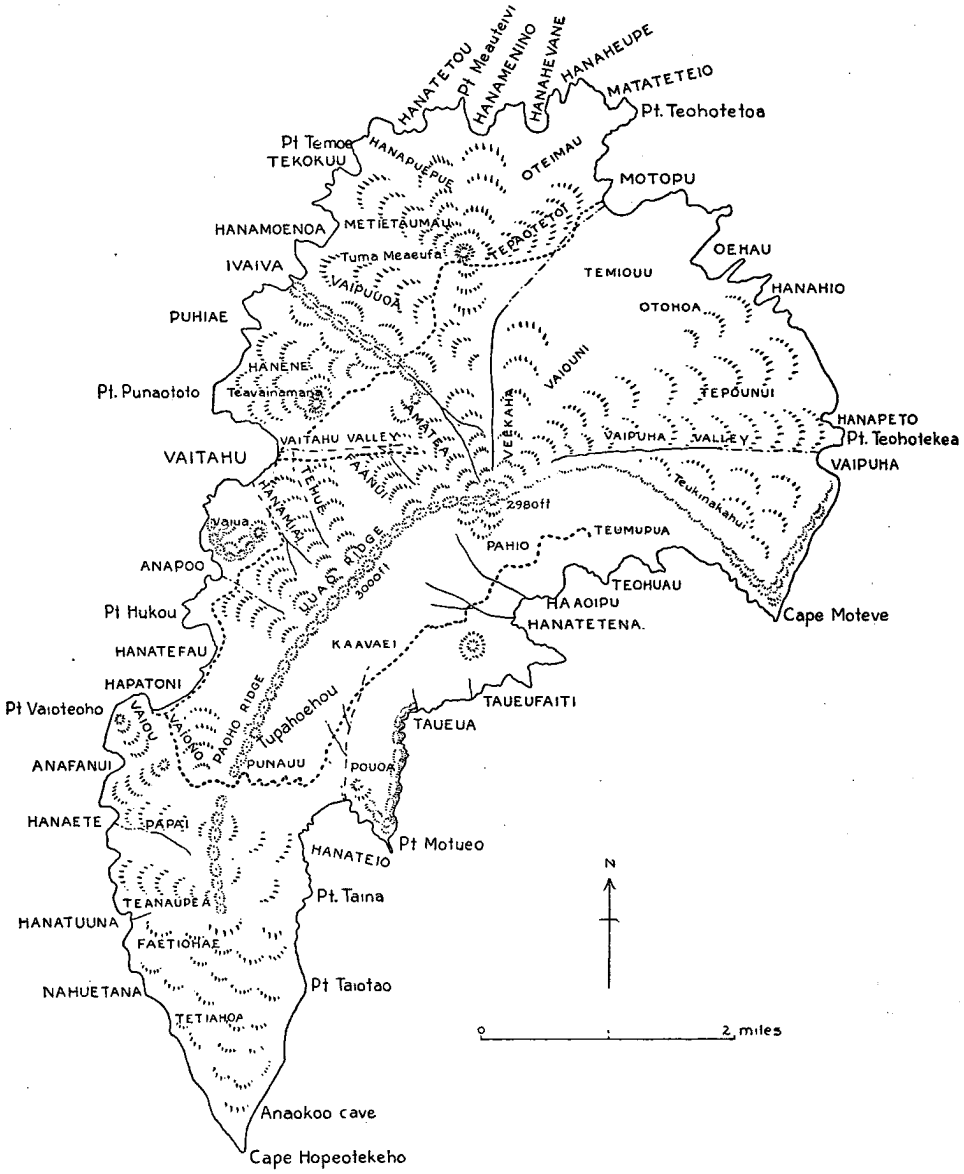

FIGURE 2.—Map of Tahuata redrawn from a manuscript sketch map by G. LeBronnec.

ridge. None of them has acquired a flat floor, save for a very short distance inland, and their streams flow swiftly over rocky beds. Hanateio Valley is longer than these three and has acquired a more gentle slope. The valleys of the northern slope are long ravines; none of them, with the exception of Motopu, are very extensively eroded.

The northern slopes end in comparatively low cliffs. On each side of Cape Moteve the cliffs are more than 1,000 feet high, and in many parts of the coasts in the middle region they exceed 500 feet. The southern promontory has precipitous slopes on each side. Chubb records a shore shelf surrounding the island, 3 to 4 feet above high water. The largest coral reefs in the Marquesas are those of Hanahevane, Hanamenino, Motopu, and Oehau in northern Tahuata; they enclose small lagoons at the heads of these bays. Smaller reefs appear at Hapatoni, Hanateio, and Ivaiva. According to Davis (20), a submarine bank surrounds Tahuata. The depths at about ½ mile from shore are 40 to 50 fathoms. Native fishermen record banks about 1 mile off the southwest coast with bottom at less than 10 fathoms. The channel separating Hivaoa and Tahuata is probably shallow, perhaps not exceeding 100 fathoms.

Chubb states that the center of the original volcano probably lay to the southeast of the island, and that a secondary crater, with its center near Taueua, appears to have arisen within it. The southeastern half of the island has been submerged, probably by downfaulting. The northern portion of the island is composed largely of ash, and Chubb believed that Tahuata arose during the second phase of volcanism in the Marquesas. "The southwestern part of Tahuata, as seen from the sea appears to be composed of massive bedded lavas, intruded by many vertical dykes . . . ." The relatively small amount of erosion of the valleys as compared with those of Uahuka, for example, may be indicative of comparative youth, though too much reliance should not be placed on this evidence. A raised beach deposit lies at 250 feet on the north side of Hanateio Bay.

The climate of Tahuata is relatively dry. All the streams are of insignificant size and only those of Hanatetena Valley have a permanent flow above ground to the sea. Elsewhere there are only small springs, or streams which fail to reach the sea during dry weather. The cloud zone is limited to a small area along the central ridge, from Paoho northward to the upper parts of the northern slopes. As the long axis of Tahuata is at right angles to the trade winds, the valleys of Vaituha, Anapoo, and Hapatoni on the west side receive much of the precipitation, and the cloud zone includes the heads of these valleys. The vegetation of this zone is true rain forest, but it is less luxuriant and probably less rich in species than on Hivaoa, Fatuhiva, and Nukuhiva. The large valleys of Hanatetena, Hanateio, Vaituha, and Hapatoni are well forested.

The greater part of the slopes at the broad northern end, from Cape Moteve on the east to Point Punaototo on the west, are sparsely forested. The dominant vegetation consists of grass and such other herbs as *Sida,* with here and there *Casuarina* groves and patches of *Miscanthus japonicus.* In the valleys there are some forests of *Pisonia, Thespesia populnea, Sapindus,* and *Hibiscus tiliaceus.* The poverty of this flora is probably due to low rainfall and porous soil, as well as to the grazing of goats, cattle, and sheep. The steep slopes of the southern promontory, from Cape Hopeotekeho northward to a line between Hanateio and Hanatuuna, have been denuded of vegetation, and even of soil, by the ravages of goats.

The population of Tahuata in 1930 was about 240. There are four villages in the middle region of the east and west coasts, and a mere hamlet at Motopu on the north coast. The principal village, Vaitahu, was the first landing place of Mendaña and the scene of activity of the first missionaries to the Marquesas. A rarely used trail ascends Vaitahu Valley for about 1½ miles, and it is possible, after cutting a way through the brush, to climb the central ridge by way of Amatea (2,150 feet), where the rain forest begins.

Fatuhiva

The following description of Fatuhiva is based on the field notes made by Monsieur LeBronnec in August-September, 1930.

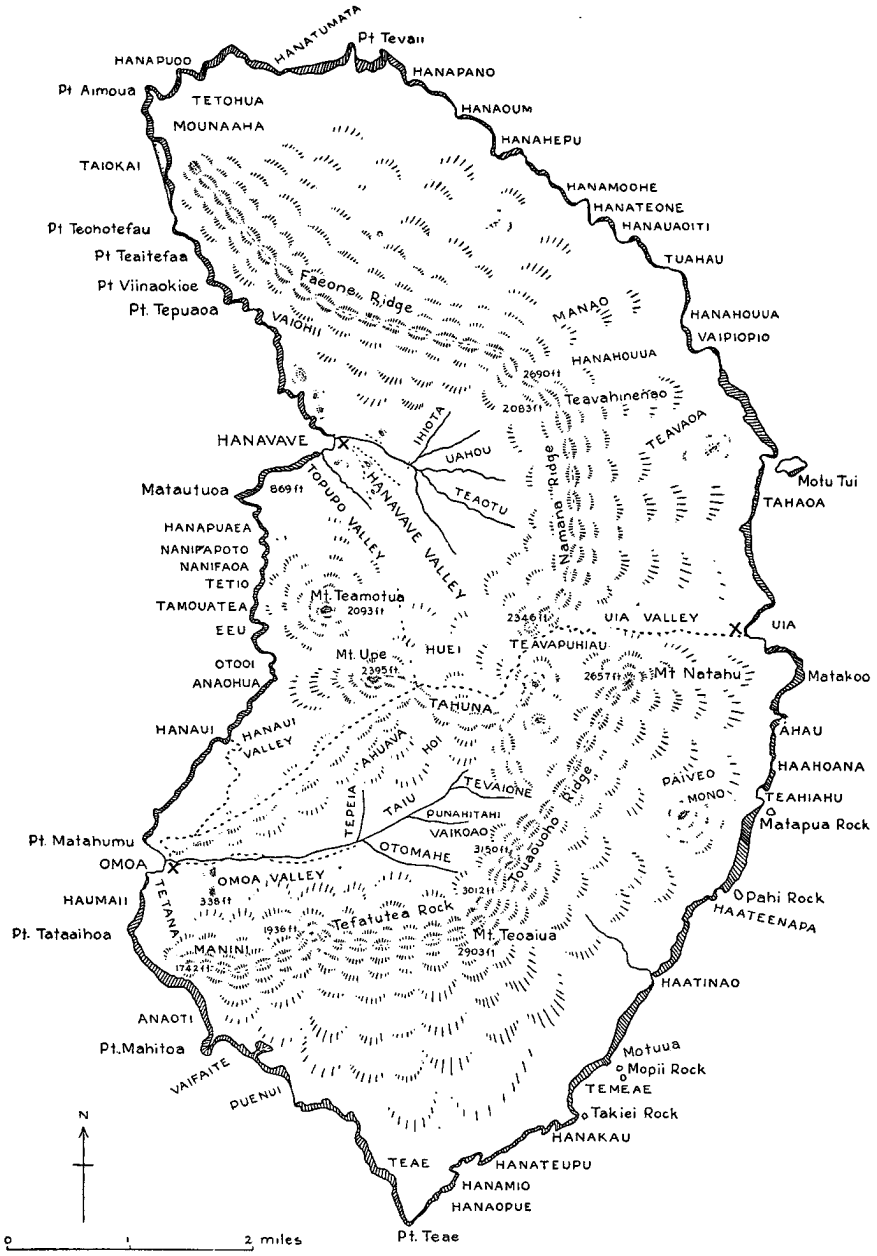

FIGURE 3.—Map of Fatuhiva, redrawn from a manuscript sketch map by G. LeBronnec.

Fatuhiva (Fatuiva) is about 9 miles long by 4.5 miles across, and its area 30 ± square miles. Topographically, and because of its heavy rainfall and luxuriant vegetation, it is one of the most beautiful and picturesque of the islands. It resembles Tahuata in having a semicircular central ridge; there is a fairly steep, but even, volcanic slope on its convex sides, and abrupt slopes into deep valleys from its inner edge. (See fig. 3.) Most of the crest of this ridge is more than 2,000 feet high; for short stretches at Touaouoho and Namana it exceeds 3,000 feet. The highest point indicated on the hydrographic charts is 3,150 feet. Picquenot (44) gives 1,020 meters (3,674 feet), which is probably correct; this height is attained on Touaouoho Ridge, north of the point marked 3,150 on the charts. Within the semicircle of the central range there are mountains rising to nearly 2,500 feet high. The two systems, outer and inner, are joined by a transverse ridge more than 2,000 feet in altitude, between the heads of Omoa and Hanavave Valleys.

