GEOLOGY OF EUA, TONGA

BY

J. EDWARD HOFFMEISTER

INCLUDES

PETROGRAPHY, BY HAROLD L. ALLING

FORAMINIFERA, BY G. LESLIE WHIPPLE

BERNICE P. BISHOP MUSEUM

BULLETIN 96

HONOLULU, HAWAII

PUBLISHED BY THE MUSEUM

August, 1932

CONTENTS

ILLUSTRATIONS

TABLES

Geology of Eua, Tonga

By J. Edward Hoffmeister

Includes

Petrography, by Harold L. Alling

Foraminifera, by G. Leslie Whipple

INTRODUCTION

EXTENT OF INVESTIGATIONS

The present report is one of a series of papers embodying the results of recent expeditions to Tonga under the auspices of Bernice P. Bishop Museum.[1] Brief preliminary reports of the geological findings of these expeditions have already appeared (41; 43; 44; 46; 48; 49).[2]

In 1926 two months on Eua, one month on Tongatabu, and a few days on Vavau were given to geological investigation. In 1928 field work was continued for two weeks on Eua, two weeks on Tongatabu, two months on Vavau, and one month on Viti Levu, the large island of Fiji.

Tonga, an archipelago of about 150 islands, is located in the South Pacific Ocean in latitude 18° 5′—22° 29′ S. and longitude 174°—176° 10′ W. As previous writers have pointed out, most of the islands fall roughly into three groups, southern, central, and northern. The southern group comprises Eua, Tongatabu, the largest of all the Tongan islands, and several smaller islands. The central or Haapai group which lies about 50 miles north of Tongatabu consists of four parts. The southern part includes Mango and Nomuka and numerous smaller islands that surround them; the northeastern part includes Lifuka and other long, low, flat limestone islands; the western part includes the volcanic islands of Kao and Tofua, highest of all the Tonga islands, and in the center is the Kotu subgroup of small islands. The northern or Vavau group, to which the westward lying island of Late may be considered to belong, terminates in the large island of Vavau itself.

ACKNOWLEDGMENTS

The investigations which form the subject of this report were made possible by the grant of a Bishop Museum Fellowship by Yale University.

[1] The program and personnel of the Tongan Expedition under the leadership of Professor W. A. Setchell is described in the Annual Report of the Director (B. P. Bishop Mus., Bull. 41, pp. 27-29, 1927; Bull. 65, pp. 21-22, 1929).

[2] Numbers in parentheses refer to the bibliography, pp. 87-90.

I wish to express my appreciation to Dr. Herbert E. Gregory, Director of the Bishop Museum, for help and encouragement during the progress of this work. I wish also to thank Dr. William A. Setchell, Professor of Botany, University of California, whose generosity, kindly interest, and enthusiasm have ever been an inspiration. The people of Tonga, both native and European, were most helpful and rendered assistance in every possible way. I thank especially His Royal Highness, Prince Tugi, Premier of Tonga, for many courtesies extended me. Mr. and Mrs. Niels Johanssen made my stay on Eua one of the pleasantest experiences of my life. Mr. and Mrs. Powell of Eua were also most kind. Above all to my friend, Dr. Harry S. Ladd, who spent two weeks with me on the island, do I express my sincerest thanks for the aid and advice he has given me. My native guides, Charlie Hama and Harry Terepo, were most helpful and faithful in their work.

Drs. T. Wayland Vaughan and J. J. Galloway have aided materially in the age determinations of the rocks, Dr. Joseph Cushman was kind enough to examine the smaller foraminifera, Dr. G. Leslie Whipple has prepared the report on the larger foraminifera (p. 79) and Dr. Harold L. Alling, head of the Geology Department at Rochester, has kindly prepared the report on the igneous rocks of Eua (p. 39).

I wish to thank my colleagues of the University of Rochester for relieving me of teaching responsibilities for three months and thus permitting longer field seasons. Thanks are also due to the United States National Museum for permission to use the large coral collection stored there.

Dr. Anders Orbeck, Professor of English at the University of Rochester, generously gave of his time in constructive criticism of the manuscript, and Miss Evelyn Newman, Mrs. Marion Moore and Miss Marguerite Lyon, artists at the same institution, have aided materially in the drawing of maps and figures and in the preparation of the manuscript.

PREVIOUS WORK

Captain Cook (13, p. 259) who visited Eua in 1773, and again in 1777, gives a description of the island, which had previously been called Middleburg by Tasman. He reported finding coral rock up to the very summits of the highest hills where "the soil is, in general, a reddish clay."

Dana (17, p. 337) in a reference to Eua records some observations made from shipboard. He states that three distinct terraces could be seen and that from the general appearance of the land he judged the interior to be basaltic. He also records that the shores are surrounded by an elevated layer of coral reef rock, twenty feet thick, worn out into caverns, and punctuated with many spout-holes.

In his revision of Darwin's work on coral reefs Bonney (18, p. 213) classes Eua with islands having a fringing reef.

In 1888, Eua was surveyed by a party from H. M. Surveying-Ship *Egeria* under the command of Captain Pelham Aldrich. Commander Oldham (67) of the *Egeria* in a brief description points out that the island has a volcanic nucleus upon which limestone has been deposited. One of his important observations is that the limestone of the upper part of the island is "foraminiferous" and that the higher part of the western terrace or Western Ridge (as it is called in the present paper) is composed of coral reef rock. Oldham's paper (67) includes a note by Professor J. W. Judd:

> . . . the limestones, some of which are fairly crystalline in character, are composed of Foraminifera and waterworn fragments of calcareous algae . . . Although the rocks forming the nucleus of the island are of igneous origin they are not modern volcanic materials. They consist of much altered glassy andesites (porphyrites) with epidiorites; and are suggestive of ancient volcanic masses which have been exposed at the surface by denudation.

Relatively little information, however, had been gained on the geology of the island until the appearance of the excellent paper by Lister (54) who gives a general description of most of the Tongan islands and a fuller account of a few of the more important, including Eua. Harker (39; 40) made a study of some of the igenous rocks collected by Lister.

Agassiz (2, p. 180), who visited Tonga during the winter of 1899-1900, describes the terraces on the eastern and western sides of Eua and also stresses the origin of the Central Valley.

Within the last few years Eua was mapped by the Surveyor of the Tongan Government, who paid particular attention to the coast line and to the boundaries between the lands of the natives. The drainage was not accurately shown, nor was topography considered.

The most recent reference to Eua, of any importance, is by Davis (19, p. 415), who describes Eua as an elevated atoll-crowned island.

CLIMATE

No meteorological records are available for the island of Eua. The precipitation is doubtless much like that at Nukualofa 12 miles northwest of Eua, where, as tabulated by Reed (70), the mean annual rainfall is 88.55 inches and the monthly rainfall ranges from 2.18 inches (July) to 14.78 (February).

Temperatures at Eua are probably like those at Alofi on Niue Island, 250 miles east of Tonga. At this station the mean annual temperature for the period 1910-1918 is 76.7°, the mean maximum 85°, the mean minimum 68.5°; the highest temperature (97°) was measured in January; the lowest (54°) in July.

PHYSIOGRAPHY

GENERAL FEATURES

Eua lies at the southern end of the Tongan archipelago in about latitude 21° 20′ S. and longitude 175° W. Its long axis, roughly 12¼ miles, lies nearly north and south. From a maximum width of about 4½ miles near the middle it tapers to points at the two ends. (See fig. 1.)

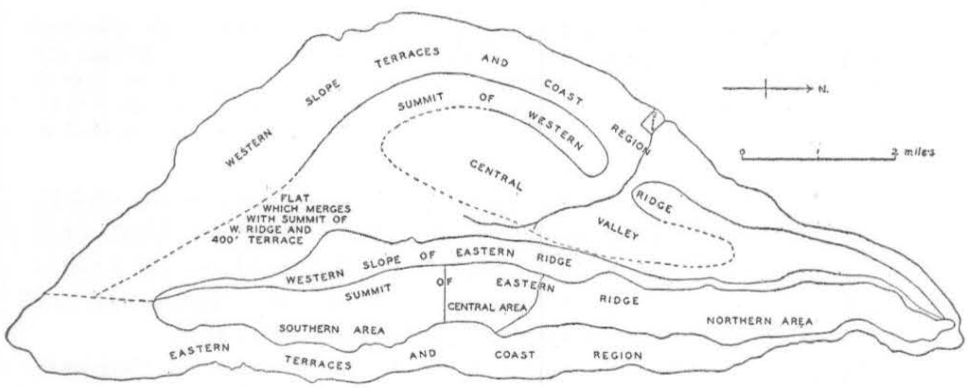


FIGURE 1.—Map of Eua showing physiographic provinces.

A high ridge extends along the eastern side of Eua for nearly its entire length. The eastern or windward side of this ridge is lined by steep cliffs interrupted in places by terraces. The western side slopes more gently toward a central valley. The highest points of the island are located on this ridge. The greatest elevation (Station H. P., fig. 2) is 960 feet, according to aneroid measurements.

A lower ridge with a maximum elevation of 400 feet along the western side of the island follows the curving contours of the coast. The ground slopes gently on both sides of the ridge, westward to the sea, and eastward to a central valley which lies between the eastern and western ridges. The valley becomes shallow at its northern and southern ends, where it gradually merges with the western ridge. Figure 4 represents the approximate profiles across Eua along the lines shown in figure 3.

For convenience in presentation Eua may be divided roughly into five physiographic provinces, fringing reef, coast region, Eastern Ridge, Western Ridge, and Central Valley.

FRINGING REEF

Eua is nearly surrounded by a narrow fringing reef that has an average width of 200 feet on the western side and 100 feet on the eastern. In general the reef consists of a seaward edge which can be considered equivalent to the Lithothamnion ridge, so common to reefs of the Pacific, behind which is a reef platform, most of it covered with a few inches of standing water at low tide. The Lithothamnion ridge is different from that found bordering the average healthy fringing reef and is similar in structure to the one Lister (54, p. 615) described edging the southern and eastern shores of Tongatabu. It rises from a few inches to several feet above the reef platform and is higher in the eastern part of the island than in the western. Its seaward side, which presents an irregular, jagged outline, drops vertically to the sea (pl. 1, *B*). Its top is covered with shallow basins, in places as much as 15 feet in length and 8 inches in depth. The basins are variously shaped. Some are subcircular, but most of them are elongated with the long axis parallel to the ridge. The rims of the basins are of the same height all around and are made of living algae. Below the top basins others occur on the landward side in terraced formation until the surface of the reef platform is reached. In places, five or six tiers of basins, one beneath the other, appear. The lower basins partly surround the upper in a scalloped formation and are consequently generally concave on their seaward side and convex on their landward side. The rims of the inner basins are usually more irregular than those of the upper ones and some string out in tortuous, snake-like fashion over the seaward side of the reef platform.

The waves dash against the vertical edge of the ridge and send spray high in the air. Much of the water is caught in the upper basins, overflows their rims, and pours down to the basins below one after another until it reaches the reef platform. The water is not entirely out of the basins before another wave refills them and the process repeats itself. In this way a steady stream of water bathes the ridge, and the life of the algae is thus assured. Thus the Lithothamnion ridge grows highest in areas where the waves are strongest. Mayor (63, p. 8) has noted that in the reefs of Tutuila, Samoa, the Lithothamnion ridge is best developed along shores where the trade winds cause heavy breakers.

The Lithothamnion ridge of Eua appears to be a more pronounced ridge than the one at Tutuila. At Tutuila it is only slightly raised above the reef platform and in places is barely uncovered at low tide. Corals are much more numerous on it and Mayor makes it plain that here the Lithothamnion is merely a cementing and veneering agent for the corals and that it would not form a ridge of itself because of its slow growth. There are very few corals on the Eua ridge. About the only species seen is a flat *Acropora* with pyramidal branches about one-fourth inch in height. The Eua ridge is much more like that of Mangaia, which differs only in lacking the basin structure. In both islands the ridge is a spongy structure although fully capable of resisting the force of heavy waves. Marshall (55, p. 10), in describing the ridge at Mangaia, calls attention to this fact and states that the knobby, spongy condition is far more effective in stopping the heavy surges than a more solid structure, as the force of the waves is more widely dispersed. The Lithothamnion ridge is the advance guard of the reef. It is here that the active reef growth takes place. Mayor (63, p. 8) has pointed out that "where the breakers become spent the Lithothamnion dies out and here the ridge disintegrates into jagged limestone masses which become detached and are washed shoreward over the reef flat by the surges." The corals which grow in the tide pool areas behind the ridge play very little part in the actual construction of the reef itself.

The reef platform is covered with a few inches of water and consists then of a large tide pool with the Lithothamnion ridge at its seaward edge and an old, recently elevated reef to the landward. Its bottom is a solid mass of calcareous algae, on the whole smooth, but interrupted in places by depressions one foot or more deeper than the common level. Near its landward edge the reef platform is in a less healthy condition; it is more indented with depressions and is covered with a thin layer of sand and silt. In this location nodular and massive *Porites* are numerous. There are relatively few corals on the reef platform. Isolated clumps are scattered around particularly in the reef depressions.

There are more corals on the reef in front of the town of Ohonua than at any other place examined. Here the width of the reef is 150 feet, there is no distinct Lithothamnion ridge, the corals grow in large numbers at the seaward edge, and the reef flat is exposed at low tide because of the absence of a seaward rim. *Acropora* is the dominant genus of the seaward edge and is accompanied by *Pocillopora*. *Acropora sarmentosa* (Brook) is one of the common species. The *Lithothamnion* acts here as a binder. In a shoreward direction the corals become less numerous, only isolated patches here and there on a *Lithothamnion* basement. *Psammocora, Pocillopora, Acropora,* and nodular *Porites,* chiefly *Porites lutea* Milne Edwards, are present, *P. lutea* becoming more and more abundant as the landward edge is approached. A few hundred feet from this area in both a north and a south direction the corals become less numerous: the *Lithothamnion* ridge is prominent and the reef platform fills with water. This condition continues nearly all the remainder of the way around the island except in a few places where there is no visible reef.

On the "liku" or windward side, where the cliffs approach the sea, there is in many places a boulder beach made of large blocks which have fallen from the cliffs. Many of the blocks have been carried out beyond the beach and are partially or totally submerged with water. The waves have truncated them to a flat surface on which *Lithothamnion* has grown. This *Lithothamnion* has the same basin-like structure as elsewhere around the island and the reef here is thus composed of a boulder basement. Between the reef patches formed in this way corals and algae gradually grow up to the surface level, knit the isolated blocks together, and make a continuous pavement. I believe that boulders play an important part in the early formative stages of many reefs. Excellent examples of this method of reef formation are the reefs on the northern coast of Vavau.

Beyond the outer edge of the reef there extends a submarine shelf which is probably 200 feet or more in width. Its surface, which apparently lies about 30 feet beneath the sea level, is rough and cut with irregular channels which approximately parallel each other in a seaward direction. This shelf can be seen in many places from high points all along the Liku side. A good deal of it is probably a platform made by wave erosion. This platform, together with boulders which have rolled over it, has probably been covered with *Lithothamnion* and a few corals. The channels have been made in all likelihood by the erosive action of the water on its return seaward. The same action has been observed on the barrier reef off Suva, Fiji, where in places deep gullies have been cut in the reef by the returning water.

COAST REGION

The coast of Eua is almost entirely a cliff coast. This is particularly true along the eastern side of the island where the greater part of the coast is either of the steep cliff type, flanked or not flanked by a narrow beach, or a bay and headland type with boulder beaches opposite the bays. In some places along this side the cliffs extend from the 400-foot terrace directly to the sea. On the whole, however, they drop from the 200-foot or the 100-foot terraces. The waves have cut deep gouges and caves into the cliffs in many places where they drop directly into the sea. Probably the most striking of these is the cave known as the Matalanga, on the southeastern coast. (See p. 24.) On the western side of the island the cliffs are not so steep; their height is 20 to 30 feet, and the beaches are more numerous and broader.

In a few places no cliffs are present or if present are so far removed from the seaward edge that a beach intervenes. One of the largest areas of beach coast is in the vicinity of Ohonua. It extends northward from the village for about one-fourth of a mile and southward about a mile. At these places it is terminated by low cliffs 20 feet or so in height which extend to the sea. A considerable beach area on the eastern side in the vicinity of the Pinnacle has been called in this paper the "Liku" beach (pl. 1, *C*).

In many places around the island the beaches are edged by an old fringing reef which stands 2 to 4 feet above present high tide (pl. 1, *A*). This old reef is 100 to 200 feet in width and has been elevated by a recent negative, probably eustatic, shift of the strand line. Its surface is very irregular, filled with pits and solution cavities. Some of the cavities are 10 feet in width, 2 to 4 feet in depth, and make tortuous channels through the reef to its edge. Many near the seaward edge are filled with water to a depth of 6 to 10 inches. The old elevated reef was evidently once very flourishing. Corals appear to make up the dominant part of it. These are recent in age and belong largely to the genus *Acropora* which relates them closely to the corals of the living reefs and distinguishes them from the older coral limestones farther inland. The *Acropora leptocyathus* type with large colonies is by far the most abundant. Besides *Acropora* immense colonies of *Symphyllia, Favites, Hydnophora,* and *Porites* are present. The *Porites* colonies are chiefly near the shore edge.

At Ohonua, where it is wider than in most places, the old reef is 350 feet wide and the landward 280-foot section is covered by a low shrub (*Pemplies acidula*) which is common to the reef. Behind the reef is a narrow strip of clean beach sand not more than 10 feet broad. To the landward of this is the low, grass-covered ground on which some of the houses of Ohonua are built. South of the village the beach behind the old reef is in places as much as 150 feet broad.

EASTERN RIDGE

The Eastern Ridge may be divided into three subprovinces: 1, the Ridge Summit; 2, the Eastern Terraces; 3, the Western Slope. The whole of the ridge was surveyed by plane table in order to get the extent and location of the Eastern Terraces and also to map the various types of rock which compose it.

Ridge Summit

The Ridge Summit, about 10 miles in length, extends from a point 2 miles from the southern end of the island to within one-eighth mile of the northern tip. It is broadest near its middle and southern parts, where it averages about one mile in width. At a distance of one and one-half miles from the southern end it narrows to a width of one-half mile, and then tapers gradually to a rounded terminus which is 800 feet broad.

The southern half of the ridge in most places is 200 to 250 feet higher than the northern half. Station H. P., the highest point on Eua, is, according to the Admiralty Chart, 1078 feet above sea level. According to aneroid readings taken by different instruments, it is only 960 feet. The second highest point (Parkers Hill) is near the middle of the ridge, at the high hill east of Parker's old sheep ranch, where the aneroids recorded 940 feet. (See pl. 2, *A*.)

As a whole the ridge summit is an open, grass-covered area on which bands of semiwild horses run. Scattered over its surface, however, particularly in the middle and southern parts, are patches of dense vegetable growth with closely placed *Lantana*, indigo, and even large trees which are covered with hanging vines. It is difficult to cross these patches without cutting the way with a coconut knife. Most of the patches are subcircular in outline, covering sink holes, or are elongated following the course of a stream.

There are three distinct areas of the Ridge Summit, the central, the southern, and the northern.

The central region is by far the most rugged. High, round-topped, treeless hills occupy the dominant positions. Most of these are covered with a thin coating of short grass. Many smaller, butte-like hills, a few of which are bare of vegetation, are scattered between the high ones. Erosion is rapid in this region. The streams have their origin in the high eastern edge, which contains the second highest point on the island. Most of them flow toward the west across the summit and then down to the central valley. A few, however, flow in an eastward direction down the precipitous slopes toward the terraces below. Most of these streams contain water only at times of very heavy rainfall. All are covered with dense vegetation which effectively hides their channels—deep, V-shaped gorges, in places as much as 100 feet deep. In order to cross this central region in a north-south direction, at least one of these thickly vegetated gullies must be crossed unless the traverse is made in the high area at the extreme eastern edge.

The central area grades into the southern part of the ridge, to which it is more closely related than to the northern. The southern part, roughly 3¾ miles long, extends from the locality of Station 105 and continues to the extreme southern tip of the ridge. A high narrow ridge of limestone (pl. 2, *B*) forms the backbone of this area and extends for the greater part of its length along the eastern edge of the summit, where it is flanked by steep cliffs on the seaward side. On the western side it slopes gently to the undulating surface of the main part of the summit. In one place near the middle of its length it leaves the eastern edge and occupies a more central position on the summit so that the relatively narrow 760-foot terrace separates it from the precipitous cliffs on the east. Where thus separated it has been cut by erosion in places so that its presence is indicated by a row of elongated, isolated hills with the long axis in a general north-south direction. Farther south it swings back again to the eastern edge and holds this position to the end of the summit. In many places this ridge is no more than a thin wall of bare limestone 4 or 5 feet above the general level of the summit and continuous with the steep eastern face leading to the terrace below. In other places, particularly where it is separated by a terrace from the eastern edge, it is considerably thicker and higher.

The ground slopes gently from this rock backbone to the west side, which is 50 to 100 feet lower in elevation. The average height above sea level of the eastern edge is 800 feet and that of the western edge, 700 feet. The sloping ground to the west of the high eastern edge is mainly open, in most places covered with short grass and dotted with limestone stacks and pinnacles, which protrude from the soil level to heights of 1 to 12 feet. (See pl. 2, *C*.)

About halfway across the summit the pinnacles disappear and an irregular, undulating topography succeeds. In this area there are some subcircular or elliptical depressions which are filled with water except during times of severe drought and which serve as watering troughs for the numerous wild horses which roam the summit. Scattered over the area are patches with thick vegetation and others which are bare of grass.

The extreme southern tip of the ridge is flanked by a vertical cliff which rises from about 500 feet to the summit level of 800 feet.

The northern part of the ridge is relatively low, 500 to 650 feet in height, and is of about the same elevation throughout its length. (See pl. 3, *B*.) As viewed from the high central area it has the appearance of an undulating terrace and was in fact referred to by Lister (54, p. 598) as "terrace *b*." The otherwise rather level appearance is marred by a single hill known as Tee Moa which rises from the general surface to an elevation of 740 feet (see pl. 3, *A*) at a point near the middle of the terrace, about 400 yards north of Parkers Hill in the central area. The eastern edge of the flat is slightly higher than the average level, and, as in the southern area, forms the tops of the precipitous limestone cliffs which bound it on this side. From this edge the land slopes down slightly in a westward direction and rises again near the middle to a low rounded ridge which runs in a north-south direction. In many places this ridge cannot be detected, the middle of the summit being occupied by a flat or undulating volcanic area. From the middle of the summit the land either slopes down gently and then rises to a slightly higher western edge or continues to slope gradually down till the edge is reached.

Nearly the whole of this part of the summit is open, grass-covered country, dotted here and there with a few patches of thick shrubs and isolated coconut palm or *Pandanus* trees. The undulations of the surface are due in large part to sinks made by limestone solution. A few subcircular lakes, one or two as much as 200 feet in diameter, occupy positions in the volcanic areas. In some of the sinks and scattered over other parts are small pinnacles of limestone similar to those on the southern part of the summit, although in general not as large.

One physiographic feature of interest which appears in all three parts of the summit is the curious limestone wall which marks the eastern edge of the area and which is continuous with the perpendicular cliffs along the edge (pl. 4, *A*). This wall stands up like a bulwark. It is made of extremely hard, jagged limestone and is covered here and there by dense shrubbery. In some places it is 30 feet high and 50 feet broad at its base; in others it is only 3 or 4 feet high and 2 feet broad at its base and tapers upward to a jagged, serrated edge. It provides an ideal railing from which to view the rugged coast and terraces on the east side.

It appears that this limestone wall is purely a product of erosion. Water falling as rain on the summit has eaten away the limestone back from the edge first. This has directed the drainage away from the eastern edge which has been permitted to remain. In a few places it has been entirely worn away, but for the most part it stands as a substantial wall. This is the character of part of what has been referred to as the "rocky backbone" of the southern half of the summit.

Eastern Terraces

Along the seaward or "liku" side of the Eastern Ridge the descent to the sea is made by sheer limestone cliffs interrupted by a series of wonderfully well-defined terraces. This whole side has the aspect of a gigantic limestone staircase. The view from the ridge top is one of the most magnificent in all the South Seas. (See pl. 4, *B, C*.) The extent of each of the terraces was mapped in some detail and the rocks composing them examined.

There are in all six clearly cut terraces. No one of these extends unbroken along the whole length of the ridge. Those of the same elevation are scattered at intervals along the coast. In some places they may be very narrow, mere fragments of their original size, and in other places they are over 1500 feet broad. The extent of each terrace is shown on the map (fig. 2).

Beginning with the lowest and going to the top part of the ridge, I found the average altitude of the various terraces above sea level to be 100, 200, 340, 400, 550, and 760 feet. The 550-foot terrace which occupies nearly the whole northern half of the Ridge Summit was called "terrace *b*" by Lister (54). It differs from the other terraces by its rougher, more undulating surface, ranging in elevation from 500 to 650 feet above sea level. All the other terraces, with the exception of the 760-foot terrace, are confined to the eastern side of the ridge. The 100-foot terrace is narrow but rather persistent. The 200-foot and 400-foot terraces are the broadest and most easily recognized. The 340-foot flat is narrow in all places where it was observed and in many places grades up toward the 400-foot terrace. The 760-foot terrace is narrow and is confined to the southern part of the island, where it is found on both sides of the ridge.

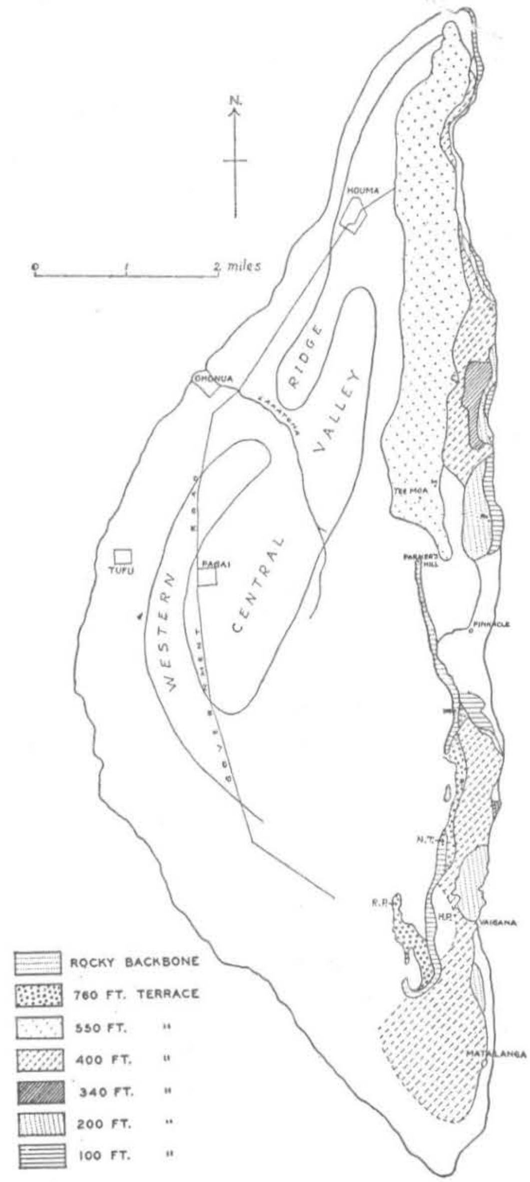


FIGURE 2.—Map of Eua showing the eastern terraces and what has been called the "Rocky Backbone."

The surfaces of most of the terraces are remarkably smooth. Some show limestone pinnacles, similar to those of the summit, protruding above the otherwise even top. They are mainly covered with dense vegetation so that it is difficult to traverse them. The 400-foot terrace extends around the southern tip of the island as a broad flat. So dense is the vegetation here that on one occasion even my native guide became hopelessly lost and we had the unpleasant experience of spending the night in the bush. In some places, however, as on the northern part of the 400-foot terrace, there are open grass lands with a few *Pandanus* or coconut trees dotting the surface.

Most of the terraces slope slightly seaward. Near the foot of each cliff there is in most places a slope leading to the terrace level beneath. This slope is mainly made of talus from above and is much larger where the cliff is of volcanic material than where it is of limestone. The limestone talus is insignificant and may even be lacking.

There are but two diminutive streams which run eastward across the terraces. One of these is near the middle of the island, and the other, the Vaigana, cuts part way across the 400-foot terrace in the southern half of the island, goes underground, and emerging from the side of a cliff at an elevation of about 160 feet, plunges as a small waterfall into the sea. This stream is one of the best-known landmarks of the island and bears no less than four names in its short course.

Western Slope

The western side of the Eastern Ridge is very different from the eastern side. Instead of the vertical cliffs and cleanly cut terraces there is a relatively gentle, heavily wooded slope, steep in places, leading from the ridge edge to the Central Valley or plain below. The drainage along this slope is mainly confined to the middle area. No streams empty into the valley along the side for the entire length of the 550-foot terrace, and no streams traverse the southern part of the slope. In between these areas three, probably more, permanent streams flow through steep, V-shaped gorges so covered with masses of thick vines, trees, and grasses that it is an exceedingly difficult matter to trace them to the Central Valley.

In this central area the slope westward is in places halted abruptly by a vertical cliff. (See p. 27.) In places along this side some ill-defined terraces can be made out, but so poorly preserved that they cannot be definitely correlated with those on the eastern side of the ridge.

WESTERN RIDGE

The Western Ridge runs parallel to the west coast of the island. It is on the whole flat-topped, with an elevation of 300 to 350 feet and with moderate slopes leading westward to the shore and eastward to the Central

Valley. It is divided into a northern and a southern half by a gap through which a stream, called by the natives "Lakatoha," flows westward out of the Central Valley and reaches the sea on the northern side of the town of Ohonua. At this gap the distance between the two ends of the ridge is about one-half mile.

To the north the Western Ridge widens rapidly so that at a distance of a little over a mile it is no longer a ridge, but a flat which extends to the foot of the Eastern Ridge. On this flat, 300 feet above sea level, is located the town of Houma. The flat continues to the northern tip of the island, curves around, and merges with the 400-foot terrace of the Eastern Ridge.

The Western Ridge broadens more slowly to the south. It keeps an average summit width of a little less than a half-mile for the distance of about two miles and then merges just south of the town of Pagai into a flat which extends to the Eastern Ridge. As at its northern end, this flat rises and becomes continuous around the southern end of the island with the 400-foot terrace.

Along the seaward slope of the Western Ridge some terraces can be easily distinguished, although they cannot be traced with accuracy for any distance. At the town of Ohonua the ground rises gradually to an altitude of 110 feet. Following this in an eastward direction there is another gradual rise to 150 feet, which is the level of the extreme rear of the town and the government road which leads to Pagai. Beyond this, in turn, toward the gap in the ridge, the Central Valley with an altitude of 170 feet is reached. This continues as a flat or slightly undulating area around the ends of the Western Ridge into the Central Valley. From the flat the ends of the ridge rise sharply to a height of 310 feet.

In this flat the Ohonua stream, Lakatoha, makes a deep V-shaped ravine with precipitous sides. The width of the ravine at its top is about 400 feet. Its bottom is loaded with fallen blocks, some of which are as much as 50 by 30 by 30 feet and can easily support trees 50 feet in height. It is a place of great beauty; lianas, tree ferns, and many other types of tropical foliage give shade and coolness. In the bottom are pools of standing water 2 or 3 feet deep. Fresh water flows in the stream only at times of rainfall, but the sea backs into its mouth through a gap in the fringing reef and goes inland for some distance, forming a small sound or estuary.

The government road from Ohonua leading south in the direction of Pagai climbs gradually the western side of the ridge until it reaches the summit altitude of 310 feet at a distance of about one mile from Ohonua. It follows the summit for a short distance and then drops to the east of it to the elevation of 285 feet. It runs parallel to the summit along its eastern side to beyond the town of Pagai, which is of the same level, and then climbs once more to a maximum height of 350 feet. It continues at this elevation for about one and three-quarters of a mile, and then descends gradually to the western face of the ridge.

CENTRAL VALLEY

Central Valley is a gentle depression between the Eastern Ridge and the Western Ridge. (See pl. 3, *C*.) Its deepest part, at an elevation of 170 feet above sea level, lies opposite the town of Ohonua. From this vicinity it becomes gradually shallower to the north and to the south until its bottom reaches the elevation of the Western Ridge. The whole area, including the Western Ridge, is similar to a flat which has been scooped out in the center while the margins have been permitted to remain. Lister described it as "terrace *a*" and spoke of the Western Ridge as its western border.

Most of the valley bottom is covered with dense brush and trees. Here and there, however, open, grass-covered spots appear. Its surface is in general rather flat or slightly undulating except for the steep-sided ravine, about 60 feet deep, made by the stream, which runs parallel to the ridge in a northward direction before it turns westward toward Ohonua. At least two other ravines cut through the basin in the vicinity of Ohonua, and in all probability eventually join the main one.

ROCKS AND ROCK STRUCTURE

EASTERN RIDGE

Ridge Summit

Eua belongs to the group of Tongan islands which is composed of a nucleus of bedded volcanic material on which has been deposited a coating of limestone. It is possible that at one time the limestone completely covered the volcanic sediments; it still makes up the highest parts of the island. However, the limestone has been cut away in a number of places and the underlying volcanics are now exposed. The areas of exposed volcanics are on the eastern part of the Ridge Summit and in places along the Eastern Terraces and the "Liku" beach. On the remainder of the island this material is still covered with limestone.

The geologic map (fig. 3) shows the approximate outlines of the areas of volcanic rocks: tuffs, agglomerates, ash beds, and surface flows. (See p. 39.)