There are only three large valleys on Fatuhiva, Omoa (Oomoa), and Hanavave, which are of similar form, on the west, and Uia (Ouia) on the east.

Omoa Valley has a flat floor extending for at least a mile inland, with steep sides, especially on the south. At its head the valley widens out into a semicircle bounded by precipitous slopes, and divided by buttresslike ridges into three main branches, Otomahe, Punahitahi, and Taiu, of which Taiu is the largest. Omoa river is the largest on Fatuhiva, and one of the most voluminous in the Marquesas. Hanavave also has a flat floor; its river is smaller than that of Omoa. On some of the ridges between the small valleys fantastic figures have been carved by erosion, and to them Hanavave owes its name of Virgins Bay. The valleys between Hanavave and Omoa are short canyons, of which Hanaui is the largest; none of them has a permanent stream.

The lower part of Uia Valley has a very narrow floor not much above sea level. It widens out at its head to form a magnificent amphitheater, with steep sides many hundreds of feet high. Haatinao Valley is a deep and narrow canyon. Its stream has cut its bed down to nearly sea level for about ½ mile inland. All the other valleys of the outer slopes of the island are small, narrow ravines with intermittent streams.

The height of the cliffs along the greater part of the east coast has not been recorded. From Motuua to the southern end, at Teae Point, and thence northwest to Tataaihoa they exceed 1,000 feet, and again along the coast north of Hanavave. Between Omoa and Hanavave there are low sea cliffs which have been formed, according to Crossland (17), by marine erosion. Marquesans state that the bottom falls steeply off the western coast, while numerous fishing banks at moderate depths are known off the eastern side.

According to Chubb's interpretation, Fatuhiva is the western half of a double crater. The semicircular central crest is the rim of the outer crater; Mount Upe and Mount Teamotua are the remains of the inner cone, and Omoa and Hanavave Valleys occupy the moat between the two systems. Hanaui Valley represents the inner crater. It would be interesting to know the relation of the Uia amphitheater to this interpretation of the original sructure of Fatuhiva. Chubb found that the outer crater, "so far as it was examined, appears to be composed mainly of lava flows, though it includes some pyroclastic rocks" and that the inner cone "is composed chiefly of ashes, agglomerates, layers of scoria, and very vesicular lava." There is evidence of uplift of Fatuhiva of at least 50 feet. Chubb records raised beach shelves at elevations of 8 and 15 feet above sea level and sea caves at 30 feet. As already mentioned, LeBronnec found a shore deposit at 50 feet near Teae Point. The extensive erosion of Omoa, Hanavave, Uia, and Haatinao Valleys is probably indicative of considerable age.

Fatuhiva is by general consent of the Marquesans the wettest island in the group. Von den Steinen's records (31) give an annual precipitation of 2,972 mm at Omoa in 1900, with 255 days of measurable rainfall. The cloud zone descends farther than on the other islands and rain forest covers almost the entire length of the central range and the mountains west of it. At Tahuna, along the ridge between the Omoa and Hanavave Valleys, at altitudes of about 2,100 feet, the cloud-zone forest is fully developed, with such genera as *Cyathea, Metrosideros, Weinmannia,* and *Crossostyles.* Beetles of the

genus *Rhyncogonus* were found below 1,000 feet, whereas on the other higher islands their lower limit appeared to be about 2,000 feet.

The cloud cap which forms over the mountains of Fatuhiva overlays the upper reaches of Omoa and Hanavave Valleys, and there is more precipitation on the leeward western side of the range than on the windward eastern side. Consequently Omoa and Hanavave are the wettest valleys in the Marquesas, and have the most luxuriant vegetation. *Piper latifolium* grows as low down as 150 feet and the *fehi* (*Musa fehi*), which is ordinarily a mountain plant in the Marquesas, grows 500 yards from the sea. The slopes of both valleys are verdant, with mosses and ferns growing even on the faces of the cliffs. Unfortunately the destructive grass *Paspalum conjugatum* flourishes exceedingly in the wet parts of Fatuhiva and it has spread through much of Omoa, Hanavave, and Uia Valleys and along the trail in the middle of the island.

The rainfall is low and the vegetation meager on the eastern side of the island. The floors of Uia and Haatinao Valleys are covered with *Hibiscus tiliaceus,* but elsewhere the goats have deforested this side of the island, all along the southwest coast and as far as Teohotefau on the northwest. In spite of its heavy rainfall, Fatuhiva has thus an extensive *terre déserte.*

The western slopes of the mountains between Omoa and Hanavave Bays are poorly forested. *Miscanthus japonicus* covers the ridges north of Omoa and a wide area of the northeastern slopes of Mount Teamotua, south of Hanavave. A narrow strip of the coast line between Matautuoa and Otooi has been deforested by goats.

There are few trails on Fatuhiva, but the route from Omoa to Uia passes through rain forest where there is rich collecting at 2,200 feet along the ridge between the heads of Omoa and Hanavave Valleys. The central ridge can be ascended from both these valleys, but a trail must be cut through the dense vegetation. There are only two important villages, Omoa with 120 inhabitants and Hanavave with 60. Uia and Hanahoua have about 10 each. Despite the luxuriant vegetation, and the calm waters for fishing off the west coast, the population of this beautiful island seems to be declining more rapidly than on any of the other islands.

Mohotani

The uninhabited island of Mohotani (Motane) is about 9½ miles south of the eastern end of Hivaoa and 14 miles east of Tahuata. It has never been surveyed, only short sections of the coast line being shown on the French charts. The sketch map reproduced here (fig. 4) is only approximately correct. The island is about 5 miles long, in a north-south direction, and only 1½ miles wide. Its area is about 6 square miles, and its greatest altitude is about 1,700 feet. It has the form of a segment of a circle. The straight side, to the east, is a wall of vertical cliffs and steep slopes, nearly 1,700 feet high toward the southeast, diminishing gradually in height towards the north. From the top of these cliffs, except at the southern end, the land slopes fairly evenly to the top of cliffs only a few hundred feet high on the western side. The greatest part of the island is thus a fairly flat slope, inclined to the west and to the north, and dissected by a few shallow valleys. The southern part of the island is a plateau, bounded on three sides by cliffs 1,000 to 1,500 feet high.

At Anafai a sandy beach is exposed at low tide; elsewhere the shores are rocky. I observed a low beach shelf along the western coast. South of Mohotani is the rocky islet of Terihi; it has vertical sides about 500 feet high.

LeBronnec made some interesting observations on the geology of Mohotani. In the northern half of the island he found the exposures to be of dark, porous rock, probably basalts, dipping to the west and north, and intermixed with layers of yellowish and reddish ash. In the southern region compact smoke-grey rocks were found, in strata dipping very slightly towards the north. Near the middle of the island, above Anauia, the southern strata were seen to overlie the northern, presumably older, formations.

LeBronnec's conclusions were in accord with those of Chubb, who suggested that Mohotani is a fragment of a volcano which had its center to the south. LeBronnec further suggests that Terihi, which is composed of pitch-black rock quite different from the rocks of Mohotani, may be an infilling of the volcanic conduit. The slight erosion of the small valleys of Mohotani suggests that it may be younger than the other islands. This is in accord with the fact that no species of animal has yet been reported as peculiar to Mohotani, and that almost all the genera that are most characteristic of the Marquesan endemic fauna were not collected by us on this island.

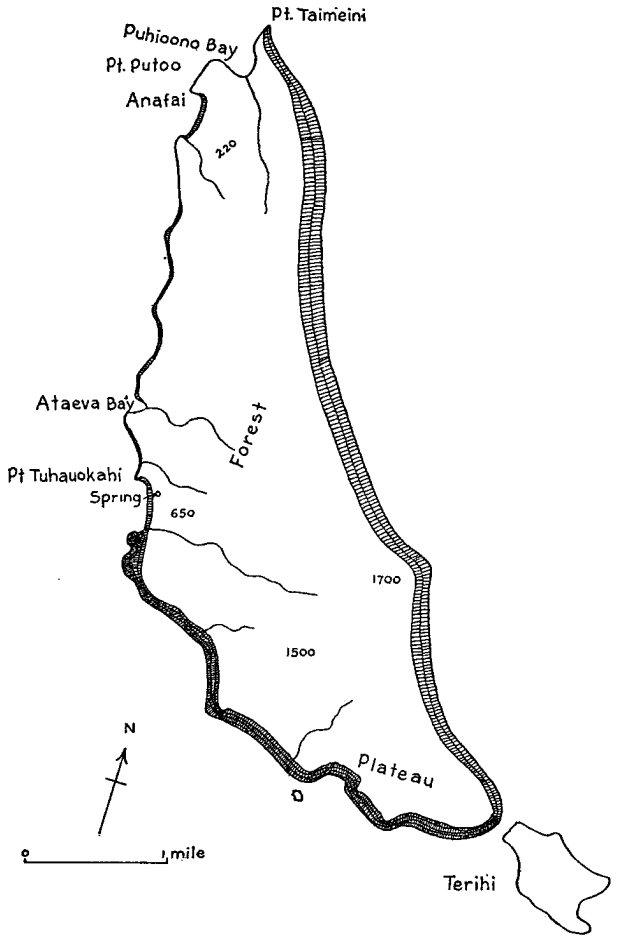

FIGURE 4.—Map of Mohotani, redrawn from a manuscript sketch map by G. LeBronnec.

The climate is dry. There is a tiny stream near the northwestern end of the southern plateau, where prawns (*Palaemon*) were collected, but in dry weather it disappears underground before reaching the sea. Two permanent springs are known, one on the western shore at Anauia, the other at an altitude of 650 feet at the top of the precipice above it. Here, in August 1929, there was a small region where moist conditions were maintained by infiltration of water, contrasting with the surrounding aridity. The north-

ern region is devoid of permanent streams. Most of the vegetation is xerophytic, but the climate is not too dry to prevent the growth of coconuts, some sugar cane, and numerous breadfruit trees.

The central portion of the island is well forested, with pure stands of immense *Pisonia* trees, the most magnificent anywhere in the islands, numerous *Cordia subcordata* and *Thespesia populnea,* which also appear to be larger here than elsewhere, and scattered *Pandanus, Aleurites moluccana, Hibiscus tiliaceus,* and other trees and shrubs. The best collecting was found in this region. The tall grass, *Miscanthus japonicus,* is dominant over much of the southern third of the island; on the southern plateau there are also copses of *Thespesia populnea.* The northern region, for 1 to 2 miles from the north end, was formerly covered by xerophytic shrubs, but it has been reduced to a barren waste of red, stony soil, by the sheep to which this island has been abandoned. The vegetation which once found a footing on the steep eastern slopes has likewise been destroyed. In wet years a sparse covering of such herbs as *Cassia occidentalis* springs up on the plateau, withering away in periods of drought. In this northern region erosion of the unprotected soil, by rain and wind, is proceeding rapidly, bare rock being exposed in many places. In many parts of the forested zone the sheep have destroyed the undergrowth, erosion of the surface soil has begun, and unless the numbers of sheep are reduced, the ultimate destruction of the forest is certain. Deforestation and denudation are not so far advanced as on Eiao, but are proceeding very rapidly.

Except for the very limited supply of drinking water, Mohotani could support a small population. Linton (39) states that it was once inhabited by a single tribe. In historic times it has probably been rarely visited, except by fishing parties, and if sheep and cats had not been introduced, the fauna might have suffered little change from human activities. Anchorage is safe in trade-wind weather at Puhioono Bay and landings can be made at several points on the west coast. There are several small sea caves on the western shore and a trail leads from one of them, Ataeva, to a coconut plantation at about 800 feet above it. All parts of the interior are accessible.

Fatuuku

The rocky islet of Fatuuku was visited by a Pacific Entomological Survey party under Hugues Tauraa in November 1930, and the following account is based on the observations made.

Fatuuku lies some 20 miles north of Hivaoa. It is only about 1½ miles long, and ½ mile wide, with an area of about ½ square mile. The highest point, according to the charts, is 1,180 feet. The coast line is everywhere rocky; a raised beach shelf is present at least in some parts, and above it the cliffs rise more or less vertically all round the island. There is a landing place—in favorable weather—on the northwest side, where the cliffs are lowest, and on the trail leading from it there are steps cut in the rock by the ancient Marquesans. The ascent to the summit is hazardous, even in the opinion of the most venturesome of the Marquesans. The most dangerous point is half-way up, where the trail passes over a rock which overhangs the precipice. At about 1,000 feet, the trail reaches the flat top of the island, an area of about 30 acres, sloping slightly towards the west and bounded on all sides by steep slopes or vertical cliffs above the sea. Near the southern end of the island, a small peak rises some 30 feet above the general level of the summit.

Little is known of the geology of Fatuuku. Reference has already been made to the supposed occurrence on the summit of fossil coral, which proved to be a highly decomposed lava. I know of no data regarding the origin and age of this island.

The climate is, of course, very dry, but on the trail at an altitude of 600-700 feet, a tiny spring was found, which is said to be permanent. Linton (39) mentions a pool of stagnant water at the top of the island, but it seems certain that it must dry up completely in periods of drought.

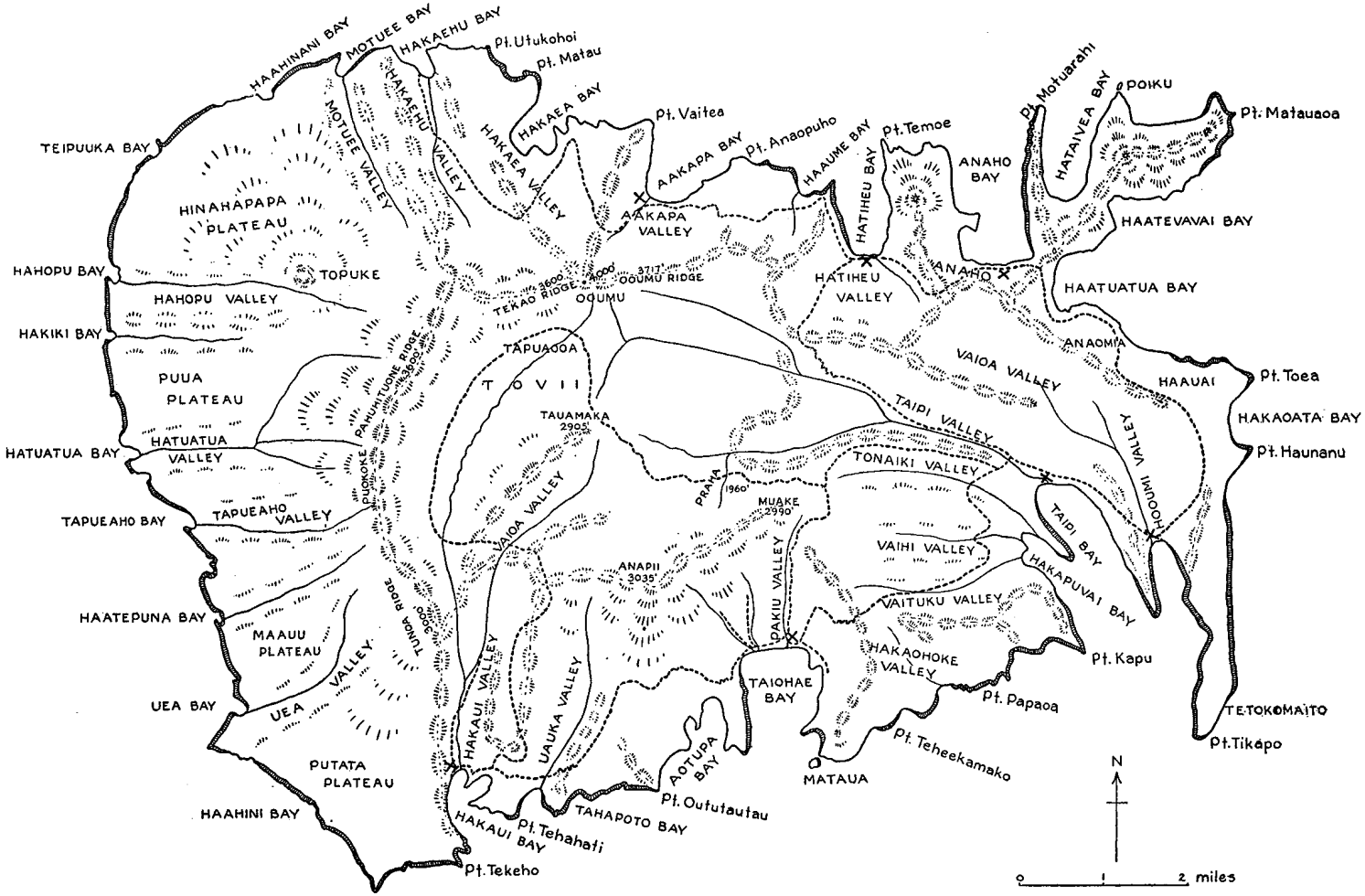

FIGURE 5.—Map of Nukuhiva based on a manuscript sketch by G. LeBronnec.

Most of the surface of Fatuuku is bare rock, more or less decomposed, with here and there a scanty growth of a few species of xerophytic shrubs and herbs, including the tussocks of a grass (*Eragrostis xerophila*), which serve as nesting sites for the sea birds. A single specimen of *Hibiscus tiliaceus* and three of *Thespesia populnea* were seen, but the southern part of the flat top bears a forest of *Pisonia* and some *Sapindus saponaria*. No other trees were observed.

It seems certain that Fatuuku was never inhabited; it was visited often by parties of fishermen and bird hunters, who may have remained for many days at a time. At present the island is very rarely visited and it is likely that conditions have been little changed by human activities. So far as I know, attempts have not been made to introduce any animals or plants to Fatuuku.

Biologically the chief interest of this island lies in the thousands of sea birds—frigates, boobies, terns, and others—which nest upon it. The physical conditions are unsuitable for anything but an extremely meager land fauna, and it is likely that no fresh-water species could find a permanent habitat here.

Nukuhiva

Nukuhiva, ranking with Hivaoa in size and importance, is the principal island in the central group. It is 16 miles long, 12 miles wide, and has an area of about 125 square miles. Its highest point is probably at least 4,000 feet. (See fig. 5.)

The mountain ranges of Nukuhiva are peripheral, surrounding the central depression of Tovii (Toovii). Along the western side the great Tunoa-Pahuhituone Ridge rises gradually from about 3,000 feet at its southern end, west of Hakaui, to nearly 4,000 feet where it joins the northern range in the highest mountain mass in the island. The crest of this western range is sharply defined. Its inner, eastern, slopes are steep and dissected by very numerous small V-shaped ravines; on the outer, western, side there are long volcanic slopes to the sea. This ridge is perhaps the most striking topographical feature of the island. The mountains along the north coast are less regular. Above Hakaea and Aakapa on the northwest there is a series of ridges and deep gulches, forming extremely rugged country, with peaks rising to about 4,000 feet. Of these peaks Ooumu was ascended several times from a camp at Tapuaooa on the plain below. Its altitude was estimated at not less than 4,000 feet; the greatest altitude on the charts, 3,904 feet, is probably that of the highest peak visible from the sea. The summit of Ooumu commands a magnificent view of the interior of the island and of the western ridge. To the north, peaks of equal or possibly greater height block the view. The northern range is continued with decreasing altitude as far as Point Tikapo at the southeast corner of the island. On the outer side of this range there are abrupt slopes into deep valleys separated by high ridges; on the south there are fairly steep slopes above Tovii and the head of Taipi Valley.

The southern mountain system surrounds the large caldera-like amphitheater of Taiohae. Its slopes rise irregularly and not very steeply above Tovii, more abruptly all along the southern side; the descent into Taiohae Valley is precipitous. The highest point on this range is probably at Anapii, which is just over 3,000 feet.

Within these mountain ranges is a wide depression named Tovii, bounded on the west by the Tunoa-Pahuhituone Ridge, on the north and south by irregular mountains, and on the east by the upper branches of Taipivai. Most of the eastern and middle region of Tovii is undulating country, traversed by low, rounded ridges and fairly shallow valleys; its average altitude is between 2,500 and 2,800 feet. The western portion is a remarkably flat plain, about 2,700 to 2,800 feet above sea level, along which the main stream flows slowly in a bed of gravel and sand, only a few feet below the general level of the plain. All the streams of Tovii descend by way of Taipivai on the east and Hakaui on the southwest.

Nukuhiva has perhaps the finest valleys in the Marquesas. Two of them—Taipivai and Hakaui—are very long and much eroded. The valleys of the western slope are

deep canyons cut out by intermittent rains. Most of the other valleys are short and wide, and are surrounded by semicircles of steep slopes. There are several valleys of this type on the north coast, only one—Taiohae—on the south.

Taipivai is the longest valley in the Marquesas, and its river the most voluminous. Its three principal branches descend in cascades from eastern Tovii, and below their junctions the river flows slowly along the flat floor of the valley, in a bed of gravel and mud, for nearly one mile before reaching the sea. Near the mouth of the river is a wide lagoon of brackish water, surrounded by marshy ground. This superb valley is famous as the "Typee" of Herman Melville, and notorious as the region most infested by biting *Simulium* flies. Hooumi Valley has somewhat the same form as Taipivai.

Hakaui Valley is the most spectacular in the Marquesas. It is a narrow canyon with an almost flat floor for about 1.5 miles inland. On the western sides are vertical cliffs nearly 3,000 feet high, fantastically sculptured by erosion; the eastern side is lower and less steep. The river from Vaioa Valley in Tovii enters the head of Hakaui Valley by a waterfall; in the floor of the valley it is joined by the stream which drains the western plain of Tovii and falls into Hakaui Valley from a height of nearly 2,000 feet. In rainy weather innumerable cascades descend the western cliffs from Tunoa Ridge.

Most of the large valleys on the north coast have the form of amphitheaters; they have numerous permanent streams flowing swiftly over stony beds. The largest of these valleys are Hatiheu and Aakapa. At the northwestern corner, the long narrow valley of Hakahu is extensively eroded and 1½ miles inland its floor scarcely reaches 100 feet altitude; Motuee Valley has a similarly flat floor for about ½ mile from the sea.

On the western slope the smaller valleys are V-shaped ravines, but Uea, Hatuatua, Tapueaho, and Hahopu, though their sides are very steep, have been sufficiently eroded to have flat floors. Their streams are all subject to dessication.

The coast line of Nukuhiva is very deeply embayed everywhere except on the west. As on the other islands, most of the beaches are of black sand or shingle, though a few of them, where no permanent stream enters the sea, are of fragments of coral and shells. The raised shore shelf, so far as it has been observed, is about 4 feet high. The sea cliffs rise well above 500 feet high at most of the headlands on the south coast; on each side of Taipivai and Hooumi on the southeast; and on the northwest near Aakapa and Hakaehu. These cliffs have presumably arisen by faulting. The western volcanic slope ends in cliffs less than 500 feet high, possibly formed by marine erosion alone.

According to Chubb's hypothesis, Nukuhiva is the remains of the northern half of a major crater, within which is a minor cone concentric with it. The peripheral mountains of the western, northern, and eastern sides represent the walls of the outer crater, and Tovii the northern portion of its floor. Taiohae is the crater of the inner cone, between which and the walls of the outer crater are the deep valleys of Hakaui and Taipivai.