The chief volcanic area and the one which seems to have been closest to the focus of volcanic activity, is the high area of the central part of the Eastern Ridge. The extreme northern edge of this region is made of some high, red, volcanic hills which rise steeply but not precipitously from the 550-foot terrace immediately to the north of them. (See pl. 2, *A.*) The base of the hills is surrounded to the north, northwest, and west by limestone, and limestone encroaches a short distance on the flanks of the hills in what appears to be an ill-defined terrace formation. The eastern flanks are all volcanic and drop sharply to the level of the 400-foot terrace. The hills rise to a height of about 940 feet and thus constitute the second highest region of the island. Most of the volcanic mounds are bare or covered with a sparse growth of grass. On the top of the highest hill are some patches of limestone which have probably aided in preventing more rapid erosion.

A fresh outcrop of the material making up the hills shows it to be an agglomerate of angular fragments of lava of all sizes up to 2½ feet in diameter, embedded in a tuffaceous matrix. The bedding is obscure or wanting. Since deposition it has been subjected to considerable crushing so that thousands of small faults occur at many angles. Some small dikes 20 inches or so in width cut through in several directions. These have been weathered to a soft clay and can be traced for a maximum distance of 25 feet.

There appear to be no foraminifera or other shell-bearing organisms in the material here. In this way it differs from the tuff in many other parts of the island. This absence of fossils can be interpreted to mean that deposition here took place above water or that the sediments were laid down beneath water very hurriedly near the center of extrusion.

To the south the eastern summit continues at an average elevation of 800 feet. Volcanic material continues to outcrop at the surface except on the extreme eastern edge bordering the terraces. In places the region is heavily forested, and in others it is the most barren, forsaken part of the island, with bare, red, butte-like hills scattered irregularly over the rough surface. Here the material is distinctly bedded. Limonite has been deposited along many of the bedding planes, imparting an iron-yellow color to much of it. The rocks here are as deeply weathered and soft as those to the north. Stratification is irregular; in places the beds are horizontal, in others they dip gently or steeply in many directions. In the vicinity of Station 105 a small valley in the bare volcanic area runs about northeast-southwest. On the eastern side of the valley the dip is 45° to the east. In a northward direction the dip turns to the southeast. On the opposite side of the valley at Station 105 the beds are horizontal. It is clear that at least part of the diversity of dip is due to faulting. Small faults may be seen in certain exposures and slickensided surfaces are locally abundant. The tuffs in this locality are loaded with small foraminifera. So abundant are these that the material might be called a tuffaceous marl. Also, in the horizontally bedded tuffs at Station 105 at 690 feet above sea level a good suite of nautiloids belonging to the genus *Aturia* was found.

A short distance north of Station 105 there are some round nipple-shaped mounds of tuff capped with small patches of limestone. The limestone does not appear to be in place and shows a sharp contact with the underlying material. In one place it is in bedded form on top of the tuff. The limestone

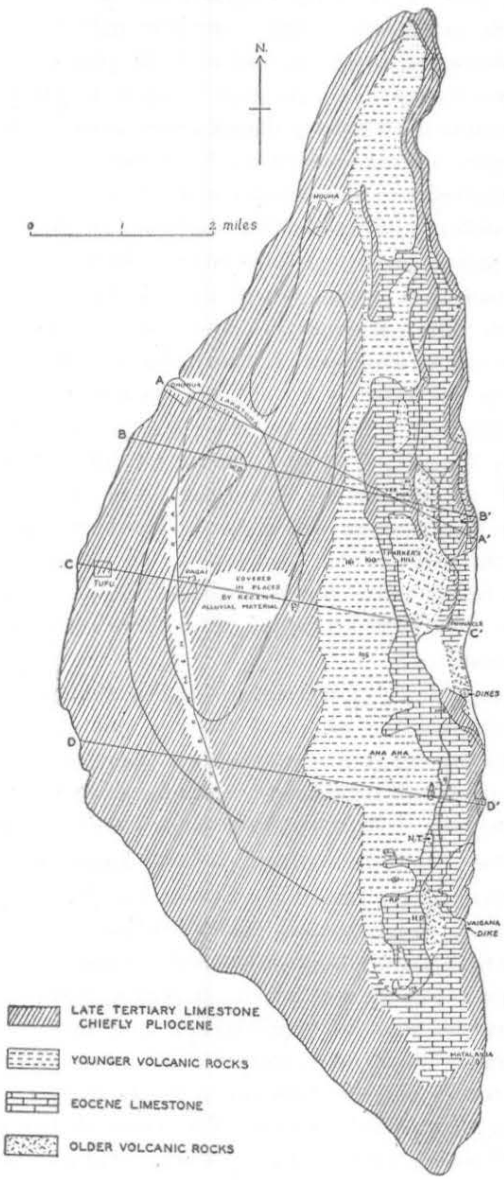


FIGURE 3.—Areal geologic map of Eua showing also the extent of most of the terraces.

beds dip 19° to the west. The volcanic beds beneath them are much disturbed, dipping at many angles in various directions. Faults run through them but do not continue into the limestone. The volcanic material contains many foraminifera, as do also the limestones above it.

The southern part of the Ridge Summit can be divided roughly into an eastern half made of limestone and a western half of volcanic tuff. The eastern half contains the pinnacles and also the limestone backbone of the island. The pinnacles (pl. 2, *C*) are gray, irregularly shaped masses of limestone, pitted by solution, with sharp, jagged edges, their surfaces covered with lichens. The largest measures about 10 by 4 feet and is 7 or 8 feet high. Most of them, however, are considerably smaller. It is obvious that they have been formed by differential weathering. Solution by rainwater has probably played the chief part in producing their present shape.

Most of the limestone of this part of the island is hard, consolidated, and rings when struck with a hammer. It is so compact that in many places no organic structure can be observed; in other places some foraminifera can be recognized; and in still others the rocks are apparently entirely made of foraminifera, as is most of the limestone that makes up the backbone of the ridge. For example, the limestones which compose the hills on which Station 108 and Station N.T. are located are somewhat softer and made of beautifully preserved, larger foraminifera which can be easily extracted. There are no corals visible in the rocks of this high part of the island. The great mass of the foraminifera belong to the genera *Discocyclina* and *Pellatispira*. Thus the limestone here is not a coral limestone as has been commonly thought, but a foraminiferal limestone.

The whole western side of the ridge including the upper part of the slope to the Central Valley is in soft, red volcanic tuff. Conical or flat-topped, butte-like hills are the results of easy erosion. Scattered throughout the area are shallow, basin-shaped depressions. In some of them water accumulates. Most of them are dry; even the largest holds water for only a short time.

In this area there are some depressions much deeper than those mentioned. Lister (54, p. 599) has described one of these, the Ana Aha or Smoky Hole. It, like the others, is funnel-shaped, and the whole upper portion, from the edge of the brim to the upper edge of the shaft, is covered with dense vegetation which forms a convex top which effectually hides the depression. A stream runs westward down the gentle incline from the brim to the shaft and then plunges straight down as a waterfall for about 200 feet. The shaft measures about 100 by 40 feet at the top and only slightly less at the bottom. The vertical sides are relatively smooth. The stream flows over solid, horizontally bedded tuff which contains many of the smaller foraminifera. From Lister's description of the Smoky Hole as "the volcanic basis of Eua" I inferred that the entire shaft was in volcanic material. I was much surprised, therefore, to find that the volcanic material at the mouth of the shaft is only 5 feet thick and that the remainder of the hole is in limestone. Here, then, is limestone underlying volcanic material in place. Evidently the water of the stream has found a crack in the limestone and has gradually enlarged it by solution and corrasion. In all probability the bottom of the shaft represents the real volcanic basis of the island and the water of the stream follows along the limestone-volcanic contact through subterranean channels until it reaches the sea.

Professor Alling describes the tuff at the top of the shaft about 5 feet above the limestone as follows:

> The slide consists of an aggregate of micro-crystalline limestone, volcanic glass, and irregular fragments of a diabasic andesite. The limestone areas show inclusions of volcanic ash and a black-brown volcanic glass. The margins of the limestone areas have experienced recrystallization with the development of rhombs of calcite. The volcanic glass is decidedly porous, having large open spaces in many cases occupied by recrystallized calcite.
>
> The fragments of igneous rocks vary from crypto-crystalline to micro-crystalline to a fine-grained diabasic rock. The minerals which can be identified in the volcanic fragments are few in number. Rods of plagioclase whose composition is uncertain, but is thought to be near andesine, and grains of altered augite and biotite are recognizable. These fragments are thoroughly weathered to secondary products, chief among which are hematite, limonite, chlorite, and sericite. There are grains of magnetite which are altered in part to leucoxene.
>
> There are one or two areas now weathered to secondary products which were obviously occupied by large phenocrysts, presumably of feldspar, judging from their shape. Some of the areas occupied by these former phenocrysts are now occupied by recrystallized calcite, and I should judge by the variable size of the grains within the fragments of volcanic rock and the occasional phenocrysts that the volcanic material belongs to the younger series. The rock may be assigned to trachyandesite.

The top of the shaft is about 550 feet above sea level. If the bottom represents the base of the limestone the volcanic nucleus of the island reaches the elevation of about 350 feet here. The finding of limestone beneath tuff explains the origin of the numerous basinlike depressions found in this volcanic area. They are merely sink holes formed by solution of the limestone beneath and lined with a layer of tuff.

The rocks of the northern part of the Ridge Summit are also of two main types, limestones and volcanic tuffs. In general, the tuffs occupy the central part of the summit and the limestones the edges. In some places along the western side, however, there is no limestone; the tuff extends to the edge and makes up the slope to the Central Valley. The sinklike depressions over many parts of the surface in the volcanic areas indicate the presence of limestone beneath. In a few places sinks go through the surface material and actually expose limestone. These, however, are not nearly as deep as those found in the southern part of the ridge.

The volcanic material is a deeply weathered, red tuff which has been considerably reworked by water and wind. It is bedded in a few places, particularly near the southern end of the flat and is similar here to the bedded tuff of the central area. Over the greater part of the terrace, however, it is structureless and soil-like with no good outcrops visible. It is difficult then to determine what part of this material, if any, represents an outcrop of the primary volcanic basis of the island and what overlies limestone.

Over some parts of this region limestone pinnacles protrude through red volcanic soil. It is clear that these are primarily limestone areas and that the red material is a combination of the products of disintegrated limestone and wind-blown and water-carried volcanic materials. Other areas are purely volcanic and show no limestone outcrops. In some places, however, the sink-like depressions give an indication of limestone beneath. In all probability very little of the volcanic rock that outcrops on this whole flat represents the primary volcanic nucleus. Most of it overlies limestone. Because of its weathered condition very little can be said of its composition.

The limestone, like that of the southern part of the Summit Ridge, is mainly confined to the eastern edge, although it also outcrops along the western side in many places and in numerous small pinnacles and blocks scattered over the more central portions. It is for the most part hard and consolidated, but nearly every fresh surface reveals some organic structure. Throughout the center of the flat, foraminifera are numerous and apparently compose the great part of the limestone. No corals are found here. In some places along the edges, however, some poorly preserved corals are found. These are typical shallow-water, reef types. Only one, *Favia pallida* (Dana) could be identified specifically, although *Orbicella, Symphyllia,* and *Leptoria* are present.

The limestone hill, Tee Moa (pl. 3, *A*), located in the middle of the flat is unusually interesting. It is surrounded at its base by a hard foraminiferal limestone, and the same kind of limestone with the same foraminifera are found nearly to its summit. Near the top it becomes more consolidated and fewer foraminifera can be seen. At the very top, at an altitude of 760 feet, I was much surprised to find a single perfectly preserved specimen of a large coral colony belonging to the genus *Maeandra.* No other corals were found on the whole hill.

It is clear that coral limestone of a reef facies is confined to the edges of the flat and foraminifera make up the central limestone areas with the single exception of the extreme top of Tee Moa. It is difficult to determine the thickness of the limestone in the center of the flat. In all probability it is thinnest at the southern end where it pinches out at the base of the volcanic hills of the central area of the Summit Ridge and becomes thicker in a northern direction.

Eastern Terraces

Volcanic rocks as well as limestones outcrop in places along the Eastern Terraces. All the volcanics here represent the primary basis of the island. The volcanic nucleus is exposed along the slopes leading from terrace to terrace and also on the eastern ("liku") beach. At the time of the formation of the terraces the waves cut through the limestone covering in several places and exposed the volcanic material. This contact is best seen beneath the highest point on the island (Station H.P.) in the southern part of the island, and at Station Monument (M) a little to the north of the central part.

At Station H.P. there is a vertical drop along a limestone wall from an altitude of 960 feet to 760 feet, at which point there is a sharp contact between the limestone and the volcanic basis. (See pl. 5, *A*.) From this point the volcanic rocks form a steep slope to the level of the broad 400-foot terrace, below which it disappears beneath the limestone and is not seen again until the sea coast is reached. Immediately below the contact the volcanic material is freshly exposed, whereas farther down it is covered by talus. The fresh exposures show various types of rocks, some soft, tuffaceous, some hard and compact, and still others conglomeritic. It is evident that some disturbance has caused small fractures in the volcanic material which have been subsequently filled with calcite. The following is Alling's description of a typical piece of the igneous material taken just below the contact:

> The rock is very much altered and it is extremely difficult to do much with it. It is a volcanic tuff exceedingly fine grained with just a suggestion of diabasic texture and fairly good-sized phenocrysts composed of oligoclase-andesine feldspars. The feldspars have been altered to sericite, scapolite, and possibly to chlorite. It evidently is composed of fragments of volcanic material now altered to a fibrous mass heavily stained with chlorite and epidote.

A similar contact was observed at Station Monument (M) on the eastern edge of the 550-foot terrace at an altitude of about 600 feet. Beneath this station there is a vertical cliff of limestone, a 43-foot drop. At its base lies the primary volcanic nucleus which slopes at an angle of about 30 degrees toward the next terrace below. The material just beneath the contact is contorted, brecciated, and filled with small faults that run in many directions. The limestone on the 550-foot terrace is only 43 feet thick. From these and similar exposures it is apparent that the volcanic rocks form slopes between the terraces and that the limestones are cliff makers.

Besides these exposures of volcanic material in the higher parts of the island, there are several near sea level. One of the most beautiful is at Matalanga in the southern part of the island. The Matalanga itself is a tremendous hole in the 200-foot terrace, originally described by Lister.

Immediately to the north of it is a series of terraces leading from the 400-foot level to the sea, along which the volcanic-limestone contact may be seen at several places. Twenty feet below the 400-foot terrace the contact is revealed by a volcanic slope leading to the 340-foot terrace, from the seaward edge of which there is a vertical drop in limestone for 30 feet where the volcanic material is again exposed. As the contact here is represented by a conglomerate 10 to 15 feet thick composed of volcanic pebbles in a matrix of limestone, it is not as sharp as in most places. Beneath it the typical fractured and faulted tuff forms a steep slope to the 200-foot level. The sea has cut a re-entrant into the 200-foot terrace at this place and thus has permitted a side view of the tuff-limestone contact all the way to the sea. Where it is exposed in the rear of the re-entrant, the limestone is about 80 feet thick beneath the 200-foot terrace.

The Matalanga is a remarkable phenomenon. The sea has gouged out a large cave into the base of the sea cliff, cutting through the limestone and reaching the volcanic material farther inland. At the time the 200-foot terrace was being made, the sea had similarly cut through the limestone into the tuff. This condition caused the landward part of the 200-foot terrace to be of volcanic material. Consequently when the sea at its present level cut the cave back into the tuff to the point where there was only soft volcanic material above it, it did not take long for the roof to fall in and produce a hole approximately 250 feet in diameter. Subsequent wave and rain water action has transported the material to the sea and cleared the hole of most of its débris. Even now, however, many large boulders are found in the bottom. The outer edge of the 200-foot terrace remains as a natural bridge of limestone about 80 feet thick, seaward of the chasm. The tuff is dark-tan in color and distinctly bedded in horizontal layers. A similar hole on the "liku" side of Tongatabu is smaller and made entirely in limestone.

The volcanic nucleus of Eua is exposed at several places along the eastern coast at sea level besides the re-entrant near the Matalanga. One of these is at the large re-entrant at the center of the coast at the place which I have called "liku beach." Here a steep, vegetation-covered slope from the high limestone ridge flanks the eastern edge of the summit down to the beach level. The volcanic basis is exposed in many places on the beach for its entire length, a distance of about 1¼ miles. The best outcrops are in the southern half where it is penetrated by six or seven dikes which stand out boldly above the beach floor. (See pp. 43-45.) The dikes have a general east-west strike and range from 3 to 40 feet in width. Around the base of some of them the old recently elevated reef has grown. The main dike cuts through the softer volcanic rock and rises to a height of 70 feet above sea level (pl. 5, *B*). It is capped by 30 feet of coral-bearing limestone. It is clear that none of the dikes penetrated the limestone above them and that they are thus older than the limestone.

A sample of the volcanic material through which the dikes cut is described by Alling as "A fine grained igneous rock, probably a surface flow, showing flowage structure; can be termed a trachyandesite porphyry."