LeBronnec observed that the rocks of the mountains surrounding Taiohae, as far as Hakaui and Taipivai, are predominantly greyish-white, compact and forming in places large blocks and pyramids, whereas the rocks of the outer regions are mostly black and vesicular. Moreover, in many parts of the inner region we observed layers of white clayey deposits; in Tovii these were conspicuous because of their impermeability to water. Specimens from the Taiohae-Hakaui trail appear to be of similar material. No whitish soil was observed in the outer mountains, on which the rocks decompose to form reddish earth. The inner region of Nukuhiva appears to be infertile in comparison with the outer. There is therefore a considerable amount of evidence for this division of Nukuhiva into two regions of which the inner is the younger.

Near the northwest corner of the island is a small hill—Topuke—which LeBronnec, viewing it from about a mile to the south, took to be a recent volcanic cone, possibly of similar age to the craters of Teepoepo and Tahoahitikau on Uahuka, and with them representing the last volcanic eruptions in the Marquesas. A small table-like formation at the south side of Uea Bay appeared to LeBronnec to represent a recent lava flow. It

seems likely, however, on the evidence of the extensive erosion of the valleys, that the outer parts of Nukuhiva are as old as any regions in the Marquesas.

It is possible that a crater lake may have occupied western Tovii before the formation of an outlet into Hakaui. Its existence would explain the formation of the layers of whitish clay observed in many parts of this plain. Brown (5) asserts that a crater lake did exist here and on a second visit to Tovii in 1931, LeBronnec inclined further in favor of this view. If there ever were such a lake, it must have offered habitats different from any now occurring in the Marquesas, and as it dried up there must have been extensive marshes. But it may be that no special fauna developed in these habitats, for lack of animals to colonize them.

Because of its large area at an elevation of over 2,000 feet, Nukuhiva possibly receives more rain than any of the other islands. There is heavy precipitation over the entire central region and on the mountains surrounding it. Taipivai is the only valley in the Marquesas, with the exception of Omoa and Hanavave, which is never seriously affected by drought, and most of the valleys of the north coast, such as Hatiheu, are almost always well watered. Taiohae and the valleys of the southwest are relatively dry, and the western slope is arid.

Rain forest covers the upper parts of the western ridge and of the mountains along the north coast. It descends the western slope for some 300 feet below the crest of the Tunoa Ridge. At the foot of Ooumu it begins at about 3,000 feet. The mountains of the inner cone around Taiohae are incompletely forested. Their northern slopes above Tovii are covered by low *Metrosideros, Weinmannia,* and other trees, with intervening areas of grass and *Gleichenia,* and their southern slopes are relatively barren, being mostly covered by short grass and *Miscanthus,* and supporting only scattered woods of drought-resisting trees.

The eastern part of Tovii, where the average altitude is about 2,700 feet, as far west as Vaioa Valley and Tauamaka, is covered only partially by forest. In the hollows there are woods of *Hibiscus tiliaceus, Piper latifolium,* and even tree ferns and *Freycinetia,* but in exposed regions there are extensive areas covered by *Gleichenia* and grasses. Western Tovii is sparsely forested; there are thickets of low *Hibiscus tiliaceus,* and scattered *Metrosideros, Weinmannia, Wickstroemia,* and *Glochidion,* but a great part of the plain is open country, covered only by *Gleichenia* and grasses. This is a flora very much less rich than we had come to associate with altitudes of more than 2,500 feet in the Marquesas, and the fauna throughout Tovii was found to be unexpectedly meager. No *Partulae,* for example, were observed much below 3,000 feet. LeBronnec concluded that the infertility of the soil of the Taiohae cone, which has probably extended its ejecta over the greater part of Tovii, may be the cause of the poverty of the flora, and indirectly of the fauna. In support of his view, he cites the relative infertility of Taiohae Valley as compared with Hatiheu, for example. It would appear that the division of Nukuhiva into two regions, of different geological history, is applicable to the flora and fauna as well.

The western volcanic slope is the *fenua ataha* of Nukuhiva, resembling in the character of its fauna and flora that of Hivaoa, like which it has been extensively deforested by goats and cattle. As on western Hivaoa, erosion is proceeding rapidly.

The best collecting grounds on Nukuhiva are thus restricted to the western ridge and the northern mountains. Here alone the cloud-zone fauna reaches its full development, and there is no natural division of this region such as occurs on Hivaoa. The high mountains above Aakapa are one of the richest regions for collecting in the Marquesas. Unfortunately it is one of the least accessible, being a day's journey on horseback from Taiohae, and nearly as much from Hakaui. So far as I know, these mountains cannot be ascended from the north. The crest of the Tunoa-Pahuhituone Ridge can be reached from the *fenua ataha.* There is a trail across the island from Taiohae by way of eastern Tovii and the upper reaches of Taipivai to Hatiheu. There are numerous cattle trails over Tovii, and much of the country is so flat and open that all parts of it are accessible.

According to Handy (30) Nukuhiva was possibly a secondary center of colonization by the Polynesians, following Hivaoa. It was at Taiohae that the majority of the New Bedford whalers anchored, and here the French established their principal military post in the Marquesas. The government's headquarters were at Taiohae until 1904, and this has been the port of call of most of the steamers which make rare visits to the Marquesas. The population of Nukuhiva in 1926 was 543, mostly divided between Hakaui, Taiohae, Taipivai, and Hooumi on the south, and Hatiheu and Hakapa on the north (48). Tovii is the largest inland habitable region in the Marquesas. There was probably never any large permanent settlement on it; LeBronnec suggests that this may be due to the lack of breadfruit at so high an altitude. A few years ago a small Czechoslovakian colony began to establish plantations of coconuts, bananas, coffee, and other crops, at "Praha" in central Tovii, but the project was abandoned in 1931.

Uapou

In a number of features, physiographical and petrographical, Uapou stands alone among the Marquesas Islands. In contrast to the other islands its outline is scarcely elongated, being roughly diamond-shaped, with axes of 9 and 8 miles. As on most of the other islands, however, there is a central ridge, which traverses the island from north to south; in the middle of the island, between Oave and Tekohepu, its altitude is about 3,000 feet. On each side of it are secondary ridges. In the upper regions the crests of all these ridges are knife-edged, with precipitous slopes into the valleys between them, so that the high interior is extremely rugged, sharp ridges alternating with deep valleys. There is no level area above 1,000 to 1,500 feet, and the region above 2,000 feet, being limited to the higher parts of the ridges, has an area of not more than 3 square miles.

Above the crests of the ridges there arises a series of about twelve remarkable pinnacles (pl. 3, *B*). When viewed from the mountains of Uahuka, on a clear day when no cloud cap has formed, Uapou resembles a fantastic cathedral with spires and turrets. The highest peak is Oave (named Poutetainui on the charts; the pinnacle of this name is north of Oave). It has the form of a steep, pointed cone, vertical on its northern side. It rises to a height of more than 4,000 feet, almost 1,000 feet above the level of the main central ridge. According to the charts, the highest point on Uapou is 4,040 feet; this probably applies to the summit of Oave, instead of Poutetainui. The tallest spire is Poumaka, a slender pinnacle with vertical sides nearly 2,000 feet high, its summit being some 3,200 feet above sea level. It tapers near the top, where it is squarely truncated. The other pinnacles are smaller, their sides more or less vertical, and sharply pointed. All of them arise from the ridges. They are doubtless due to unequal erosion, but otherwise their origin and significance are unknown. On the other islands, the only structures which resemble these pinnacles are the sharp peaks above Aakapa on northern Nukuhiva.

The drainage of Uapou is comparatively simple, all the streams pursuing fairly direct courses to the sea. The largest streams and the finest valleys are on the eastern side, where the most important valleys are Hakahau, Hakamoui, Paaumea, and Hohoi. Hakahau is the widest valley on the island. The village is situated on a large level area, extending for a considerable distance inland and surrounded by gentle slopes. Two main streams descend into the valley, uniting to form a lagoon near the beach. Paaumea Valley has the form of an amphitheater with a very steep slope at the head of the valley up to the central ridge. Its main stream, fed by numerous branches, has the largest volume of any on the island. Hohoi Valley is wide and shallow; it has two permanent streams.

On the northwest is the large valley of Aneou, which is shallow and has a wide bay at its mouth. The numerous valleys on the leeward, western side are narrower than those just described; they are poorly wooded and of less interest biologically than the others. Pepehitoua Valley—which is not indicated on the charts—is long and narrow;

at its junction with Tamouaiki Valley is the village of Hakahetau (pl. 3, *C*). On the ridge between these valleys are three great pinnacles, Poumaka, Toutaamahiti, and Poutemota.

As the map (fig. 6) shows, almost all the valleys are drowned at their mouths, especially on the windward, eastern side. The beaches at the mouths of the valleys are mostly of black sand or shingle. Elsewhere the coast is rocky, with cliffs or steep slopes above it. But the great vertical walls many hundreds of feet high, which are found on all the other islands, are not present here. None of the sea cliffs that I observed on Uapou seemed to be more than 200 or 300 feet high.

The charts show a bank at 17 to 22 fathoms about 2 miles northeast of Hakahau Bay. The Marquesans report numerous other banks some miles off the northeastern

FIGURE 6.—Map of Uapou, redrawn from a manuscript sketch by G. LeBronnec.

and eastern coast, at depths of 15 to 80 fathoms. Four of these, 1 to 1.5 miles north and north-northeast of Hakahau, are said to be only 15 fathoms deep, and there are two banks at 20 and 30 fathoms one mile east of Paaumea. About ½ mile east of Paaumea depths of only 5 fathoms are reported. Off the south coast, about ½ mile from shore near the islet of Motutakae, banks are said to occur at 30 to 50 fathoms.

According to LeBronnec's observations the exposed rocks of Uapou are predominantly greyish white, porous and very friable, and disposed vertically, instead of in more or less horizontal beds, such as are exposed in many parts of the other islands. The soil of Uapou is whitish, in contrast to the reddish earth of most of the islands.

The petrography of Uapou, as described by Lacroix (37), is of exceptional interest. Rocks from some of the pinnacles differ in composition from those of any other islands in the Pacific. Lacroix believes that Uapou has arisen independently of the other Marquesas Islands and probably later than most of them. By analogy with the needles of the recent dome of Mount Pelée, he suggests that the pinnacles of Uapou are relatively recent.

The St. George Expedition did not visit Uapou, and no geological interpretation of its distinctive physiographical features has been offered. If Uapou is the remnant of the summit of a volcano, it has been so worn down that no remains of a major crater are as clearly recognizable as on the other islands. Moreover the somewhat rounded outline of the island, and the comparatively low sea cliffs, suggest that faulting was at least not so active as in other parts of the group.

Uapou is the most sterile of the six inhabited islands. In LeBronnec's opinion this may be due as much to the infertility of the soil as to low rainfall. The windward valleys of the western side are wider and have larger streams than those of the eastern side, and the northeastern corner of the island is arid.

Only the upper parts of the ridges near the center of the island are covered with rain forest, and vegetation does not reach the luxuriance of the forests of Hivaoa, Nukuhiva, and Fatuhiva. Most of the *Cheirodendron* trees seen were small and even stunted, and in general the mountain forest of Uapou tends to be scrubby. From the middle of the central ridge, at Teavaituhai, the rain forest descends a few hundred feet down into the valley of Pepehitoua, and for a greater distance, and more luxuriantly, on the windward side above Paaumea.

The pinnacles are mostly devoid of vegetation, but those of the central region, such as Oave and Poumaka, are clothed at least in part. With field glasses *Ophioglossum pendulum* could be seen on the vertical sides of Poumaka, other ferns on the flat top, and *Freycinetia* on the incline below the summit. It is barely possible that special faunulae may exist on peaks which are more than 1,000 feet above the crests below them.

The large valleys of the eastern side, Hohoi, Paaumea, and Hakamoui, are well wooded over most of their extent, except on the slopes near the sea, which the goats have denuded. In the valleys on the eastern and northeastern sides the woods are mostly of *Casuarina* and such xerophytic trees as *Dodonaea* and *Sapindus,* and in many places they give way to open ground, or patches of *Miscanthus.* Along the ridges the forest disappears rapidly with altitude, and most of the ridges below 2,000 feet are clothed here and there by ironwoods and grasses, or are entirely bare.