Near the center of the "liku beach" a stream emerges which has water in it only during times of heavy rain. This stream has brought from the interior rounded boulders of hard igneous rocks of many sizes. These, mixed with the boulders derived from the exposed dikes, litter the beach behind the old elevated reef. Even the reef contains many of them firmly embedded in the limestone matrix. Harker (39) described a boulder collected from the beach by Lister, as "uralitized gabbro." I brought back many of a similar character which have been called by Alling "diabasic norites." (See p. 46.) It is evident that the stream has carried these from some point in the interior where the mother rock is or was exposed. Although I traced the stream as far as possible to its source, no exposures of this rock were found. It is in all probability covered with talus at the base of the high cliff west of the beach. Whether it is a dike or a larger igneous mass is impossible to say.

The limestones of the terraces vary in composition. The 760-foot terrace is made up entirely of limestone similar in character to that found on the summit. It is hard, dense, and shows no organic structure except a few foraminifera. The 400-foot terrace is similar in many respects to the 550-foot terrace at the northern end of the island. It is made of hard, foraminiferal limestone at its landward part and some coral limestone with poorly preserved shallow-water reef corals in places along its seaward edge. The 340-foot terrace is exactly similar in structure. The 200-foot terrace is noteworthy in that its seaward edge contains the best coral fauna of the island. At a place to the east and slightly to the south of Station Monument (M) a small stream has cut into the 200-foot terrace, and has exposed at Station Ra. a real coral reef with numerous corals in place. Twenty identifiable species were obtained here and at other places along the seaward edge of the terrace. Behind the edge the corals gradually disappear and the foraminiferal limestone takes the place of the coral reef. The narrow 100-foot terrace also contains numerous corals; from it 5 species were obtained. The small stream which cuts through the 200-foot terrace also makes a ravine in the 100-foot terrace beneath it. At this place the genus *Discocyclina* was found in the foraminiferal limestone beneath the thin, coral reef coating of the lowest terrace.

Near the northern end of the "liku beach," where the re-entrant swings around to the coast, a high, isolated pinnacle of limestone rises to a height of about 300 feet above sea level (pl. 5, *c*). The native name for this shaft is Manake. Behind it and facing south is the cliff from which it stands out and to which at one time it was joined. Lister called this limestone tower the "Pinnacle." The base of its vertical sides is at an altitude of about 150 feet, from which point a talus slope leads first steeply and then gently to the beach, a distance of 500 feet. The rock at the base of the pinnacle is hard and compact, showing mainly foraminifera of the genus *Discocyclina*. Murray studied some sections of the rock collected at this place by Lister (54, p. 603) and found it "made up principally of calcareous algae together with fragments of echinoderms, molluscs, and a number of foraminifera." No coral structure is visible.

About 1,000 feet north of Manake along the coast the limestone of the cliff is bedded and conglomeritic. This conglomerate is made of igneous pebbles ranging in size from smaller than a pea to a foot in diameter. They are chiefly of intrusive igneous rock similar to the dikes farther south, and some are of diabasic norite. The matrix is beach sand of loosely consolidated shell fragments. It consists mainly of foraminifera and echinoid fragments, although bryozoa, pelecypods (*Pecten*), and gastropods are numerous. On the whole there is not a great deal of sorting, although in some places this is well developed. In places large pebbles are mixed heterogeneously with smaller ones. The beds have been gently tilted in several directions and faulted. From south to north the dip at first is south, then horizontal, then gently north, and then again horizontal. Nowhere does the dip exceed 8°. About 100 feet to the north the igneous pebbles become smaller and fewer and the rock changes into a purer limestone until it seems to grade into the nonstratified, structureless material of which most of the island is composed. *Discocyclina* is the main genus of foraminifera in this conglomerate. The average thickness of the conglomerate is about 80 feet. It forms a vertical cliff and is capped by about 20 feet of coral limestone. These two beds make up the 100-foot terrace at this place. The cliff is wave-worn, with caves at its base. The stratification stands out well in relief. At present there is no doubt that the wind is a powerful factor in eroding it.

In summary it may be said that the volcanic basis of Eua is exposed in many places along the terraced eastern side where the sea has cut through the coating of limestone. The limestone is of two general types, a true coral reef structure, and a hard, homogeneous limestone, largely foraminiferal. Besides these there is in one place a conglomerate made of igneous pebbles in a shell fragment matrix. The coral limestones are confined to the seaward edges of the terraces and the foraminiferal limestones to the lower parts of the cliffs and the landward portions of the terraces.

WESTERN SLOPE

Volcanic material is exposed in many places along the Western Slope of the Eastern Ridge leading to the Central Valley. In the vicinity of Stations 100 and 101, on the western edge, the tuff is nearly horizontal or locally dips in several directions. Immediately to the west of these stations a stream starts to flow down the slope to the valley. The top of the ravine made by the stream is 700 feet in elevation at its head and 650 feet at the bottom. The tuff here is rather solid and nearly horizontally bedded. It is riddled with joint cracks which strike approximately N.-S. and E.-W. Some of these have caused a series of small waterfalls in the course of the stream with a maximum drop of 15 feet. The material here is the same as that at Station 105 and contains many foraminifera.

The entire Western Slope, with the exception of its northern end, is covered with some of the densest vegetation on the island, so that various physiographic and structural details are not visible from the summit, but can be determined only after a close investigation. In tracing several of the ravines down the volcanic slope one is nearly invariably halted by a vertical limestone cliff 40 to 80 feet high. The water from the slope goes under the limestone and follows along the contact on its way to the sea. Thus all along this central area for a distance of at least two miles there are fragments of this vertical cliff marking the separation between the limestone and the tuff. It is obvious that the top of the limestone was at one time continuous with the volcanic slope and that the slope has been gradually uncovered by stream erosion. The cliff is formed by the undermining of the limestone and gradual solution of the blocks fallen from above. In this way the cliff is slowly retreating down the side of the slope, which is itself moving westward. The limestone here is hard and compact but shows some coral structure.

In many ways this situation is similar to that at Mangaia described by Marshall (55). In Mangaia the streams flow down the Volcanic Slopes, cross the Taro Flats, and disappear beneath the inner cliff of the limestone Makatea. Marshall has described the Makatea as an elevated barrier reef and the Taro Flats as the floor of the old lagoon. It is possible, and in fact it seems extremely likely to me, that the Makatea was at one time continuous with the Volcanic Slopes and that it has gradually been separated from them by the erosion of streams flowing at the volcanic-limestone contact. The vertical inner cliff of the Makatea is just such a feature as would be developed under these conditions. In several places the Volcanic Slope is still continuous with the Makatea which abuts directly against the volcanic spurs. In many other places it very nearly joins it. The so-called lagoon is widest at places where the streams emerge on the Taro Flats.

Marshall (55, p. 22) explains the peculiar condition of the inner wall in the following manner:

The vertical inner wall of the Makatea is an important feature; for it appears that during the period of its upward growth the reef which formed the Makatea was sufficiently wide to prevent the transport of much material over its surface. There appears also to have been little or no growth over the wall itself. This suggests that the reef encircled the island completely and that water within it was to a great extent cut off from the ocean, thereby lacking some of the freshness and agitation that seems to be necessary for the growth of corals and to a less extent of various other reef-building organisms.

I have treated this problem in some detail in a separate paper (44, pp. 549-554).

WESTERN RIDGE

The Western Ridge is made entirely of limestone. Along its top it contains corals of the reef-building type. These outcrop in many places along the government road which follows the summit. At the town of Ohonua the slope leading from the beach to the ridge is likewise covered with corals. A good cross-section of this limestone is afforded by the ravine made by the stream Lakatoha, which flows through the ridge at the northern end of the town. The sides of the ravine show corals from top to bottom, a vertical distance of about 80 feet. Besides corals the calcareous algae *Halimeda* makes up a large part of the limestone, especially in the lower part. Molluscs and echinoderms appear in lesser numbers. The whole has the appearance of coral reef limestone.

At the ridge summit above the town of Tufu, outcrops of coral limestone appear. Several genera can be made out, among which are *Meandra, Favites,* and *Acropora.* The species belonging to the genus *Acropora* is very similar to *A. gemmifera* (Brook) and is of the type frequently found growing on the outer edge of a coral reef. The elevation here is 310 feet. There is an average slope of about 15° toward the sea from this ridge. The corals can be traced down the slope for a vertical distance of 60 or 70 feet. From this point on the limestone seems to be made up chiefly of *Halimeda,* although small gastropods and foraminifera are also present. The following species of foraminifera were obtained: *Amphistegina lessoni* d'Orbigny, *Calcarina spengleri* (Linné), *Baculogypsina sphaerulata* P. and J., *Cycloclypeus gumbelianus* Brady, *Gypsina vesicularis* P. and J., *Heterostegina depressa* d'Orbigny, *Marginopora vertebratis* Quoy and Gaimard, *Operculina bartschi* ? Cushman, *Peneroplis pertusus* Forskål, *Sorites duplex* Carpenter.

The slope leads to a terrace 180 feet above sea level, which in turn drops gently to one on which the town of Tufu is located at an elevation of 65 feet, and where excellently preserved corals are found in numerous outcrops. The gentle slope to the sea from this level terminates in a beach or limestone cliff 20 feet high which drops abruptly to a reef flat behind the Lithothamnion Ridge. The limestone of the cliff is also a true coral limestone and is probably younger in age than that found above it.

In general it can be said that the limestone of the Western Ridge is largely a coral limestone, although in some places, particularly in the lower parts, *Halimeda* and other calcareous algae are the main constituents.

CENTRAL VALLEY

The bottom of the Central Valley is rather flat except for the few steep ravines which have been cut by streams emptying into the main Ohonua stream, Lakatoka. Over the flat surface the outcrops are relatively few, although numerous enough to show its general structure. In the main it is covered with dense vegetation and thick soil. Here and there an occasional patch of limestone a few feet in diameter appears. These are for the most part dense and structureless, although foraminifera and an occasional coral can be seen.

A traverse was made from the Western Ridge at Station W. P. eastward across the valley in the general direction of Parkers Hill along the line shown by the profile B-B′ in figure 4. It was necessary to cross a ravine about 50 feet deep cut in limestone which contains some corals and a mixture of calcareous algae and other lime-secreting organisms. Corals appear to be more numerous near the top than below. The whole limestone has the appearance of a rubble zone, although now it is fairly well consolidated.

To the east of the ravine there is some open, undulating ground with bright red soil, which contains quartz grains and is to some extent at least of volcanic origin. The area is flat in places and there are little depressions in others. One or two patches of limestone appear. The whole area is undoubtedly underlain with limestone. Beyond this a patch of flat-lying tree country is encountered, and then the ground gradually rises. No outcrops appear until at an altitude of 390 feet a cliff of coral reef limestone is met. This is a true coral reef with corals in place. The western face of the cliff is irregular, much eroded, and stands about 40 feet above its base. The reef has an east-west width of about 700 feet, and terminates abruptly in a vertical cliff which faces the volcanic slopes of the Eastern Ridge. This reef was at one time fringing and its top was continuous with the volcanic slope. The eastern facing cliff is a product of erosion. (See p. 27.)

Farther to the south in the vicinity of Pagai, along the cross section C-C′ of figure 4, the Central Valley can be examined again to good advantage because of its open character. Here it is decidedly shallower, in fact nearly level with the western rim. Passing from this rim, that is, the Western Ridge, in an eastward direction, the distinctive features of the valley appear. The rim at an elevation of 310 feet slopes gently to the government road at Pagai which is 285 feet above sea level. This level represents the bottom of the valley and extends as a flat for slightly more than a mile across tree land

and open field. No outcrops are visible but the soil is reddish and contains quartz grains. Beyond this the ground rises slightly to an undulating area 335 feet above sea level. This is covered with red, much weathered volcanic alluvial material. The undulation is due to numerous shallow sinks which indicate the presence of limestone beneath. This area continues for about 1000 feet and is halted abruptly by a steep north-south running ravine. The upper 25 feet of the ravine shows soft, weathered, volcanic, alluvial material and residue from weathered limestone. Beneath this at an altitude of 310 feet lies an elevated coral reef through which the stream has cut to a depth of 50 feet. The corals here are very numerous and in good state of preservation. Eight identifiable species, of which three are new, were obtained. Beyond the ravine the undulating area continues until the sloping volcanic hills of the Eastern Ridge are met. Separating it from the hills, however, is a depression similar to the others already described on the western slope of the Ridge Summit and caused by water flowing down the volcanic slope and eroding the limestone of the reef at the contact.

The reef exposed in the ravine is undoubtedly a fringing coral reef, the

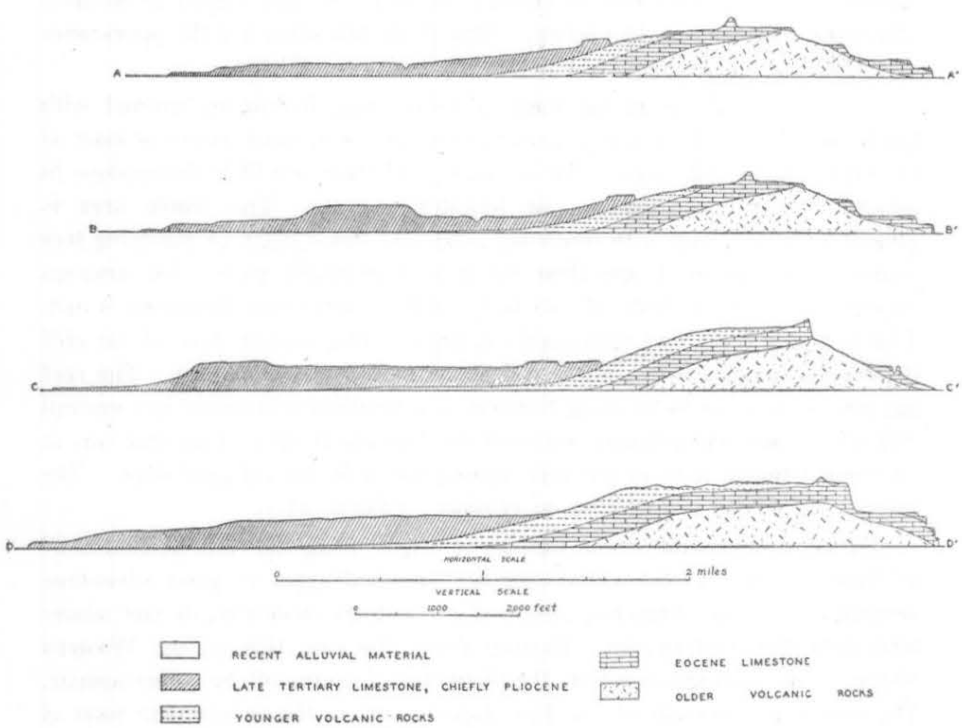


FIGURE 4.—Structure sections across Eua, along lines shown in figure 3.

upper surface of which was at one time joined to the volcanic slopes of the Eastern Ridge. It is at least 1000 feet broad and its top stands 310 feet above sea level. It is separated from the western rim by the shallow flat on which Pagai is located. It is difficult to determine the thickness of the soft material which covers the flat. The absence of sink holes indicates that the limestone which it overlies must be at some little depth beneath it.

It is evident that the Central Valley is a depression bounded on the west by the Western Ridge and on the east by a fringing reef of the same elevation. Directly above this fringing reef in some places is at least one more fringing reef with its top at an average elevation of 450 feet. Remnants of both of these can be traced along the western slope of the Eastern Ridge.

Lister (54, p. 603) was under the impression that Central Valley was in existence before its elevation and thus that it is not merely a product of subaerial erosion. He suggested that the Western Ridge is an elevated barrier reef with a break in it (the gap behind Ohonua) and that it enclosed a lagoon which is now the Central Valley. This barrier reef joined the shore at its northern and southern ends, merging here with the fringing reef lining the shore. He likened this to the present barrier reef which runs along the southern shore of Viti Levu, Fiji, and which continues as a fringing reef along the island a few miles to the west of Suva.

Agassiz (2, pp. 180, 187) considered Central Valley merely a sink of denudation. He writes: "Certainly there is nothing less like a lagoon than this inner valley or sink of erosion of Eua," but gives no reason for his conclusion. It is evident that much of Agassiz's interpretation of the topography is based on the map of the British Admiralty survey of 1888 on which the relief in several places is incorrectly shown. The southern part of the Western Ridge is actually about the same level as the flat to the east of it; there is no great drop from this part of the ridge into a deep valley to the east of it as pictured on the Admiralty map.

I am inclined to agree with Lister that the valley is an elevated lagoon behind a small barrier reef. The reasons are as follows:

1. Water which falls on the limestones of Eua has the tendency to make either precipitous ravines or steep sided holes like the Ana Aha. This seems to be the general character of erosion in limestone of this type. In Vavau, at the northern end of the Tongan archipelago, nearly all of the many beautiful sinks have precipitous sides. The narrow, steep-sided embayments along the southern coast of Vavau were originally elongated sinks, the southern sides of which have been cut into by wave erosion. In other words, there is no indication that a broad, nearly flat-bottomed depression with gentle slopes, such as that of the Central Valley, would result from water falling on a level surface. The ravines are steep, narrow gorges cut below the level of the

valley floor. Their existence is not revealed until their edges are reached. Certainly then the flat, nearly level bottom must have been in existence before active stream erosion began.

2. A fringing reef of the same elevation as the barrier reef (310 feet) lies along the eastern edge of Central Valley and rests upon the volcanic slopes of the Eastern Ridge. This reef is somewhat higher than the valley bottom, and still a stream has cut a steep gorge through it which not only cuts across the reef but runs parallel to it for some distance. If the Central Valley was the result of erosion, the expected position of a stream is in the valley bottom and not in the higher lying coral reef. But no stream now runs in this part of the valley bottom and there is no indication that one ever occupied this position. Thus many of the streams are not only independent of the direction of the depression as Lister (54, p. 603) has pointed out, but in places do not even cut through its lowest part.

3. Where ravines are cut in the center of the depression the limestone exposed seems to be rubble. Many of the coral heads are upside down; the material is more or less waterworn and lacks the characteristics of a true coral reef. On the other hand, it is exactly what might be expected to accumulate in a lagoon behind a barrier reef.

4. The gap in the Western Ridge just east of Ohonua must have been in existence before the elevation of the island. The distance between the parts of the ridge, that is, the width of the gap, is more than one-half mile. The gap is too wide and the slopes too gentle to have been cut by streams such as flow through the island. The ground at the base between the two ends of the ridge is flat, with the exception of the steep gorge cut by the Lakatoha, which drops precipitously from the level of the flat.

5. The volcanic material which covers parts of the valley bottom has been carried down from the Eastern Ridge by streams which in a few places have cut across the fringing reef and deposited their material in the valley. I am convinced that a great deal of deposition has been going on in this way and that the valley is being filled up by débris from the east as fast if not faster than it is being eroded by water.

AGE OF THE ROCKS

The composition and structure of the rocks show that the limestones and the volcanics of Eua are of several ages. (See fig. 4.)

1. The oldest rocks of the island are in all probability the diabasic norites found only as boulders on the eastern coast. All that can be said regarding their age is that they are either early Eocene or pre-Eocene.

2. Next in age are the tuffs and lava flows which form the volcanic nucleus of the island. These outcrop in several places along the Eastern Terraces, and may possibly be represented in the high area of the central

part of the summit of the Eastern Ridge in the vicinity of Parkers Hill, where most of the volcanic material belongs to a younger period of vulcanism. This nucleus contains no diagnostic fossils and can only be said to be of early Eocene or pre-Eocene age. Intruding it and older than the limestones which overlie them are the dikes of the eastern coast.

3. Above the primary volcanic basis of the island lies some limestone which can definitely be designated as Eocene. It consists chiefly of foraminifera although molluscs and echinoids contributed appreciably to its bulk. The basal layers also contain numerous pebbles and boulders of the underlying volcanic material, as is shown in the conglomerate along the eastern coast and at several other places. The appearance of such species of foraminifera as *Discocyclina fritschi* (H. Douvillé), *D.* (*Asterocyclina*) *stella* (Gümbel), and *Pellatispira rutteni* Umbgrove has caused Whipple to assign an upper Eocene age to this limestone. It is clear that reef corals played very little if any part in the formation of this Eocene cover and none of it can be called coral reef limestone. It can be recognized now only along the eastern side of Eua. The localities of the chief outcrops are the following:

a. The summit of the Eastern Ridge from about Parkers Hill to the southern tip of the summit at Station 115.

b. The middle of the northern part of the summit of the Eastern Ridge (the 550-foot terrace), particularly the hill Tee Moa and the area immediately surrounding it.

c. The lower part of the limestone cliffs separating the Eastern Terraces at such places as the base of the Pinnacle and the conglomerate, and also the landward part of some of the terraces.

d. At several places in the volcanic area of the summit of the Eastern Ridge, where rain water has exposed the underlying limestone in such holes as the Ana Aha.

4. Overlying the Eocene limestone are bedded volcanic tuffs which contain numerous foraminifera. These tuffs outcrop over a large part of the summit of the Eastern Ridge and along the western slope of this ridge. They were considered by Lister to represent the primary volcanic nucleus of the island but they are underlain by the Eocene limestone.

Dr. Joseph Cushman, who was kind enough to examine the foraminifera of the tuffs, reported that they include the genera *Orbulina, Globigerina, Globoratalia* and *Cassidulina,* and that they indicate an age not older than Miocene and probably are Pliocene. At Station 105 in the midst of these same beds was found a good suite of fossils of the nautiloid *Aturia*. These were examined by Dr. John B. Reeside, who stated that he did not believe the deposits to be younger than Miocene. It is difficult then on the basis of the fossils to assign a definite age to these beds. In view of the large amount of of limestone which has been formed subsequent to their deposition and because of the elevation of the island to perhaps 700 feet since then, I am inclined to consider them of Miocene age.

5. Directly above the younger tuffs on the western side of the island

and the Eocene limestone on the eastern side, are some younger limestone deposits. These are in the main typical coral reef limestones although corals play a more important part in the composition of their upper than in their basal parts, where the chief lime-contributing organisms seem to be calcareous algae. In general it can be said that these limestones make up the whole western side of the island, from their contact with the volcanic material on the western slopes of the Eastern Ridge over to the sea, and also the seaward edges of the Eastern Terraces from the 550-foot terrace down. They are found thus chiefly in the lower parts of the island.

The main identifiable organisms are foraminifera and corals. Whipple reports that the foraminifera are "upper Miocene or younger," and that the species are found living now around the Tongan islands. The best coral fauna came from the seaward edge of the 200-foot terrace, where 23 species obtained are diagnostic enough to give the limestone a Pliocene age. Although those from other localities are not as satisfactory as age determiners, I believe that they demonstrate that the Western Ridge and the seaward edges of the 100-foot, 340-foot, and 400-foot terraces are likewise Pliocene.

Not enough corals were obtained to give an age to the edges of the 550-foot terrace. The only identifiable species, *Favia pallida* (Dana), is a common species living today in the Pacific, but it has also been reported by Gerth (38) from the upper Miocene of Java. It is clear from the amount of recrystallization, their weathered condition, and their physiographic position, that the corals from the upper parts of the island are older than those below. They are, however, decidedly younger than the Eocene limestone. In general, I believe that these younger limestones are no older than upper Miocene and that in all probability they are Pliocene.

6. In many places the Central Valley is lined with soft alluvial deposits which are chiefly volcanic. They represent material which has been washed down from the western slopes of the Eastern Ridge. At least one stream is depositing material in a shallow, alluvial fanlike form in the flat southeast of Pagai and there are probably others. Where the valley is cut by steep gorges this recent alluvial material shows a maximum thickness of 25 feet above the overlying limestone. In lower parts of the valley it is probably thicker than this.

GEOLOGIC HISTORY

SEQUENCE OF EVENTS

The geologic history of Eua is considerably more complicated than a brief examination would seem to indicate. The finding of boulders of diabasic norite along a stream that crosses the eastern "liku" beach suggests plutonic conditions somewhere in the vicinity. It may be that the early history of Eua is related in some way to an old western Pacific continent.

At some time either during or shortly before the early Eocene, volcanic eruptions built up a mound of pyroclastics and lava flows. This mound was subsequently intruded by andesite dikes, some of which can now be seen outcropping on the eastern coast. The material of the mound was probably reworked by the waves and much of it carried by the prevailing currents to the west of its original position where a submarine platform was built.

The volcanic activity was followed in the upper Eocene by a period of quiet during which lime-secreting organisms, chiefly foraminifera, managed to obtain a foothold and deposited a coating of limestone over the volcanic base. This limestone cover was at least 200 feet thick and may have been considerably thicker. There is no way of knowing how much has been subsequently eroded away. It is possible that a portion of the high area of the central part of the Eastern Ridge remained above sea level and thus was not covered with limestone. It is evident that reef corals played very little if any part in the formation of this limestone.

The next event in the history of the island is doubtful because the tuff of Miocene age overlies the Eocene limestone, leaving the period of time represented by the Oligocene to be accounted for. Two alternative explanations are possible:

1. At the end of the Eocene Eua was uplifted to a position probably higher than it now stands, and was subjected to much erosion. By later subsidence nearly the whole of the island was submerged. During the Miocene another period of vulcanism was initiated during which tuff mingled with the foraminifera in the water and was bedded over the Eocene limestone of the western part of what is now the Eastern Ridge and also over the lower platform to the west. It is believed that the high volcanic area of the central part of the Eastern Ridge was close to the center of this eruption. Similar volcanic action is well demonstrated by the recently emerged Falcon Island (43). Here the waves and winds of the southeast trades have deposited the pyroclastics to the northwest of the crater, where a platform made of reworked tuff is being formed.

2. The island remained under water during the Oligocene. This would mean that some of the limestone designated as Eocene really belongs to what is called in other regions Oligocene and that not enough is yet known of the faunas of the South Pacific to be able to differentiate between the rocks of these two epochs. Following the deposition of this limestone while the island was still submerged, renewed volcanic activity occurred in the Miocene.

There is no way at present to tell which of these two explanations is the correct one. A decision can be reached only after future work in the region.

After the period of volcanic activity during the Miocene, the history of the island has been one of intermittent uplift. During periods of still-stand well defined terraces were cut by marine abrasion, chiefly on the eastern or windward side. On the western or leeward side the record is chiefly one of aggradation. During the entire time that uplift was progressing such shell bearing organisms as molluscs, echinoids, calcareous algae, and corals were depositing a coating of lime over the platform of tuff and Eocene limestone to the west of the Eastern Ridge and gradually building it up toward sea level.

At the time the 550-foot terrace was cut coral limestone was deposited on the outer edges and as a thin veneer over some of the central part. The hill Tee Moa withstood erosion and probably projected above the water as a tiny islet separated from the higher land to the south. A thicker coating of this later limestone was made in the northern part of the flat than in the vicinity of the hill. Further elevation was interrupted several times as is shown by the presence of fragments of some narrow fringing reefs which are clinging to the volcanic western slopes of the Eastern Ridge. The best preserved of these is at the elevation of 480 feet. The still-stand at this level was long enough to cause the formation of a reef at least 700 feet wide. Continued elevation caused it to be stranded high and dry.

The longest period of still-stand is indicated at what is now the 400-foot level. Here a flat at least three-fourths mile broad was cut into the Eocene limestone and in places even into the underlying primary volcanic nucleus on the eastern side. On the seaward edge of this terrace a thin veneer of coral reef limestone was deposited directly on the Eocene limestone. On the west a barrier reef was built up on the now shallow platform with a corresponding fringing reef behind it with which it merged to the north and south. The formation of this barrier reef went on relatively fast as soon as the water over the platform became shallow enough to permit the growth of a true coral reef. The barrier reef contained a break which is still seen as the gap in the Western Ridge behind Ohonua.

Later elevation tilted the island so that the eastern and southern sides now stand higher than the western and northern. The 400-foot terrace which formerly was level with the barrier reef of the western side of the island, now stands 80 or 90 feet higher in some places. This differential elevation is like that of the large island of Tongatabu about 12 miles to the northwest, which has been elevated in such a way that the southern and eastern sides are considerably higher than the others.

The 340-foot, 200-foot, and 100-foot terraces have been cut during successive stands in the progressive rise of the island. The 200-foot and the 100-foot terraces have the most coral patches along their seaward edges.

Most of this uplift occurred during the Pliocene, although it may have been initiated during late Miocene times. Certainly the cutting of the 400-foot terrace took place no longer ago than Pliocene times.

During the Pleistocene the island was probably subjected to low-level abrasion, although very little is known of the suboceanic topography around Eua. As previously described in more detail (48), the latest movement of the strand line has been a eustatic negative shift of the magnitude of 8 to 12 feet. This caused the death of the old fringing reef. Since then the present small fringing reef has formed.

In brief the various steps in the geologic history of Eua are as follows:

1. Diabasic norites suggesting plutonic conditions in the vicinity. Earlier than upper Eocene.

2. Volcanic eruptions with formation of bedded tuffs to build up primary nucleus of the island (older volcanic rocks). Earlier than upper Eocene.

3. Deposition of limestone chiefly foraminiferal. Upper Eocene.

4. Elevation of the island and period of denudation followed by subsidence or continuation of conditions of step no. 3. Oligocene.

5. Period of volcanic activity during which tuff mingled with foraminifera was deposited (younger volcanic rocks). Miocene (?).

6. Elevation of island in stages to form terraces with coral reef veneers on the eastern side and coral reefs on the western. Pliocene. May have been initiated during late Miocene.

7. Probable low level abrasion. Pleistocene.

8. Negative eustatic shift in strand line and formation of present fringing reef. Recent.

INTERPRETATIONS OF OTHER WRITERS

Lister (54) first pointed out that the Western Ridge was in all probability a raised barrier reef and that it was not necessary to call in the hypothesis of subsidence to account for its formation. He also recognized that the Eastern Terraces were cut by wave action during intervals between stages of elevation. Lister failed, however, to distinguish between the two major periods of vulcanism. He considered the tuff of the western part of the Eastern Ridge to be of the same age as that exposed along the eastern side and believed that all the volcanic material represented the primary volcanic nucleus. In other words, he failed to see that most of the tuff of the summit of the Eastern Ridge is underlain by limestone. Because of the condition of the paleontological record of that time Lister was unable to refer the various rock formations to definite ages.

Agassiz (2, p. 180-187), whose account of Eua is based on what he saw from shipboard and from a brief excursion inland, apparently accepted most of Lister's interpretations but insisted that Central Valley was not a lagoon but merely a sink of erosion. Davis (19, p. 416) has pointed out that Agassiz recognized the dikes of intrusive rock which "cut through the volcanic deposits but do not enter the overlying calcareous strata," but instead of interpreting this as showing that the limestones were deposited on top of the volcanic rocks he seems to have regarded the volcanic eruptions of later date than the limestones. Agassiz wrote:

> The present topography of Eua indicates that at one time it must have been a large, flat, limestone plateau originally similar to Tongatabu and Vavau, but of greater height and less extent, pushed up by volcanic outbursts on the east coast, which was little by little disintegrated according to the hardness of the various terraces.

The most recent reference to Eua is that by Davis (19, p. 415), who based his interpretation on the accounts of Lister, Oldham, and Agassiz, although he differs widely from these writers. Davis attributes the barrier reef and elevated fringing reefs of the west side to subsidence of the island instead of elevation. He says:

> It may therefore be inferred that the barrier reef would have grown up in a single reef of that thickness (1000 feet), had not the later phases of the subsidence been accelerated. Inasmuch as the upper fringing reefs appear to have been successfully drowned by the impulses of subsidence which then took place it is eminently possible that the culminating atoll also was in its turn drowned before the subsidence was reversed into the upheaval by which the reef-benched island was given its present altitude. Although incompletely studied, Eua is already one of the most instructive reef-bearing islands in the Pacific coral seas. Darwin colored it red on his chart to indicate that it has been fringed with a sea level reef after its elevation; he would surely have been glad to know the evidence now forthcoming to show that, before elevation, it had subsided and become reef-fringed and atoll-crowned.

Of course, to consider the summit of the Eastern Ridge as part of an atoll is impossible. It is made not of coral reef limestone but of an old foraminiferal limestone of Eocene age. Also it is clear that the terraces were made chiefly by wave abrasion and that the upper ones are older than those below. In other words, they were made during elevation of the island and not during subsidence.

Davis apparently also misread Lister's profile of Eua (54, fig. 1), which shows an east-west cross section through the island, and interpreted the part of the diagram that shows a portion of the eastern coast farther to the north as a downfaulted block. This does not accord with Lister's idea or with the facts.

EUA AND THE SUBSIDENCE THEORY

One of the chief points of interest in the interpretation of the geology of Eua is that a barrier reef can be formed on an island at the same time that the major movement is one of uplift. The elevated barrier reef of the western side of Eua was made by the accumulation of calcareous algae, corals, and other reef materials on the outer edge of a platform of Eocene limestone and volcanic tuff during times of elevation and still-stand. The clearly cut terraces of the eastern side of Eua and the ages of the limestones composing them prove beyond doubt that uplift in stages has been the later history of the island. The corals of the barrier reef and the Eastern Terraces are of the same age. Of the 10 species found on the barrier reef, 7 are found on the 200-foot terrace and 2 of the 7 also on the 100-foot and the 340-400 foot terraces. Thus the barrier reef was forming at the same time the terraces were being cut and coral reef veneers were being made on the eastern coast. Here is one place, then, where the subsidence theory for the formation of barrier reefs does not apply.

PETROGRAPHY

By Harold L. Alling

INTRODUCTION

Through the courtesy of J. Edward Hoffmeister I have had the opportunity of studying a suite of specimens of various rocks from the island of Eua.

With the exception of Harker's study (39) of specimens supplied by Lister, authors have made but casual references to the igneous rocks of Eua. My conclusions are much in accord with Harker's, but it appears that Hoffmeister's more extensive collections reveal additional types of rocks. The location of the igneous dikes and the micrographic structure of the rocks examined are shown in Plate 6.