The northeastern corner of the island, from Hakahetau to Hakahau, is the *fenua ataha* of Uapou (pl. 3, *A*). Deforestation has been due largely to the herds of wild donkeys, for which this island is famous, and to some extent to the goats. In December 1929 and November 1931 wide expanses of this region were found to be completely denuded of vegetation and even of the surface soil. Here and there a few patches of trees were seen, but the upland region between Hakahau and Aneo is veritable desert, more desolate than any other region that I have seen in the Marquesas, excepting only the uplands of Eiao.

The population of Uapou in 1931 was about 380. The principal villages are Hakahetau and Hakahau, with some 100 inhabitants each. The Pacific Entomological Survey had its headquarters on this island at Hakahetau, and most of the collecting at low levels was carried on in Pepehitoua Valley above this village. The horse trail up this valley

ends at Papaika, at about 1,000 feet above sea level, but a footpath can be followed through the staghorn fern (*Gleichenia linearis*) and tall grass (*Miscanthus japonicus*) to where the *Freycinetia* begins at about 2,000 feet. Thence a trail was cut up to Teavaituhai, on the central ridge. No region much above 3,000 feet on Uapou is accessible. It is said that the ancient Marquesans could scale many of the pinnacles, but such feats will perhaps never be repeated.

Uahuka

Uahuka is one of the smallest, the lowest, and in general the least important of the six inhabited islands. Its area is only about 30 square miles, its length 9 miles, and its breadth 5 miles. The island is roughly crescentic in plan, with a semicircular central range rising gradually from about 1,800 feet at its western end to 2,805 feet towards the east. Slightly to the west of its highest point this range is joined by a smaller ridge. There is thus a small area above 2,000 feet on Uahuka, constituting the only region in the cloud zone, on the crests of these ranges and the upper parts of their deeply dissected slopes. To the north of the main range there are steep but fairly uniform slopes to the sea, dissected by numerous small valleys. The inner southern sides are abrupt, and in the high eastern region there are precipitous slopes into the deep valleys of Hane and Hokatu. At the southwest corner of the island a small hill, Teepoepo, which is probably a recent crater, rises to nearly 1,000 feet above sea level.

The principal valleys of Uahuka are Hane and Hokatu, which together form a small amphitheater, and Vaipaee and Haave, which are long, narrow, and deeply eroded. Hane Valley is short and wide; its floor rises gradually to the foot of the steep surrounding slopes. It has three main permanent streams, which unite about 500 yards from the shore. Hokatu is similar in form to Hane, but its stream disappears below ground in dry weather, reappearing 150 yards above its mouth. Vaipaee has a flat floor, along which the stream meanders slowly at altitudes of scarcely 100 feet, more than one mile upstream. There are steep slopes on both sides of the valley. Haave is of similar form, but though its stream is intermittent it is wider than Vaipaee, and its sides are less steep. It is surprising also that there is no embayment at the mouth of Haave Valley. LeBronnec suggests that the stream from Vaikivi may once have reached the sea by way of Haave, having since been diverted into Vaipaee.

Between Hane and Vaipaee the small valleys of Hinitaihava, Hiniaehi, and Huhuapi have been sufficiently eroded to attain a flat floor at their mouths, but none of them has a permanent stream. The valleys of the outer slope of the main range are short, V-shaped ravines. Only two of them, Hanahoua and Katoahu, are said to have permanent streams.

The entire coastline, except at the mouths of the valleys, appears to be cliffed, and along the south coast there are vertical cliffs several hundreds of feet high, probably due to faulting. Off this coast are some interesting islets. Two of these, of totally different structure, shelter the anchorage at Haave. The outer islet, Hemeni, slopes steeply from its northeast side to nearly vertical cliffs more than 300 feet high at the southwest. It appears to be composed of the same reddish rock, and with beds dipping in the same direction, as the headland at Teuae. Between this headland and Hemeni is Teuaua, a low, flat-topped islet, inclined very slightly from northeast to southwest, with vertical and even concave sides from 15 to 50 feet high. It is composed of whitish rock, and has all the appearance of a "phosphate" island. It is the nesting place of an immense colony of sooty terns (*Sterna fuscata*). LeBronnec found that Tetutu peninsula is formed by rock of the same appearance. Motuhane, at the entrance to Hane Bay, he found to be composed of smoke-grey rock, different from any that he observed on the main island.

All round the coasts of Uahuka there are numerous banks which are sufficiently well known to the Marquesans to have been named by them. The depths of many of these banks at 1 to 2 miles off shore are estimated at about 30 fathoms. The depth at Tehuemana Bank, 3 to 4 miles off Teohotepapa Point, is said to be 90 fathoms, and about 18 miles east of Uahuka the charts show a bank at 35 fathoms. There is some suggestion here of a wide platform round the island.

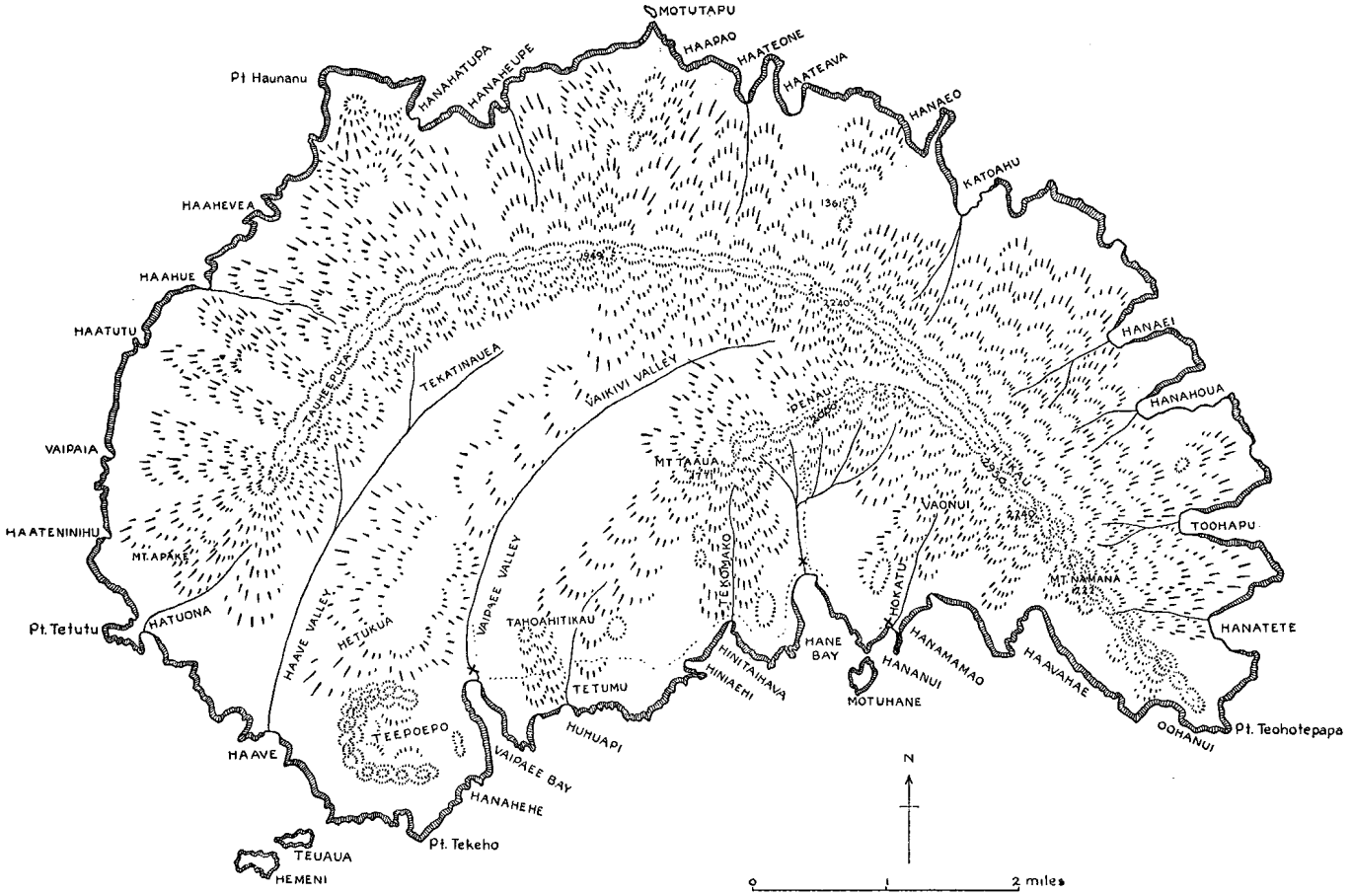

FIGURE 7.—Map of Uahuka, redrawn from a sketch map by G. LeBronnec.

The original structure of Uahuka was probably similar to that of Fatuhiva and Tahuata. A glance at the map (fig. 7) suggests that the semicircular central crest is the rim of the northern half of a crater. Analogy with Fatuhiva, Tahuata, and Nukuhiva suggests the presence of an inner cone. This may be represented by the amphitheater at Hane and Hokatu, with Penau Ridge as part of its rim. But if this is indeed a secondary crater, it differs from those of the other three islands, since it is not concentric with the major crater but has erupted on one side of it. The long valley of Vaipaee may correspond, in its relation to the two craters, to Hakaui on Nukuhiva and Hanavave or Omoa on Fatuhiva.

Lacroix (36) has examined rocks from Uahuka, and found them to resemble those of Nukuhiva. Reference has already been made to the elevated calcareous deposits in Hane Valley and at Tetutu Point. LeBronnec believes that there are signs of marine planation in a low plain, about ½ mile wide, dissected by a few ravines, along the coast between Vaipaee and Hiniaehi, and in a similar flat, at about the same altitude, between Hokatu and Hanamamao.

Teepoepo and Tahoahitikau hills, on each side of Vaipaee, were examined by LeBronnec, and he regards them as recent craters. Teepoepo crater is about 1 mile in diameter, with sides up to 977 feet above sea level; it is composed of lava, decomposing to red soil. Tahoahitikau is a flat-bottomed pit about 400 yards in diameter; its steep walls are about 800 feet above sea level on the south side and about 700 on the north. With the possible exception of Topuke on Nukuhiva, these appear to be the most recent traces of volcanoes in the Marquesas.

The extensive erosion of Vaipaee and Haave valleys is suggestive of considerable age, but it may be due to the friability of their rocks.

Because of its low altitude, Uahuka probably receives less rain than any of the other inhabited islands. There are only two valleys—Hane and Vaipaee—with streams of considerable size. The mountain flora is less rich than on any of the other inhabited islands. During the prolonged drought that ended in 1928, many wild horses are said to have perished in the barren, southwestern region.

A cloud cap forms only over the mountains towards the eastern end of the island. Rain forest covers the crests of these mountains, and the slopes and gulches for some distance below the central crest on its southern side. The forest resembles that of intermediate zones on Hivaoa and Nukuhiva. *Hibiscus tiliaceus* is the dominant tree up to the highest points; *Piper latifolium* is abundant in the gulches. There are few *Metrosideros* and *Weinmannia* trees and these are of small size. Many genera of high-altitude plants of the Marquesas appear to be absent from Uahuka. But the branches of the trees in sheltered places are overgrown with mosses and filmy ferns, and it is probable that permanently moist conditions prevail.

As one leaves the rain forest and passes west along the crest of the central ridge, the vegetation soon changes to that of dry country. *Hibiscus tiliaceus* remains dominant, but *Metrosideros, Weinmannia,* and *Freycinetia* give place to *Pandanus, Glochidion,* guava, and *Miscanthus.* The forest descends for a very short distance down the northern slopes; so far as I have observed these slopes, from above Katoahu Valley to the western end of the ridge, there appeared to be no rain forest on them.