The oldest rocks so far discovered on Eua are volcanic tuffs, breccias, ash beds, various pyroclastics, and surface flows. Much of the material is heavily stained with iron oxides and hydroxides. There is much evidence that a large portion was deposited under water or at least reworked by water. The beds are rather well stratified and there has been some sorting due to wave action. The tuffs are much disturbed, folded, mashed, and sheared in a complex manner making any determination of the structure impossible. In general the tuffs are andesitic, but there are certainly rhyolitic and dacitic types as well.

SURFACE FLOWS

The surface flows appear to be more acidic than the tuffs, and show a fine grained porphyritic rhyolite with distinct flowage structure.

The phenocrysts consist of orthoclase with Carlsbad twinning and are often found to be slightly zonally grown. Quartz appears as interstitial grains, sometimes as large as the orthoclase phenocrysts but usually intermediate in size between them and the minerals of the groundmass. The groundmass is a very fine matted mass of fibrous and needle-like crystals of orthoclase, soda orthoclase, and occasionally an untwinned acidic plagioclase. The darker minerals, the ferromagnesians, are completely altered to secondary products. Sufficient structure remains, however, to suggest a mica, a hornblende, and a magnetite. The most prominent secondary mineral is epidote, which exists as pale yellow-green flaky aggregates. A carbonate and iron oxides complete the list.

Other specimens of surface flows contain more plagioclase and hence pass towards monzonitic composition, but it seems probable that the surface flows of the island are more acidic than the tuffs. Whether the flows represent an earlier rock than the tuffaceous forms remains obscure. It seems likely, however, that the flows are now interbedded with the pyroclastics, and that both have had a similar source, though not necessarily the same.

TUFFS

The volcanic tuffs represented by the specimens and slides show considerable variation in composition, size of grain, degree of weathering, and amount of iron staining. Most of them are colored brick-reds and reddish-buffs by secondary ferric compounds, frequently obscuring much of the detail of the rock.

The tuffs consist of irregular subangular grains, of devitrified feldspathic glass, plagioclase microlites, hornblende, augite, scapolite, epidote, chlorite, pyrrhotite, magnetite, quartz, red garnet, and occasionally a blue tourmaline. There are, in addition, fragments of igneous rocks. These appear to be chiefly andesitic, although dacites, trachyandesites, dolerites and diabasic gabbros are well represented. Secondary minerals, such as limonite, goethite, bastite, hematite, uralite and a little leucoxene produce a matted groundmass difficult to study in detail. The plagioclase is frequently beautifully zonally grown, showing slight optical strain as well. Some of the quartz is strained to the extent that interference figures are abnormally biaxial. Some of the fragments of quartz exhibit microfaulting and healing as well as enlargement due to the introduction of silica. The volcanic tuffs of Eua appear to have been water laid; they are crudely stratified and banded as though the product of sorting by wave action. The tuffs according to Hoffmeister's field observations are completely folded to the extent that it is not possible to determine the structure.

Hoffmeister's studies reveal two distinct ages of volcanic rocks on the island. Specimens of the earlier group of such pyroclastics were collected from the sides of a small natural bridge at Liku. They are significant in that they represent rock in place.

In the hand specimen the rock presents characteristics of a thoroughly weathered volcanic tuff. It is brick-red and yellow in color and easily scratched by a knife.

The microscope reveals the rock to be heterogeneous, consisting of fragments of diabasic andesitic flows and pyroclastics of several degrees of crystallinity cemented by fine volcanic ash of somewhat similar composition.

These fragments appear to differ from one another, although the dissimilarity may be more apparent than real, due to the pronounced secondary alteration the entire rock has experienced. One fragment shows a porphyritic diabasic andesite rock with well formed phenocrysts of an acid plagioclase near oligoclase-andesine, set in a fine groundmass of labradorite-bytownite rods arranged in a diabasic pattern. Interstitial grains of epidote and chlorite point to an original pyroxene, presumably an augite. Small rusty grains appear to be magnetite, now considerably altered to hematite and limonite. It is not possible to identify any additional minerals. The degree of darkness of the groundmass under cross nicols strongly suggests that some glass is present.

Other fragmental pieces in the tuff are more acidic in that the phenocrysts are untwinned, with low extinction angles, and hence are thought to be feldspars relatively high in potash. Some of the phenocrysts are twinned according to the Carlsbad law and can be identified as soda orthoclase or even sanidine. The groundmass of these more acidic fragments appears to be composed of plagioclase rods usually with diabasic structure and ranging in composition from andesine to labradorite. Still other fragments with soda-orthoclasic perthite phenocrysts exhibit a potash feldspar in the groundmass showing that the rocks here represented range toward trachytes.

Quartz is identified with some uncertainty and is thought to be secondary.

The secondary minerals are especially noticeable. Epidote, clear pale green in ordinary light with pronounced pleochroism in polarized light, and bright oranges, reds, greens, and purples under crossed nicols. To ascertain the original mineral for the large epidote masses is fraught with much uncertainty; of course, some ferromagnesian is suggested. Other phenocrysts have been completely replaced by carbonates and still others by aggregates of scapolite, sericite and chlorite.

The cementing material varies in amount throughout the slides and from specimen to specimen. As a rule it is exceedingly fine grained and only yields its make-up under the high power objectives. It seems to consist of plagioclase grains, glassy in appearance but crystalline in nature. Some areas under crossed nicols with a high power objective, appear amorphous and hence are regarded as glass.

Some of the predominant phenocrysts have been replaced by introduced substances. Carbonates, as noted above, constitute only one of the many substances now replacing original minerals. The epidote may be entirely secondary but its widespread development may call for introduction of some or all of its composition. Some phenocrystic areas are now occupied by clear unaltered soda-orthoclastic microperthite feldspar with long fibrous blebs of a soda-rich plagioclase. These blebs extend across grain boundaries, showing that if the blebs are secondary and due to exsolution that they seem to be independent of definite crystallographic directions.

Most of the phenocrysts which have not suffered alteration or replacement are poikilitic with small grains of another feldspar, a muscovitic mica, which may be in part secondary, and possibly quartz.

A few phenocrysts were seen as well as some of the feldspars of the groundmass that appear to have suffered magmatic corrosion or experienced what may be the incomplete operations of a reaction series.

Rusty cubical grains, chiefly hematite with halos of limonite staining the adjacent substances, may represent former pyrite. Its distribution as aggregates arranged in long parallel rows strongly suggests that it is an introduced mineral.

Some of the specimens of the older series of volcanic pyroclastics show microfaulting and subsequent microveining with calcite and quartz.

The striking feature of this group of rocks is the diversity of grain size of both phenocrysts and groundmass constituents from fragment to fragment within a single miscroscopic slide, also the apparent fact that they range from porphyritic andesites to porphyritic trachytes with an emphasis upon trachyandesite with a decided tendency towards tephrite with nephelite as a remote possibility.

YOUNGER VOLCANICS

The suite of specimens of the younger series of volcanic pyroclastic ash beds from Red Hill, near Parkers, reveal in thin section similarities to those of the older group, as well as differences. The comparisons here described are based upon relatively few slides and hence undue emphasis should not be placed upon the conclusions reached, although they appear to be justified as far as the amount of material available for study is concerned.

In general, the composition of the younger series is similar to, and in some areas identical with, representatives of the older volcanics on the island.

The original phenocrysts appear to be acid plagioclase, probably oligoclase. A few untwinned grains may be potash-bearing, but definite proof is not possible, due to the alteration they have experienced. They do not occur as abundantly nor are they as large as the phenocrysts in the older series. They are poikilitic with dark dust particles, some of which may be magnetite and occasionally pyroxene. Magmatic corrosion appears here as having affected somewhat the plagioclase crystals, provided they are large, for the small phenocrysts of plagioclase with slightly higher extinction angles possess clean-cut margins exhibiting crystallographic outlines.

The relatively large phenocrysts show alteration to secondary products to such a degree that detailed identification of the exact composition of the feldspar is out of the question. They are sericite, or micaceous minerals of allied nature, pale green chlorite and possibly scapolite. Epidote has not been noted in the younger series.

Some of the larger phenocrysts are zonally grown; this is shown even in grains showing excessive alteration, as the secondary products are more abundant in juxtaposition to that portion of the plagioclase grain possesing a higher lime content. Secondary products may include some zeolite, but its identification is very uncertain.

The groundmass is finer grained, more matted and less diabasic in texture than is the case with the other pyroclastics. There is more variation in size, however. They contain more glass and are more irregular in the degree of weathering. This latter point may be purely local, and additional slides show that this is not a significant point of distinction between the two series.

Identification of the ferromagnesian constituent is not possible. Limonite and goethic staining, irregular patches of cloudy aggregates of carbonates and fibrous secondary micas are thought to represent them. Augite is, of course, possible, and so is an amphibole.

The particular slides available for study show a greater diversity of rock fragments than was seen in the older series. The fragments are smaller, possess considerable range in composition, varying from possible dacites to trachyandesites. They seem less angular and finer grained. In many of them the groundmass is very dense and nearly opaque even under plain polarized light. Apparently the rate of cooling was more rapid in the younger series, as is shown by the smaller size of the individual grains and the opaqueness of the groundmass. There is more volcanic ash now cementing the fragments than in the older series.

The few contrasting features, distinguishing the representatives of the two series studied, can be summarized as follows:

The older series possesses large irregular and more angular fragments, larger phenocrysts with marked "magmatic corroded" margins, abundantly poikilitic with dust, while the younger rocks exhibit smaller phenocrysts with sharper crystallographic outlines and less supplied with included dust particles.

In the groundmass of the rocks of the older series the individual grains are recognizable. They are clear, well defined, and show a decided diabasic texture not possessed by the younger group of rocks. The younger rocks show more rapid cooling and more opaque groundmass. The epidote of the older series is not present in the higher beds.

The geologic history that this petrographic study indicates is that two volcanic outbursts were separated by considerable time and took on different aspects. The younger volcanic material may have been more explosive and produced ash beds with a less amount of actual flows.

The older series of agglomerates possess petrographic features linking them more to the diabasic-noritic dikes of the east coast than with later pyroclastics. The similarity is so striking that some slides could be confused with dike material if not distinctly labeled. It at once suggests that following the deposition and extrusion of the early volcanics, the dikes intruded. Lack of this similarity to the volcanics of the younger series suggests that the dikes do not intrude the younger series but represent intermediate activity. After reaching this conclusion Hoffmeister informed me that this is the case.

The source of the volcanic fragments is unknown. The fragments of such minerals as feldspar, quartz, and augite are sufficiently large to suggest that they have been derived from the erosion of surface flows. Other considerations would point to plutonic conditions prevailing near by. The garnet and tourmaline have suggested to Harker (40) that "The fragments [were] blown out from a volcano, [and] point to the existence of metamorphic rocks below, though at what depth it would be idle to speculate."

DIKES

Harker reports that Lister noted three dikes on the eastern shore of the island. Hoffmeister has secured specimens of six dikes which probably include the three mentioned by Lister. They cut the tuff but are overlaid by the limestone. Figure 5 indicates their approximate position and character.

1. Southern dike (H298): 25 feet long, 3 feet wide, strike N. 72° W.

Under the microscope it appears to be a fine-grained porphyritic andesite or trachyandesite. The phenocrysts are of plagioclase, near andesine-labradorite and altered augite. The groundmass consists of small rods of an acid plagioclase. Accessories include magnetite and perhaps nephelite. The latter mineral cannot be demonstrated, but most of the dike rocks have a nephelite-like appearance. Secondary alteration products include sericite, epidote, chlorite and various carbonates.

2. Dike No. 2 (H297): 15 feet long, 4 feet wide, strike S. 76° W. The rock is similar to that of the southern dike but perhaps a little coarser grained. The plagioclase phenocrysts are perhaps more acid.

3. Main dike: 40 feet wide, 70 feet high, capped with coral-bearing limestone, strike N. 85° W. Hoffmeister has supplied four specimens, taken at 10-foot intervals across the dike. They are somewhat similar to each other and to the rock of the other dikes but with this interesting difference:

fragments from the main dike, chiefly those from its margins, hold inclusions of a finer grained, more basic rock.

These fragments are somewhat smaller but are more weathered. They show abundant limonite and chlorite. The chlorite exhibits the form of halos around limonite cores. Certain grains look like leucite, but are too thoroughly weathered to be positively identified. The center of the dike is an andesite or a trachyandesite with labradorite phenocrysts. The augite has altered to uralitic hornblende and to chlorite. In one slide (H293) there are two metallics; one is evidently magnetite altered in part to hematite, while the other is a steel-black mineral with a slight bluish tinge which does not show any alteration. I don't know what it is; it may be chromite. No leucoxene is present.

The slide from the northern edge of the main dike appears to contain quartz, somewhat fractured and rehealed; the plagioclase is perhaps approaching anorthite in composition and is somewhat magmatically corroded. It may be dacitic.

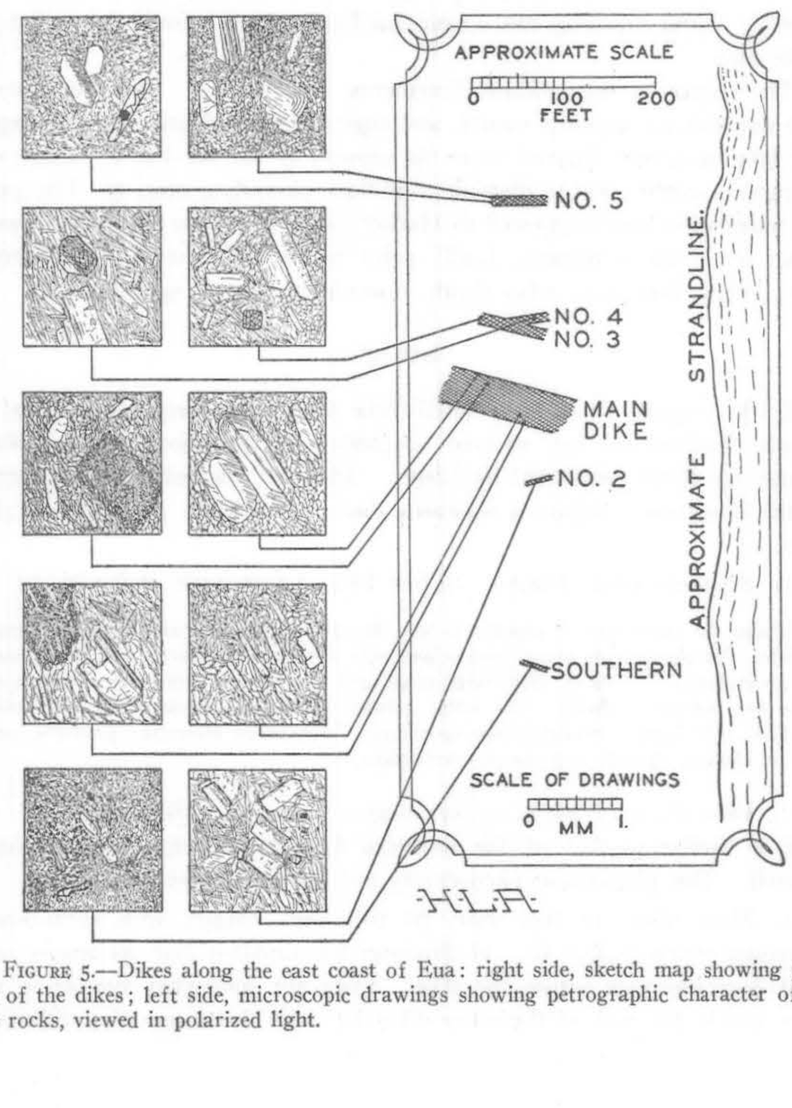


FIGURE 5.—Dikes along the east coast of Eua: right side, sketch map showing position of the dikes; left side, microscopic drawings showing petrographic character of the dike rocks, viewed in polarized light.

The significance of these observations, it seems to me, is that as the dike magma entered, it had a more basic composition than it did later. The early intrusion, represented by the margins of the present dike, basic, fine grained, was followed by a slightly more acidic, hotter magma which shattered the earlier rock, engulfed fragments, replaced others, and on cooling formed a composite dike 40 feet thick. I believe that the difference in composition between the early and late phases of the rock is due to differentiation. This engulfing of fragments of earlier rocks is not confined to the main dike. Dike No. 5 shows an inclusion of a highly porphyritic volcanic rock of andesitic composition, consisting of beautifully zoned and cored plagioclase phenocrysts in a brown glassy groundmass. Altered hornblende, magnetite, chlorite and "goethite" are noted. It is not clear whether this is a fragment of a surface flow to be classed with the above described rocks or whether it is an early phase of the dike itself.

4. Dike No. 3 (H299): 70 feet long, 10 feet wide, and 12 feet high, strike parallel with the main dike.

Slides of No. 3 show phenocrysts of bytownite-anorthite, slightly zoned. The groundmass is difficult material to study. Small rocks of andesine, magnetite, and alteration products may be identified.

5. Dike No. 4 (H296): 10 feet high, strike S. 81° W., merges with No. 3. It is capped by conglomerate consisting of limestone with dike fragments.