On the south coast the valleys of the Hane-Hokatu amphitheater are well wooded. In the valleys west of Hane the forest is meager. In Vaipaee the slopes from 2 to 3 miles up the valley are barren, though along the floor of the valley there is a green ribbon of coconut palms. At Putatauua, about 3 miles up the trail in Vaipaee Valley, at an altitude of 880 feet, the forest becomes fairly rich, with numerous *Piper latifolium.* Haave Valley is arid except in its upper reaches.

The north coast being uninhabited, the slopes have been abandoned to the goats, which have deforested them from Tetutu Point on the west as far as Haavahae on the southeast, from sea level to almost a mile inland. A few trees and clumps of *Miscanthus* remain in the valleys and here and there on the slopes, but for the most part this region is covered only by low grass or is entirely bare. Most of the southwestern region, where

the rainfall is low, is barren country—the *fenua ataha* of Uahuka. The dominant plant over much of it is *Miscanthus japonicus*. The forest is limited to a few copses of such trees as *Xylosma suavolens* and *Pisonia*. Large areas are bare save for a scanty covering of *Waltheria, Sida, Cassia occidentalis,* and in rainy weather a transient growth of *Rynchosia minima.*

The central ridge is easily ascended at its western end, and the crest can be followed eastwards for its entire length. For a more direct route from Hane up to the cloud zone, a trail must be cut through dense *Miscanthus* and later through *Freycinetia,* up to the crest of Penau Ridge and so on to Hitikau. There is a good anchorage at Haave. Uahuka has probably always had the smallest population of the islands; in 1931 it was only about 130, divided between Vaipaee, Hane, and Hokatu on the south coast.

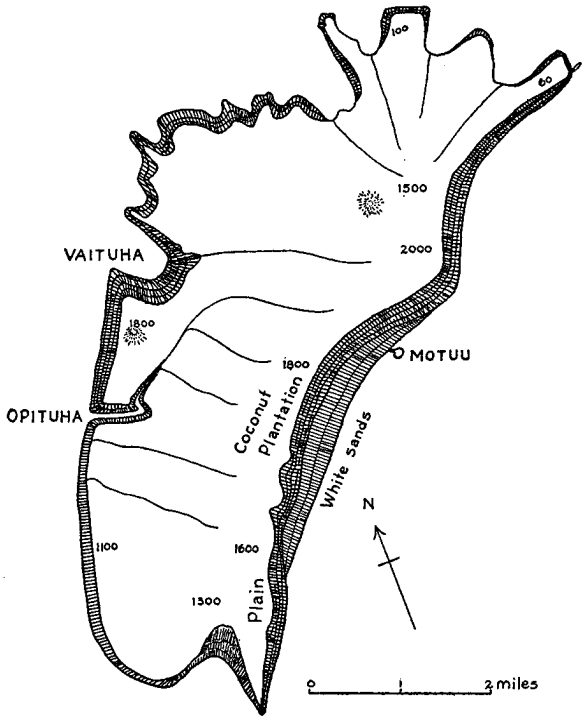

FIGURE 8.—Map of Eiao, redrawn from a sketch by G. LeBronnec.

EIAO

Eiao, Hatutu (Hatutaa), and the "Îles de Sable" constitute the uninhabited northern group of islands, between latitudes 7° 53′ and 8° 2′ S. and longitudes 140° 20′ and 140° 44′ W. All of them are little known and have never been surveyed, and the sketch maps of Eiao and Hatutu given here are rough approximations, made without instrumental observations.

Eiao (pl. 4, *A*) is slightly arcuate in form, about 8 miles long in a northeast-southwest direction by 4 miles at its widest part, with an area of about 20 square miles (fig. 8). Its maximum altitude is about 2,000 feet. The eastern side, which is slightly concave, is an uninterrupted precipitous slope more than 1,500 feet high for most of its length and reaching 2,000 feet towards the northern end. From the eastern edge, the land slopes

gently to the top of slightly lower cliffs on the western side (pl. 4, *B*). Most of the interior of Eiao is thus a plateau 1,500 to 2,000 feet high, sloping gently towards the west and south and bounded by cliffs and abrupt slopes along the northeast and southwest. The general surface of the plateau is fairly flat, broken by shallow depressions into a series of low, rolling hills (pl. 5, *A*).

Almost all the drainage is towards the west. The valleys at the north end are extensively eroded, and, though their streams are intermittent, the coastline is deeply embayed at their mouths. Vaituha Valley is a small amphitheater with steep slopes more than 1,000 feet high on three sides, the sea entering on the fourth and drowning the entire floor of the valley. It resembles on a small scale the craterlike amphitheater of Taiohae, and is the only valley of its kind on Eiao. The only permanent stream on the island drains the highest part of the plateau above Vaituha, entering this valley in a series of cascades. Its water has a brackish taste. Even during the drought that had prevailed up to October 1929, water filtered through from the slopes above the right bank of the stream a few hundred yards above its mouth, forming a small marshy area where the only land snails, other than helicinids and endodonts, were found. Prawns (*Palaemon lar*) and *Simulium* larvae were collected in the stream here, and it was surprising to find two fresh-water species which were not seen anywhere else in the Marquesas, namely the isopod *Ligia vitiensis* and an undetermined species of *Navicella.*

Opituha Valley is a narrow, sinuous canyon; its stream is intermittent, though it drains a large part of the plateau above. Its bed has been cut down to sea level at its mouth, but it is drowned for a distance of not more than a few yards from the general coastline.

At the foot of the eastern slope is a long, narrow stretch of white sand. This is one of the very few sandy beaches in the Marquesas that are not situated at the mouths of valleys. There are small beaches of sand or shingle at the heads of the bays at the northern end of Eiao. A raised shelf is well developed along the western side; south of Opituha Bay I estimated its height above sea level as about 15 feet, which is higher than any other shelf of its kind known in the Marquesas. It diminished in height and finally ended towards the south end of the island.

Eiao is possibly the remnant of the western half of a volcanic cone, the other half having been lost, perhaps by downfaulting. The steep eastern slope may be the inner wall of the crater. The vertical cliffs of the western side may be due to further faulting or to marine erosion or both. The considerable amount of erosion of the valleys, despite the small size and present low rainfall of the island, may indicate that it is of considerable age. This supposition is supported by the finding of two species of *Rhyncogonus* among many other species which are probably peculiar to Eiao, or at least belong to the characteristically endemic Marquesan fauna.

The island is too low to cause much precipitation from the trade winds. There is only one permanent stream—at Vaituha—and a few springs, one of which issues about 200 feet above the sea on the cliff just north of Opituha. But, judging by the existing vegetation, it appears that Eiao was at one time well forested, before the introduction of sheep and pigs, to which this island was abandoned some fifty years ago, and which now number many thousands, along with some cattle, donkeys, and horses. In October, 1929, after a prolonged drought, the greater part of the island was denuded of all vegetation (pl. 5, *A-B*). There was a low forest of *Hibiscus tiliaceus,* a few hundred yards square, covering the highest part of the island at the northeast, and here and there groves of *Pandanus, Thespesia populnea, Cordia subcordata,* thickets of xerophytic shrubs, and occasional large *Pisonia* and *Ficus* trees. No new growth of young trees was to be seen anywhere. The unforested parts of the plateau were expanses of bare, red, stony soil, with scarcely any covering except a sparse growth of *Cassia occidentalis,* which is apparently unpalatable to the sheep. Rapid erosion of the surface soil, in which the wind plays an important part, was evident, and bedrock was exposed in many places where the rains had cut deep channels.

A party of Tahitians engaged in planting coconuts in 1927-29 had left 5 horses on the island, and we were able to gallop almost everywhere over the island. On these trips the wide expanse of bare red earth, over which wandered great flocks of starving sheep and gaunt pigs, the open groves of grotesque screw pines, and the large *Pisonia* trees killed or injured by the donkeys seeking water in the spongy wood, all combined to give the island an appearance of indescribable desolation.

In 1931, however, LeBronnec found that a rainy period had converted much of the plateau into green prairies. A dense scrub of *Triumfetta bartramia, Ageratum conyzoides, Sida,* and other herbs covered most of the open spaces where enough soil remained. But it is obvious that in wet periods erosion must far exceed the soil formation by this transient vegetation. The extent of the "run-off" from the west coast, as viewed from the sea after heavy rain, may be judged by this extract from a letter from LeBronnec: " . . . des centaines de cascades d'eau rougeâtre, quelques-unes larges de plusieurs mètres, tombant à pic dans la mer; c'était comme si cette partie de l'île se relevait après avoir plongé dans la mer, comme on voit le faire les navires certains jours dans la tempête." It seems certain, unless the grazing animals are controlled, that the denudation of Eiao will be completed within a very few decades.

In analyzing the fauna, as it is known from the collections of 1929 and 1931, it is important to decide how much change there may have been since deforestation by sheep and other animals began. There is reason to believe that the amount of forest has been greatly reduced, and though it is possible that few if any species of trees have been exterminated, it is likely that many herbaceous species have disappeared. Deforestation must have greatly reduced the amount of water conserved, and reduced the habitats for freshwater species. Perhaps of greater importance is the destruction of the undergrowth and consequent reduction in habitats of terrestrial species that are unable to aestivate over periods when almost the entire surface of the island is parched. Possibly the reduction in numbers of individuals may have been more important than that of species of animals, but of course reduction in individual numbers affects the numbers of species likely to be collected. It will therefore be well to base few conclusions on the absence of species from our collections from Eiao.

Eiao is capable of supporting a considerable population, but whether or not it was ever permanently inhabited seems to be uncertain (30). Christian (12) mentions a tribe —the Tuametaki—which inhabited Eiao. Linton (39) states that rocks from this island were the most preferred for adz-making of any in the Marquesas, and if not permanently inhabited, Eiao probably received frequent and prolonged visits. It was used as a convict settlement until about 40 years ago, and in 1927-29 a party of Tahitians was employed to plant coconuts near the middle of the island, and around the settlement at Vaituha. A trail still leads from Vaituha to the plateau above, and near the top the building of a wide road had been begun; it has now been washed away by the rain. In 1929 the enclosure of the coconut plantation near the middle of the island was still intact and the undergrowth flourishing within it; the fence has doubtless been destroyed since then. There is a good anchorage at Vaituha, and other landing places at the south and north ends, as well as on the beach on the east side.

Hatutu

Hatutu (Hatutaa) is separated from Eiao by a channel about 2 miles wide, of unknown depth. It is 5 miles long, 2 wide, and its area is about 7 square miles. The island is crescentic in plan (fig. 9), with the eastern convex side a precipitous slope up to 1,000 feet high, and the concave western side formed by more or less vertical cliffs a few hundreds of feet high. Between these cliffs, most of the interior is a fairly steep slope, inclined from east to west, and dissected very slightly by valleys. The largest valley observed is near the middle of the island; its bed has been cut down to sea level at its mouth, and here the coastline is very slightly embayed. So far as I have observed the western cliffs are interrupted only at this point and by some small hanging valleys.

For the northern two thirds of the length of the island, the eastern crest (pl. 6, *C*) is of fairly uniform altitude, about 1,000 feet. At a distance of about one third of the length of the island from the south end, the crest flattens out to form a small level area.

The coastline is simple, and everywhere rocky except for a small beach of sand at the southern end. There is a low beach shelf along the western coast. Near the north end is a conical islet with a sharply pointed summit. Off the south end are two flat islets, at least one of which is a nesting place of sooty terns.

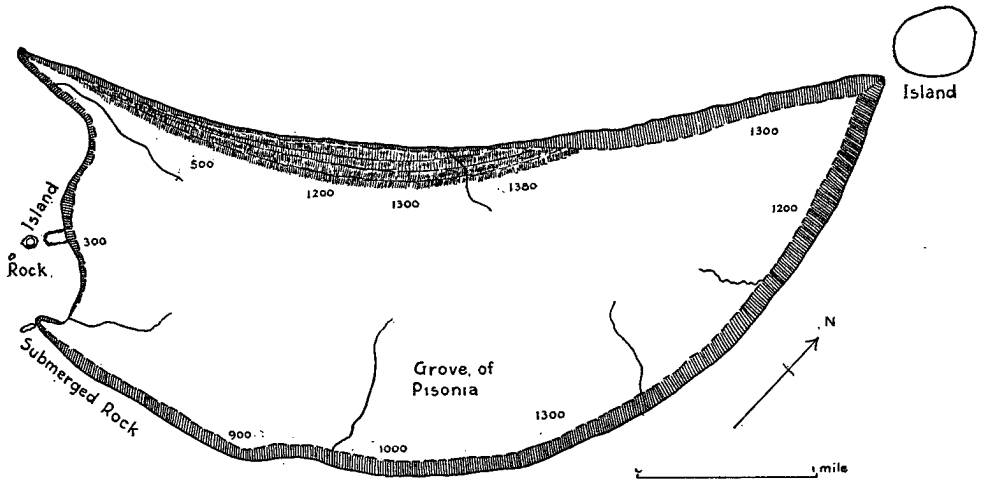

FIGURE 9.—Map of Hatutu, redrawn from a sketch by G. LeBronnec.

Like Eiao, Hatutu is probably the remains of a crater, but here it appears to be the western half that has been lost instead of the eastern half as on Eiao. It may be that the fairly steep western slopes are the inner slope of a crater, and that the precipitous eastern side lies along a line of downfaulting. Nothing is known of the petrography of Hatutu. The proximity of Hatutu and Eiao, the alinement of their long axes, and their similarity of shape may imply that these islands are of approximately the same age. The presence of the insect genera *Rhyncogonus, Proterhinus,* and *Germalus* is in keeping with the view that Hatutu is relatively old.

The climate is arid. No permanent streams or even springs are known. The dominant vegetation (pl. 6, *C*) over a great part of the island is the large tussocks of the grass *Eragrostis xerophila.* Large areas are covered by thickets of xerophytic shrubs, and the only large trees are *Pisonia,* of which there are a few groves along the top of the island and here and there on the cliffs. In October 1920 the vegetation was extremely parched; the tussocks of *Eragrostis* were entirely withered and almost the only verdure, besides a few succulent plants and one or two xerophytic shrubs, was in the *Pisonia* groves. In April 1931, however, after a long rainy period, the entire island was verdant.

Hatutu is an important nesting place of frigates, boobies, terns and other sea birds. On the western slopes the most striking features of the landscape in October, 1929, were the blood-red inflated pouches of the frigates (*Fregata minor*), which were nesting on the low shrubs and tussocks of grass.

No anchorages are known round Hatutu. There are landing places at the south end, and at the mouth of the small valley near the middle of the western side. There are no trails, but all parts of the interior are readily accessible except for the dense thickets of low shrubs. It seems certain, in the absence of permanent springs, that Hatutu was never

inhabited, but LeBronnec found several house platforms (*paepae*), some of them high up, which seemed too large to be the work of mere fishing parties. Possibly visits were prolonged during rainy periods. In historic times the island has probably been very rarely visited, and it appears to have been little affected by human activities, directly or indirectly. A ground-dove (*Gallicolumba rubescens*) is still abundant here because of the absence of introduced enemies, which have probably exterminated it on other islands. No animals or plants are known to have been purposely introduced here.

Cotar Island

About 10 miles northeast of Hatutu are one or two low islets, which are known as "Coral Island" or "Islands," "Îles de Corail" or "Îles de Sable," or, on the U. S. Hydrographic Office Chart, as Cotar Island. Very little appears to be known about this part of the Marquesas, and I did not have an opportunity of visiting it. Rollin (48) mentions "deux îles basses de corail" and the Pacific Islands Pilot (55, p. 228) describes Cotar Island as "a small coral island not over 150 feet long" and "only from 6 to 9 feet" high. Agassiz (1) quotes the statement of the Marquesans that here alone in the Marquesas is there an abundant growth of coral.

Monsieur LeBronnec landed here in 1922 or 1923, and he has sent me the following information. He refers to an island of white sand; for more than a kilometer along the side facing Hatutu there were low shrubs and tussocks of grass, in which great numbers of sea birds were nesting. He mentions a lagoon, apparently shallow, in which many fish and lobsters were caught. No pass to the lagoon was seen.

On the above evidence, it seems impossible to decide whether this island (or islands) is a small atoll, or the subsided or worn-down remnant of a volcanic island. It seems unlikely that it supports a terrestrial fauna of much interest.

Motuiti

Regarding this rocky islet, I can merely repeat parts of the description given by the Pacific Islands Pilot (55, p. 726). Motuiti (Hergest Rock) lies 27 miles west-northwest of Nukuhiva. It is 720 feet high, without landing places, and bears only a little verdure on its lee side. There are two lower rocks east of Motuiti; landings can sometimes be made on them; they are devoid of vegetation. The three rocks are surrounded by a bank of muddy sand and coral, on which depths of only 15 to 20 fathoms are found as much as two miles from the rocks.

The only biological interest of these islands would appear to be in the sea birds which frequent them in great numbers.

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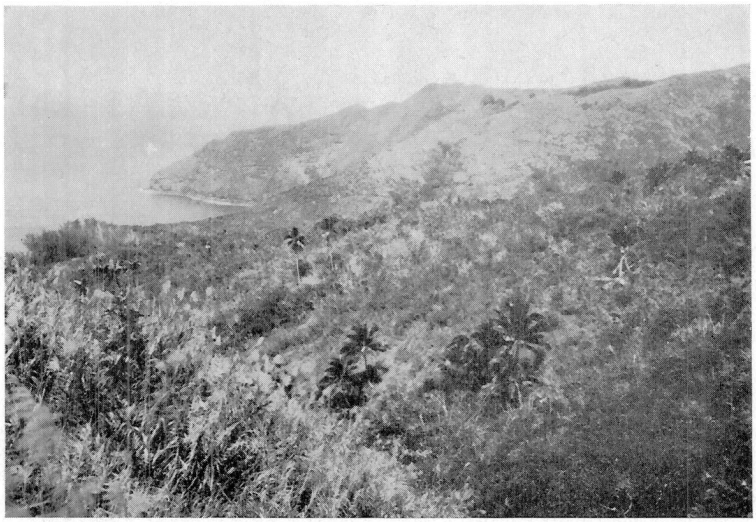
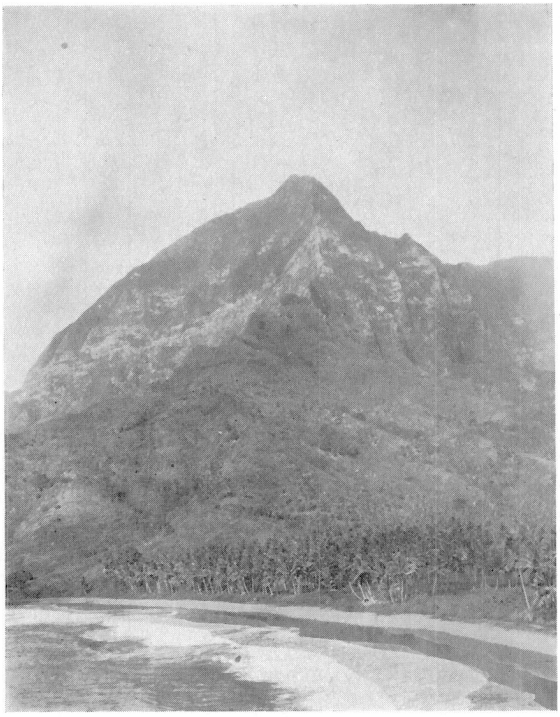


A

B

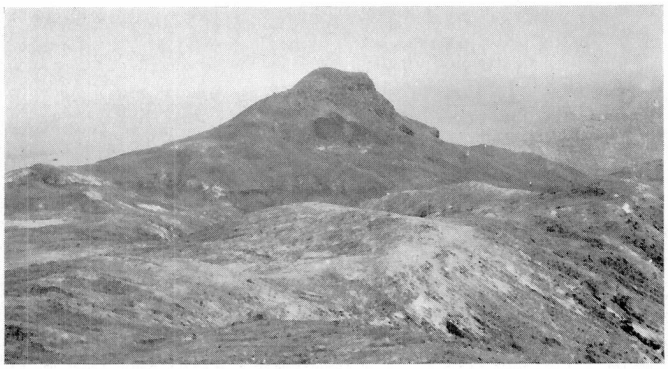
HIVAOA: *A*, NORTHERN SLOPES NEAR HANAPAOA, TYPICAL SEMI-ARID FOREST; *B*, ATUONA BAY SHOWING BEACH OF BLACK SAND, FLOOR OF THE VALLEY WITH COCONUT PLANTATION, AND IN BACKGROUND, THE INNER FACE OF THE CALDERA-LIKE AMPHITHEATER.



A

B

HIVAOA: *A*, MOUNT TEMETIU, VIEW LOOKING ACROSS ATUONA BAY FROM NEAR POINT "KERETO"; *B*, VIEW NEAR TEAVA UHIA I TE KOHU, ALTITUDE ABOUT 2,100 FEET, SHOWING DESTRUCTION OF NATIVE FOREST BY PASPALUM CONJUGATUM.



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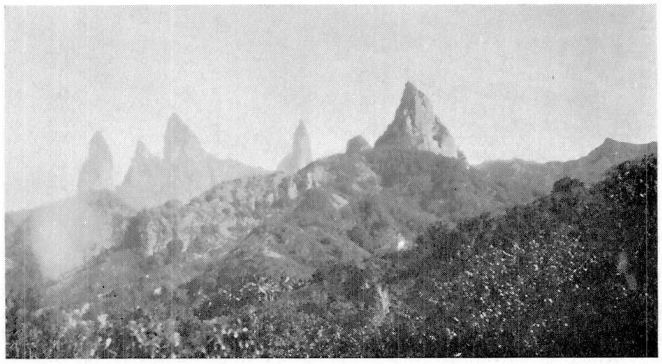
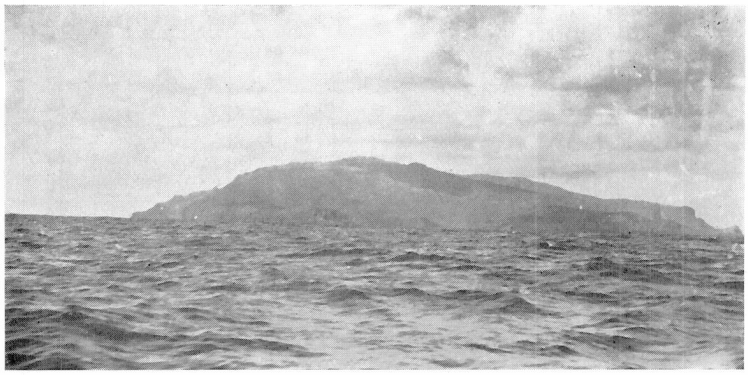


B

C

UAPOU: *A,* PART OF THE BARREN REGION BETWEEN ANEOU AND HAKAHAU; *B,* PINNACLES, AS SEEN FROM NEAR HAKAHETAU VILLAGE, LEFT TO RIGHT, POUTETAINUI, TEVATUTAI, OAVE, POUMAKA, TOUTAAMAHITI, POUTEMAKO; *C,* HAKAHETAU VALLEY FROM ITS SOUTHERN SIDE (PHOTOGRAPHS BY G. LEBRONNEC).