Dike No. 4 is distinctly more acidic than dike No. 3. The plagioclase is labradorite, strikingly zoned. Augite, altering to bastite, enstatite weathering to chlorite, magnetite decomposing into hematite and martite, and titanite changing to leucoxene are present. The rock is an andesite.

It is difficult to understand the relation between dikes Nos. 3 and 4. If the two merge, then differentiation has taken place, perhaps in situ. Can it be that one is an offshoot of the other or that one cuts the other?

6. Dike No. 5: 60 feet long, 10 feet wide, 4 feet high, strike N. 90° W.

Porphyritic andesite or trachyandesite, very similar to the southern dike and dike No. 2. It has a perplexing inclusion. A few phenocrysts of a clear glassy feldspar, first taken to be sanidine, proved to be an acid plagioclase, without twinning. This is an illustration of what may be called a potash oligoclase or a sodic anorthoclase. Harker says that the "northern" dike contains sanidine. Whether dike No. 5 and Harker's "northern" dike is the same, I, of course, do not know.

These dikes furnish some problems in the mechanics of dike intrusion worthy of further investigation.

PYROCLASTIC LIMESTONE TUFFS

Specimens are available which are pyroclastic limestone tuffs. It would appear that much of the pyroclastic material, certainly that at the surface, was reworked by wave action at the time of the deposition of basal portions of the overlying limestones.

Slides show well-rounded grains of zoned plagioclase, enstatite, augite, magnetite, pyrrhotite, epidote and fragments of andesite and trachyandesites, set in a matrix of rhombs of calcite, magnesian carbonate and siderite. Some of the limestone minerals are recrystallized, somewhat enlarged, and suggest that some of the limestone may have been derived from some other marine sediment. Many specimens contain shells of foraminifera (pl. 6, *E*).

BOULDERS ON EAST COAST

Strewn on the east coast are many boulders of igneous origin. Lister evidently supplied Harker with specimens. Hoffmeister brought back 30 or more. Of these, 13 have been thin sectioned.

Most of the specimens studied petrographically appear to the diabasic norite. Harker (39) says "The structure of the rock points to a plutonic origin, the general characters being those of a gabbro rather than a diabase, though to some extent transitional." I have found sufficient hypersthenic enstatite, hedenbergite and bronzite to suggest the term diabasic norite.

The rock contains beautifully zoned plagioclase of varying composition from bytownite to oligoclase. They are idiomorphic towards the ferromagnesians, but their outlines are modified by each other. Much of the pale greenish brown hornblende is fibrous in structure and is evidently secondary. It is believed to be paramorphic and pseudomorphic after augite and hyphersthenic enstatite. Cores of unchanged pyroxene can be found. The magnetite is of several generations; small well-formed grains of early crystallization occur, but much of the magnetite has crystallized later as the feldspars modify its form. Some of the magnetite is apparently ilmenitic and in some slides is strikingly abundant, and in one slide is intergrown with ilmenite.

Many alteration products occur, uralite, bastite, chlorite, and epidote, in addition to the paramorphic hornblende. In certain specimens (3121 and 3123) situated between plagioclase rods of the smaller-grained portions of the rock are small untwined squarish grains which may be orthoclase. Others with an apparent uniaxial figure suggest nephelite.

Such rocks may be approaching trachyandesites or nephilite-tephrites in composition and hence suggest kinship with some of the dikes. The exact relation between the diabasic norites and the dikes remains obscure, but it may be that both have had sources in a common magma.

CONCLUSIONS

The foundation of the island of Eua consists of a complex series of rhyolitic flows and andesitic pyroclastics apparently interbedded. The tuffs were evidently deposited in oceanic waters and experienced considerable sorting and stratification by the action of the waves. They were subjected to orogenetic disturbances which folded, crushed, faulted, sheared, and slightly recrystallized them prior to the intrusion of pre-limestone dikes.

There is both field and petrographic evidence for two series of pyroclastic tuffs on the island. The older series exhibits larger and more angular igneous rock fragments. The groundmass of the older tuffs shows a distinct diabasic texture not possessed by the later rocks. The younger tuffs appear to have experienced more rapid cooling and were the product of more explosive volcanic activity than were the older series of tuffs. The petrographic characters of the older series link them genetically with the dikes on the east coast, suggesting that the dikes entered the older series soon after deposition. The dikes do not cut the younger group of volcanic tuffs.

Dikes occur on the east coast, and it is reasonable to suppose that many others occur but are overlain by the limestone cover, and are hence unobservable. The dikes are porphyritic andesites and trachyandesites with an apparent trend towards nephelitic and leucitic varieties; others have a dacitic composition. At least two dikes exhibit a compound character. The early phases of the dike magma appear to have been more basic than the later injections. The first dike matter contains anorthite feldspar and abundant ferromagnesians. The later and more acidic magma engulfed fragments of the early rock, so the dikes, more particularly on the margins, contain inclusions of the other.

The pyroclastic limestone agglomerates show that at the time of the deposition of the limestones the tuffs were subjected to wave action. The limestones as studied in thin section, show many sections of foraminifera and other organisms.

Strewn on the east coast are boulders of diabasic norites, with leanings towards nephilite-tephrites. I am at a loss to account for them. They have suffered considerable uralization.

In the pyroclastics, red garnets and blue tourmalines point to metamorphic rocks in the vicinity. These observations in connection with the diabasic norites strongly suggest plutonic conditions near by. It is my belief that Eua and probably other Tongan islands are the remnants of a continental series of volcanoes, situated on the coast of a former continent, or perhaps I should say these islands represent a pre-Eocene continental shelf. Later these volcanics were overlain by limestones.

CORALS FROM THE ELEVATED LIMESTONES

DISTRIBUTION

The fossil corals of Eua are found chiefly on the seaward edges of the terraces of the eastern side of the island and in places along the Western Ridge particularly in the vicinity of the town of Ohonua. Besides these localities a collection was made from the deep gorge east of Powells Field at Station P, and also one coral was taken from the top of the hill Tee Moa on the Eastern Ridge.

The 100-Foot Terrace

Of 5 species of corals from the 100-foot terrace, 3 species (60%) are living and 2 are new. Identifiable species were found only at the seaward edge of the terrace directly east of Station M. It is difficult to tell the age of this reef from such a small collection. However, when it is seen that 4 of the 5 species are common to the 200-foot terrace of Pliocene age and 4 to the 340-400 foot terrace of slightly older Pliocene, it is pretty safe to place the reef in the same epoch. Because of its physiographic position I believe it is somewhat younger in years than the reef of the 200-foot terrace. Of the species listed in Table 1, *Favites* c.f. *complanata* and *Goniastrea retiformis* are known as fossils in Pliocene and younger formations.

Table 1. Corals from the 100-Foot Terrace

Species	100-foot terrace	200-foot terrace	340-400-foot terrace	Gorge (Station P.)	Ohonua	Other Localities
Favites cf. complanata (Ehr.)	×	×	×	....	....	Recent: Red Sea. Pliocene: Timor.
Goniastrea retiformis (Lamarck)	×	×	×	....	×	Recent: Red Sea; Indian Ocean; Amboina; Pacific Ocean. Pleistocene: reefs of Red Sea and Christmas Island. Pliocene: Ceram; Dutch New Guinea, and Pliocene or Pleistocene: Timor; Sumatra.
Leptoria cf. phrygia (E. and S.)	×	×	....	×	....	Recent: Cocos-Keeling; Pacific Ocean.
Maeandra euaensis, n. sp.	×(?)	....	×(?)	....	....	
Astreopora tongensis, n. sp.	×	×	×	....	×	

THE 200-FOOT TERRACE

The 200-foot terrace contains by far the richest coral fauna of Eua. Wherever exposures are, good corals were easily obtained. The stations where the main collections were made are at the Matalanga near the southern end, at Ravine (Station Ra.) a little north of the middle of the island, and at Station Y. On the seaward edge of the terrace at the Matalanga, I found a small number of very well preserved corals loose in a little gully. They had either been washed loose from the 200-foot terrace or from one of the higher terraces. In all probability they had originally come from the 200-foot terrace and in close proximity to the place where they were found, as they show practically no indications of being water worn. However, I am not including them in calculations regarding the age of the terrace. In a ravine at Telea River, also on the seaward edge of this terrace, only one identifiable specimen was collected.

In Table 2, 22 species are recorded, 21 of which were identified. After subtracting the 2 which were found loose in the gully at the Matalanga there are 19 identifiable species known from the terrace. There is very little doubt that those from the various stations are of the same age. Four species are common to two or more of the stations. Of the 19 identifiable species, 12 (about 63%) are known to be living. Of the 7 that remain, 4 are new, while the other 3 are known only as fossils from the Pliocene and Pleistocene.

Many of the living species are also found as fossils. *Galaxea fascicularis* (Linnaeus) is known from the Pliocene of Java, the Neogene of Sumatra and the Miocene of Borneo; *Favites complanata* (Ehrenberg) from the Pliocene of Timor; *Goniastrea retiformis* (Lamarck) from the Pliocene and Pleistocene of several localities; *Maeandra lamellina* Ehr. from the Pliocene of Java and Borneo and the Pliocene or Pleistocene of Timor; *Diploastrea heliopora* (Lamarck) from the Miocene or younger of Java, the Pliocene of Dutch New Guinea, the Pliocene or Pleistocene of Timor and the Neogene of Nias.

Orbicella mansfieldi is new in name only, having been reported by Felix from the Pliocene or Pleistocene of Timor as *O.* cf. *praeheliopora* Gregory. This species may possibly be *O. praeheliopora* Gregory originally obtained from the Pleistocene of Christmas Island, but a redescription of the type of that species is necessary before identification can be certain. *Cyphastrea cymotoma* Felix is known elsewhere only in the Pliocene of Java and the Neogene of Nias, and *C. wanneri* Felix from the Pliocene of Timor. I believe it is safe to say that the corals of this 200-foot terrace are of Pliocene age.

Table 2. Corals from the 200-Foot Terrace

Species	200-foot terrace				100-foot terrace	340-400-foot terrace	Gorge (Station P)	Ohonua	Other Localities
	Matalanga	Loose at Matalanga	Station Y	Ravine (Station Ra.)					
Orbicella tongensis, n. sp.	×	×	×	----	----	----	----	×	
Orbicella mansfieldi, n. sp.	----	----	×	----	----	----	----	×	Pliocene or Pleistocene: Timor. Possibly Pleistocene: Christmas Island.
Orbicella parksi, n. sp.	----	----	----	×	----	----	----	----	
Orbicella laddi, n. sp.	×	----	----	----	----	----	----	----	
Cyphastrea cymotoma Felix	----	----	----	×	----	----	----	×	Pliocene: Java. Neogene: Nias.
Cyphastrea wanneri Felix	----	----	×	----	----	----	----	×	Pliocene: Timor.
Galaxea fascicularis (Linnaeus)	×	----	----	----	----	----	----	----	Recent: Red Sea; Indian Ocean; Pacific. Pliocene: Java. Miocene: Borneo. Neogene: Sumatra.
Favites cf. complanata (Ehr.)	×	----	----	----	×	× (?)	----	----	Recent: Red Sea. Pliocene: Timor.
Acanthastrea echinata (Dana)	×	----	----	----	----	----	----	----	Recent: Red Sea; Pacific; Sang Kuliran, Borneo. Upper Miocene: Borneo.
Goniastrea retiformis (Lamarck)	×	×	×	×	×	×	----	×	Recent: Red Sea; Indian Ocean; Amboina; Pacific. Pleistocene: reefs of Red Sea and Christmas Island. Pliocene: Ceram; Dutch New Guinea. Pliocene or Pleistocene: Timor; also Sumatra.
Leptoria cf. phrygia (E. and S.)	×	----	×	×	×	----	×	----	Recent: Cocos-Keeling; Pacific.
Leptoria cf. gracilis (Dana)	----	----	×	----	----	× (?)	----	----	Recent: Red Sea; Indian Ocean; Pacific.
Maeandra aspera (Verrill)	----	----	×	----	----	----	----	×	Recent: Loo Choo Islands; S. Philippines.
Maeandra cf. lamellina Ehr.	----	----	×	----	----	----	----	----	Recent: Red Sea; Indian Ocean; Pacific. Pliocene: Java. Pliocene or Pleistocene: Timor; Pliocene: Borneo.
Maeandra, sp.	----	----	×	----	----	----	----	----	
Pavona ostergaardi, n. sp.	----	×	----	----	----	----	----	----	
Diploastrea heliopora (Lam.)	----	----	----	×	----	----	----	----	Recent: French Somaliland; Pacific. Miocene or younger: Java. Pliocene: Dutch New Guinea. Neogene: Nias. Pliocene or Pliestocene: Timor; from Ceram and Sumatra.
Astreopora cf. ocellata Bernard	----	----	×	----	----	----	----	----	Recent: Great Barrier Reef and Bandin Island.
Astreopora tongensis, n. sp.	×	----	×	----	----	×	----	×	
Alveopora fijiensis, n. sp.	----	×	----	----	----	----	----	----	
Porites aff. lutea M.E. and H.	----	----	×	----	----	----	----	----	Recent: Fiji; Murray Island; Samoa. Possibly Upper Miocene: Borneo. Plio-Pleistocene: Ceram and Christmas Islands.
Porites aff. lobulata Dana	----	----	×	----	----	×	----	----	Recent: Hawaii; Fanning Island; Fiji.

The 340-400 Foot Terrace

The 340-foot and 400-foot terraces are distinct in some parts along the eastern ridge but in many places they merge into each other by a gentle slope. In this discussion I am treating them as one terrace.

Corals were collected from three stations on the 340-400 foot terrace. Most of them came from Station R in the northern part of the island; some were taken from the seaward edges of the terrace at Vaigana and Matalanga. Most of the specimens are poorly preserved and hard to identify. Of the 9 species recorded in Table 3, 6 are given specific names, although with some doubt as to 3 of them. Of the 7 species identified, 5 are also found on the 200-foot terrace and 4 on the 100-foot terrace. Four species are still living. It would seem that the corals of this terrace belong to the same geologic epoch, the Pliocene, as those of the 200-foot terrace. The poorer state of preservation, the more compact and harder condition of the limestone, as well as their physiographic position show that they are older in years.

The 550-Foot Terrace

At least 6 species of corals were taken from the seaward edge of the 550-foot terrace at Station C. Because of their poor condition only one of them was capable of being identified. The limestone here is very hard; the corals are worn and entirely recrystallized. *Favia pallida* (Dana) seems to fit rather well the only identifiable specimen. This is a common species living today in the Pacific, but it has also been reported by Gerth from the upper Miocene of Java and the upper Miocene and Pliocene of Borneo. Likewise, Umbgrove has reported it from Sumatra and the Plio-Pleistocene of Ceram. Although there is insufficient evidence to tell the age of the corals from this terrace, their appearance, amount of recrystallization, and physiographic position make them older than those of the 200-foot and 340-400 foot terraces. Whether they are Pliocene or Miocene cannot be told.

Vicinity of Ohonua

Most of the corals found in the vicinity of Ohonua come from the road-bed which runs through the town or from the sides of the ravine made by the stream Lakatoha, which cuts through the Western Ridge and enters the sea at the northern boundary of Ohonua. Elevations from which corals were taken at these two places may range from 20 feet to 100 feet. One specimen, *Cyphastrea wanneri* Felix, was found just east of the town on the top of the Western Ridge at an elevation of 310 feet.

Table 3. Corals from the 340-400 Foot Terrace

Species	340-400-foot terrace			100-foot terrace	200-foot terrace	Tee Moa	Ohonua	Other Localities
	Station R	Vaigana	Matalanga					
Favites cf. complanata (Ehr.)	× (?)	....	....	×	×	....	....	Recent: Red Sea. Pliocene: Timor.
Goniastrea retiformis (Lamarck)	×	....	....	×	×	....	×	Recent: Red Sea; Indian Ocean; Amboina; Pacific. Pleistocene: reefs of Red Sea and Christmas Island. Pliocene: Ceram; Dutch New Guinea. Pliocene or Pleistocene: Timor; also Sumatra.
Leptoria cf. gracilis (Dana)	....	× (?)	....	....	×	....	....	Recent: Red Sea; Indian Ocean; Pacific.
Maeandra euaensis, n. sp.	× (?)	....	....	× (?)	....	×	....	
Maeandra, sp.	×	....	....	....	....	....	....	
Hydnophora, sp.	....	....	×	....	....	....	....	
Pavona, sp.	×	×	×	....	....	....	....	
Astreopora tongensis, n. sp.	×	....	....	×	×	....	×	
Porites aff. lobulata Dana	....	×	....	....	×	....	....	Recent: Hawaii; Fanning Island; Fiji.

Of the 11 species listed in Table 4, 10 were indentifiable; of these, 5 (50%) are living and 2 are new. (*Orbicella mansfieldi* Hoffmeister is equivalent to *O.* cf. *praeheliopora* of Felix from the Pliocene or Pleistocene of Timor.) Of the 10 species, 7 are found on the 200-foot terrace and 2 of these also on the 100-foot and the 340-400 foot terraces. Both *Cyphastrea cymotoma* Felix and *C. wanneri* Felix are known elsewhere only from the Pliocene. Of the 5 living species, 3 are known to go into the Tertiary, 1 of these, *Favia pallida* (Dana), as far back as upper Miocene. I feel safe in saying that the corals from Ohonua are of the same age as those of the 200-foot terrace, that is, Pliocene.