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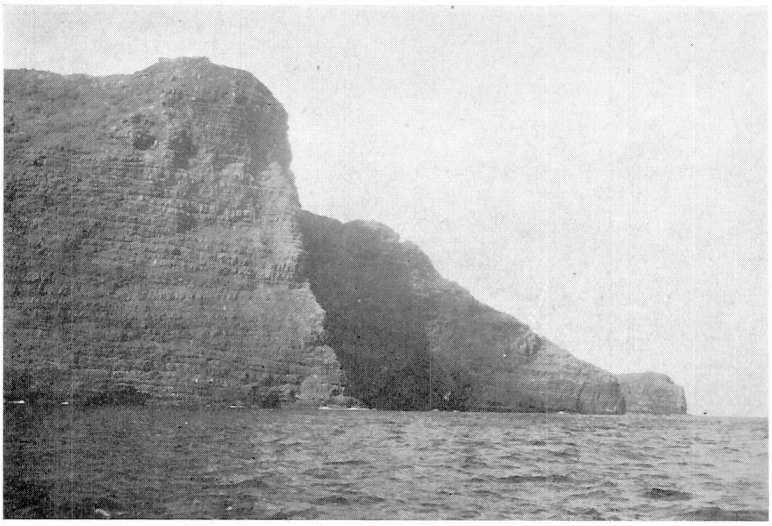

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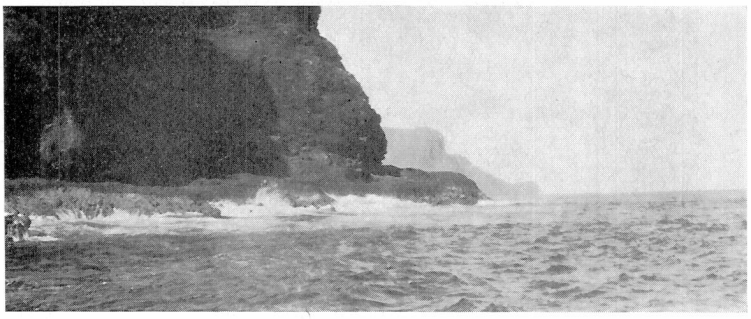
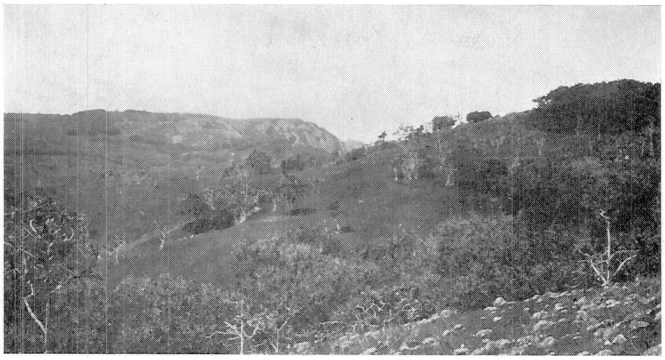


C

EIAO: *A*, VIEW FROM NORTHEAST; *B*, SEA CLIFFS NEAR SOUTHWESTERN END OF THE ISLAND; *C*, RAISED SHORE SHELF NORTHEAST OF VAITUHA BAY.



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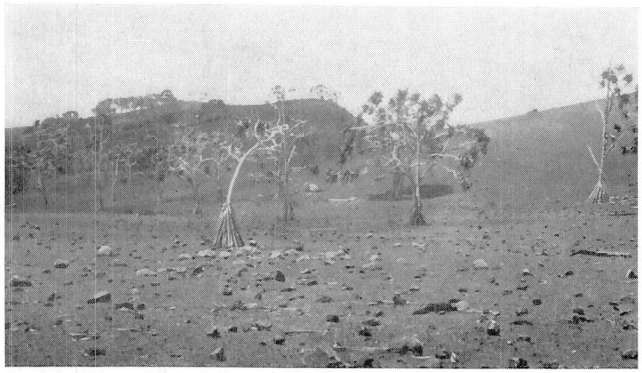

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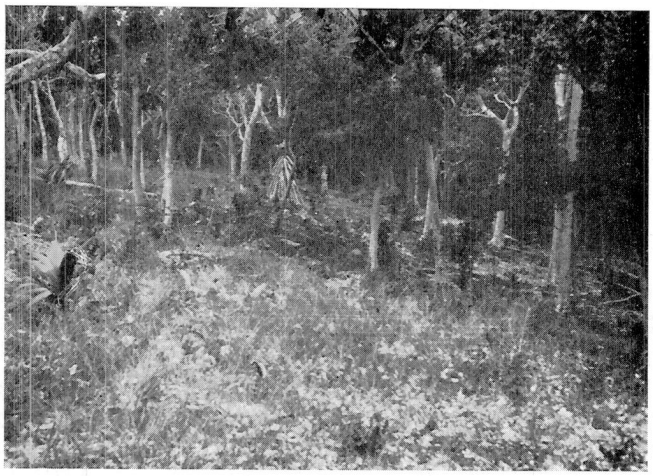
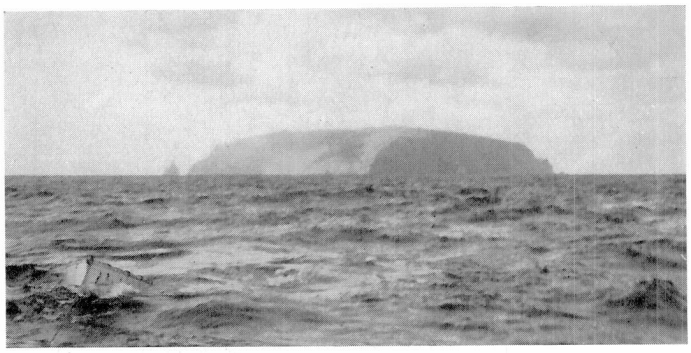


C

EIAO: *A*, UPLANDS NEAR EAST SIDE SHOWING TOPOGRAPHY AND DEFORESTATION, DRY PERIOD (SEPTEMBER 1929); *B*, UPLANDS NEAR CENTER OF ISLAND SHOWING GROVE OF *PANDANUS*, ABSENCE OF YOUNG TREES, SCANTY UNDERGROWTH MOSTLY OF *CASSIA OCCIDENTALIS*, DRY PERIOD (SEPTEMBER 1929); *C*, VIEW NEAR CENTER OF ISLAND INSIDE ENCLOSED COCONUT PLANTATION, SHOWING *SAPINDUS SAPONARIA*, *PANDANUS*, AND ABUNDANT UNDERGROWTH (OCTOBER 1929).



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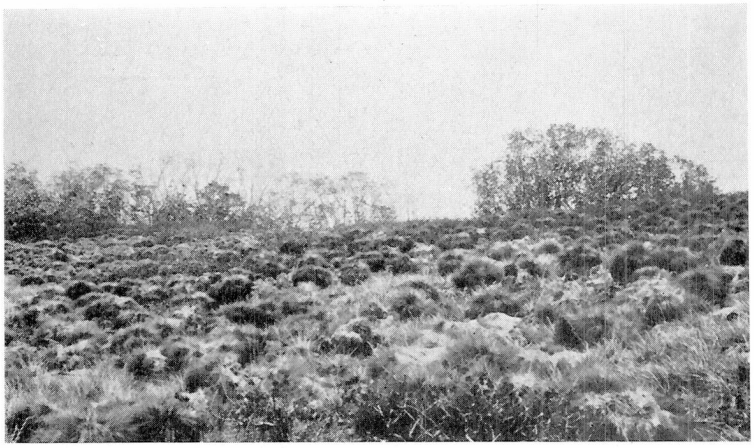
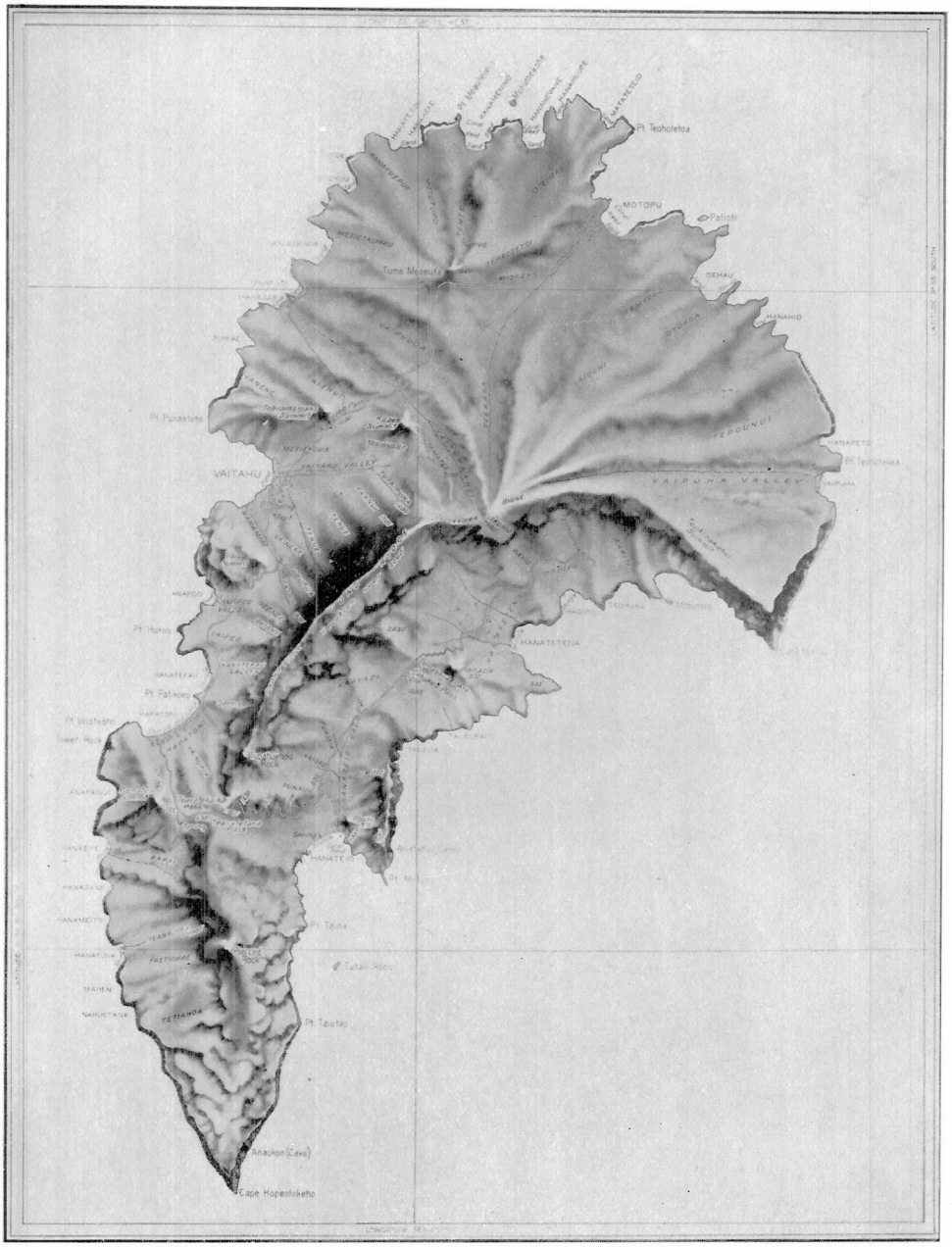


B

C

HATUTU: *A,* VIEW FROM SOUTHWEST; *B,* SUMMIT NEAR MIDDLE OF ISLAND SHOWING CHARACTERISTIC VEGETATION OF *ERAGROSTIS XEROPHILA* AND *PISONIA,* DRY PERIOD (SEPTEMBER 1929); *C,* CREST OF MAIN RIDGE AND NORTHWEST SLOPE, NEAR MIDDLE OF ISLAND, SHOWING *ERAGROSTIS XEROPHILA,* XEROPHYTIC SHRUBS, AND GROVES OF *PISONIA,* DRY PERIOD (SEPTEMBER 1929).



AIR BRUSH REPRODUCTION OF SKETCH MAP OF TAHUATA (FIG. 2) PREPARED BY THOMAS BROTHERS AND FRANK W. DAY.

AIR BRUSH REPRODUCTION OF SKETCH MAP OF NUKUHIVA (FIG. 5) PREPARED BY THOMAS BROTHERS AND FRANK W. DAY.