Gorge East of Powells Field

Some of the corals from the sides of the deep gorge east of Powells Field (Station P) were loose and slightly waterworn; others were collected in place. The waterworn specimens, because of their good condition, must have come from the very near vicinity. The elevation from which most were obtained is about 300 feet above sea level. The following 9 species were collected. (Asterisk indicates living species.)

Cyphastrea vaughani, new species
*Galaxea cf. lamarcki M. E. and H.
*Favia speciosa (Dana)
*Favia pallida (Dana)
Favia pseudostelligera, new species
*Goniastrea retiformis var. parvistella (Dana)
*Leptoria cf. phrygia (E. and S.)
Leptoria setchelli, new species
Montipora, species

Of the 8 identified species, 5 (62.5%) are living and 3 are new. *Leptoria* cf. *phrygia* (E. and S.) is also found on the 100-foot and the 200-foot terraces. *Goniastrea retiformis* var. *parvistella* (Dana) is a variety of the typical form which is found on the 100-foot and the 200-foot terraces. *Favia pallida* (Dana) is common to the ravine at Ohonua and the 550-foot terrace as well as to Station P. This group of corals seems to be somewhat different from those at the other localities. This is probably due to the differences in environment. The limestone from which these corals were obtained represents an old, elevated, fringing reef behind the barrier reef which is now the Western Ridge. The small number and lack of any deciding species makes the age of this limestone problematical if judged solely by paleontology. The general geological relations, however, show that the rock is of the same age as the Western Ridge or old barrier reef, which is believed to be Pliocene.

The highest point at which coral was found is 760 feet above sea level

Table 4. Corals from the Vicinity of Ohonua

Species	Vicinity of Ohonua: Road-bed	Vicinity of Ohonua: Lakatoha Ravine	Vicinity of Ohonua: Western Ridge	100-foot terrace	200-foot terrace	340-400 foot terrace	550-foot terrace	Gorge (Station P)	Other Localities
Orbicella tongensis, n. sp.	×(?)	×	....	....	×	....	....	....	
Orbicella mansfieldi, n. sp.	×	....	....	....	×	....	....	....	Pliocene or Pleistocene: Timor. Possibly Pleistocene: Christmas Island.
Cyphastrea cymotoma Felix	....	×	....	....	×	....	....	....	Pliocene: Java; Neogene: Nias.
Cyphastrea wanneri Felix	....	....	×	....	×	....	....	....	Pliocene: Timor.
Favia pallida (Dana)	....	×	....	....	....	....	×	×	Recent: Maldives and Chagos eastward to Tonga. Upper Miocene: Java. Pliocene and Upper Miocene: Borneo; Sumatra. Plio-Pleistocene: Ceram.
Goniastrea retiformis (Lamarck)	×	....	....	×	×	×	....	....	Recent: Red Sea; Indian Ocean; Amboina; Pacific. Pleistocene: reefs of Red Sea and Christmas Island. Pliocene: Ceram; Dutch New Guinea. Pliocene or Pleistocene: Timor; also from Sumatra.
Goniastrea pectinata (Ehr.)	×	....	....	....	....	....	....	....	Recent: Great Barrier Reef; S. Philippines; Fiji; Samoa; Tonga. Pliocene: Java and Timor. Neogene: Nias; from Sumatra.
Maeandra aspera (Verrill)	....	×	....	....	×	....	....	....	Recent: Loo Choo Islands; S. Philippines.
Fungia, sp.	×	....	....	....	....	....	....	....	
Pachyseris speciosa (Dana)	....	×	....	....	....	....	....	....	Recent: East Indies; Murray Island; Tahiti; Samoa. Fossil: Lower Miocene (?): Borneo. Neogene: Nias.
Astreopora tongensis, n. sp.	×	....	....	×	×	×	....	....	

at the top of Tee Moa—an isolated hill which rises above the 550-foot terrace. Nearly the whole hill is made of a hard foraminiferal limestone of Eocene age, but the large specimen which I have called *Maeandra euaensis* was found on the very top of the hill where there is little trace of other corals. (See p. 70.) Some specimens from the 340-400 foot and the 100-foot terraces were doubtfully referred to this species. No age can be given.

SYSTEMATIC ACCOUNT OF SPECIES

Genus ORBICELLA Dana

Orbicella Dana, U. S. Expl. Exped. Zooph., p. 205, 1846.
Orbicella Vaughan, Carnegie Inst. Wash., Pub. 213, p. 85, 1918.
Orbicella Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 19, 1925.
Type species: *Orbicella annularis* (Ellis and Solander).

Orbicella tongensis, new species (pl. 7).

Corallum forming rounded masses 11 cm. or more in diameter.

The callices in the type are subcircular, and average 4.5 mm. in diameter. The distance between calices is from 2 to 5 mm. with an average of 3 mm. This is a little greater than in some of the other specimens. The space between the calices is covered with very conspicuous costae. These alternate in size, the larger ones 0.75 mm. thick and the smaller ones approximately one-half or slightly less than one-half as thick. They are beaded on the edges and join in the intercorallite depression either directly or by transverse rods. They correspond to all the septa, the thick ones to the higher cycles of small septa and the thinner to the large septa.

There are about 16 large septa of nearly equal size. These represent the first two cycles and some of the third. Those of the first and second cycles reach the columella, but frequently the large septa of the third cycle join those of the first two just before the columella is reached. Alternating with these large septa are small rudimentary ones which correspond to the thick costae. Septal faces somewhat granular and edges serrate. Paliform lobes on the inner ends of the primaries and secondaries.

Columella composed of septal trabeculae, upper surface papillate.

Endothecal dissepiments numerous, forming curved vesicles.

This species is distinguished by having the thick costae correspond to the small septa and the thin costae to the large septa. This character is remarkably constant in the Eua specimens. A small, worn specimen from Cocos-Keeling in the U. S. National Museum (No. 38375) and identified as *Orbicella versipora* (Lamarck) has this same character and seems to be very close in other respects.

Eua: No. 177 (Type), seaward edge 200-foot terrace at Matalanga; Nos. 5008 and 5027, seaward edge 200-foot terrace at Y; No. 189, loose in small gully at seaward edge of 200-foot terrace at Matalanga; No. 193, *Orbicella* aff. *tongensis* Hoffmeister, roadbed at Ohonua, altitude 85 feet; No. 13, in limestone cliff in ravine made by the Lakatoha near Ohonua west of bend.

Orbicella mansfieldi, new species (pl. 8).

Orbicella cf. *praeheliopora* Felix. Jungteriäre und quartäre Anthozoen von Timor und Obi, 1 Teil, Paläontologie von Timor, lief. II, p. 16, pl. 38, figs. 7, 7a, 1915.

Corallum forms large rounded masses. The type, which is a fragment of one of these large masses, measures 12 cm. deep from the calicular surface toward the basal portion of the corallum. The surface itself is subrectangular with a length of 9 cm. and a width of 5.5 cm.

The calices are usually subcircular although some are elliptical or somewhat distorted. The diameter as measured between the summits of calicular walls is 3.5-4.5 mm.; diameter of calicular opening, 3-3.5 mm. A few elongated calices measure 5.5 mm. in diameter. The distance from summit to summit of calicular walls of adjoining corallites is about 1 mm.

The costae are conspicuous; from 20-22 large subequal ones are plainly visible. In the fully developed corallites, very small, rudimentary costae alternate with most of the large ones although they seldom make a complete round. The costal edges possess a few beads near the bottom of the intercorallite valleys. Occasionally the costae join to corresponding ones of adjoining corallites, but they usually end loosely in the intercorallite valley.

The septa range in number from 20 to 44; primaries and secondaries subequal and reach the columella, as do also a few tertiaries in some of the calices. From 8 to 10 tertiary septa are rather well developed, which makes in all 20 to 22 large septa. These correspond to the 20 to 22 large costae. In most of the calices there are very small rudimentary septa which alternate with the large ones. These usually, but not always, have corresponding rudimentary costae. The septal faces are rather rough with irregularly placed granules. Paliform lobes are on the inner ends of the septa which reach the columella.

The columella is composed of septal trabeculae, is large and spongy.

Endothecal dissepiments numerous and nearly horizontal. Exothecal dissepiments coarser and measure 15 to 18 in 1 cm.

Reproduction by intercalicular budding. Occasionally a calice becomes elongated and subequal fission occurs.

This species seems to fit the specimen described by Felix under *Orbicella* cf. *praeheliopora* Gregory. It is so difficult to tell from Gregory's description and figure of the type of *O. praeheliopora* just what that species is like that I have separated the Eua specimens under a new name. A redescription of the type of *O. praeheliopora* is needed and even then it would be difficult to work with because of its poor preservation.

Orbicella mansfieldi is very close to *O. irregularis* (Martin) (Die Tertiärschichten auf Java, p. 141, Taf. XXV, fig. 1, Taf. XXVI, fig. 5) from the Miocene of Java, as pointed out by Felix. Martin's figure of that species, however, shows somewhat larger and more irregular calices. A specimen (No. 61) from the western side of Eua near the village of Tufu, shows slightly larger and more irregular calices, but not to the extent of placing it with *O. irregularis*.

Eua: No. 5016 (Type); No. 5007, seaward edge of 200-foot terrace at Y; No. 61, from road leading from Tufu to Ohonua, same altitude as Tufu and about 500 feet north of it.

Reported by Felix from the Pliocene or Pleistocene of Timor from an altitude of about 260 meters above sea level.

Orbicella parksi, new species (pl. 9, *A*).

Large, flat frond with calices on all sides, except base, where it has been broken from remainder of corallum. It measures 11 mm. in length and 11.5 mm. in width, and has a maximum thickness of 3 mm.

The calices are small, subcircular, with an average diameter of 2 mm. Depth of calices appears to be normally about 1 mm. Distance between neighboring corallites 1 to 2 mm. with an average of 1.5 mm.

Intercorallite areas are costate. Costae subequal or alternate in size; moderately elevated; edges apparently dentate. There are from 18 to 22 subequal costae in each calice. Occasionally a few small ones alternate with these. Costae either join those of neighboring calices or alternate with them.

Character of septa is not very clear on type because of wear and recrystallization. About 12 seem to reach the columella. The six primaries are somewhat larger than the secondaries and very distinct. The septa of the third cycle, which are very small, are seen only in the best preserved portions and it is impossible to say whether or not this cycle is complete. A paliform lobe appears on the inner end of each septum which reaches the columella. Septal faces finely granulate.

Columella rather well developed, formed by the septal ends.

This species is very similar in size of calices and general appearance to *Orbicella annularis* (Ellis and Solander), which is very common in the Atlantic Ocean today, and in the Pleistocene and Recent throughout the elevated reef areas of the West Indies, eastern Central America and Florida. The main difference between these two is that the primary septa of *O. parksi* are larger than the secondaries. This character places it near *O. limbata* (Duncan). The latter species, however, usually has larger calices, more conspicuous costae and wider intercorallite areas.

Eua, No. 90, from seaward edge of 200-foot terrace at Ravine (Station Ra).

Orbicella laddi, new species (pl. 9, *B*).

Corallum forming rounded masses. Type and only specimen is fragment measuring 8 cm. in its longest dimension.

Calices subcircular in places where they are crowded, or somewhat distorted; project 1 or 2 mm.; variable in size; diameter usually 5.5 to 6.5 mm. with an average of 6 mm.; distance between calices from 0.5 to 3 mm. Corallites joined by prominent, rather thick costae, which correspond to all the septa. Costae in a few places appear subequal, but in the main three sizes can be made out corresponding to the 3 cycles of septa. Those corresponding to the primary septa and two of the secondaries are very large, as much as 0.75 mm. thick; those corresponding to the other secondaries are thinner, and those to the third and fourth cycles are thinnest. Costal edges with large beads; most prominent near intercorallite valley.

Septa 24 to 32 in number. In smaller calices three complete cycles; first two reach columella and third extends nearly half way from wall to center. In the average-sized calice 14 reach the columella and 14 smaller septa alternate with these. Septa thickened in wall. Septal faces slightly granulate. Septal edges roughly serrate; exsert 1 mm. above wall; paliform lobe on inner ends of those which reach columella.

Columella formed of twisted septal trabeculae; well developed.

Endothecal dissepiments well developed, sloping from wall to center at 45° angle. Exothecal dissepiments nearly horizontal, 4 or 5 within 2 mm.

This species is somewhat similar to *Orbicella laxa* Klunzinger, but differs in several ways. The septa are thicker and the costae are more inclined to vary in size according to the cycle.

Eua, No. 166, seaward edge of 200-foot terrace at Matalanga.

Genus **CYPHASTREA** Milne Edwards and Haime

Cyphastrea Milne Edwards and Haime, Acad. Sci., Comptes rend., vol. 27, p. 494, 1848.

Cyphastrea Vaughan, Carnegie Inst. Wash., Pub. 213; p. 87, 1918.

Cyphastrea cymotoma Felix (pl. 10, *C*).

Cyphastrea cymotoma Felix, Die fossilen Anthozoen aus der Umgegend von Trinil, Palaeontographica, Bd. 60, p. 346, Taf. 26, figs. 4, 4a, 1913.

Felix (31) has described two specimens, Nos. 98 and 99, which are somewhat different from each other. The Eua specimen agrees in growth form and general appearance with No. 98 which Felix has figured on Plate 26, figs. 4 and 4a. The only difference is that the calices are slightly larger, 1.4 to 2 mm. In this respect it agrees with Felix's example No. 99. One of the outstanding features of the species is the distance between the corallites, which frequently amounts to 3 mm.

Eua: No. 213, cliff at south side of ravine at Ohonua; No. 111, seaward edge of 200-foot terrace at Ravine (Station Ra.).

Reported by Felix (30) from the Pliocene coral reef of Duku Pengkol from the left bank of the river Solo, near Trinil, Java. Reported by Gerth (38) from the Neogene of Nias.

Cyphastrea wanneri Felix.

Cyphastrea wanneri Felix. Jungtertiäre und quartäre Anthozoen von Timor und Obi. Pal. von Timor, Lief. II. Teil 1, p. 17, pl. 38, figs. 1, 1a, 2, 1915.

This species seems to be distinct from any living ones that have been reported up to the present time. It is characterized by having three cycles of septa, rather large calices and rather thick calicular walls. The septa of the first two cycles are subequal and reach the columella. In worn calices the septa of the first cycle are more distinct and resist the wear better than the others. Felix says that the septa of the third cycle are often not completed. Twelve septa, however, always reach the columella. In this it differs from the living *C. microphthalma* (Lamarck) which usually has only 10 septa reaching the columella and 10 small ones alternating with the larger ones.

The calices in the Eua specimens are 2.5-3 mm. in diameter. The calicular openings are 1.5-2 mm. in diameter. The distance between the calicular walls of adjacent corallites is seldom more than 1 mm.

Gerth (37, p. 86) has placed *C. wanneri* Felix with *C. chalcidicum* (Forskål). As Vaughan has recorded (82, p. 87), there is a good suite of specimens belonging to *C. chalcidicum* in the U. S. National Museum including one from Goidu, Maldives, labeled by Matthai. It is clear that the two species are distinct. The calicular walls of *C. wanneri* are decidedly thicker than those of *C. chalcidicum*. It may be that Gerth's specimens belong with *C. wanneri* but his description is too brief to make it possible for me to state an opinion.

Eua: Nos. 5001, 5002, 5006, and 5011, seaward edge of 200-foot terrace at Y; No. 468, top of Western Ridge just behind Ohonua, altitude 310 feet.

Reported by Felix from the highest point at Gempol-Rand, Timor, at an elevation of 1200 meters above sea level; from Plateau one hour east of Tjamplong in Dutch Timor, at an elevation of 250 meters above sea level; also from Niki Niki in Dutch Timor, Pliocene age.

Cyphastrea vaughani, new species (pl. 10, *A, B*).

Corallum large, massive; upper surface rounded, mainly smooth with a few undulations. Upper surface measures roughly 26 by 19 cm. and the corallum is 18 cm. thick.

Corallites 1.5-2 mm. in diameter, including thickness of walls; calicular openings 1-1.5 mm. in diameter, usually 1.2 mm. Calices deep, may be 2 mm. or slightly more. Distance between the summits of the walls of adjacent corallites never more than 2 mm., usually 1 mm. or less; evenly distributed over surface. Corallites project only slightly above exotheca.

Intercorallite spaces covered with distinct pappillate granulations, some of which continue in rows from the beaded costae. The latter are usually beaded only in their basal parts. The costae corresponding to the first two cycles of septa are distinct and slope down to the intercorallite space. Those corresponding to the third cycle of septa are rudimentary if not lacking.

The septa are in three cycles. Those of the first two reach the columella. The primaries are slightly thicker than the secondaries, although this is not always noticeable. The secondaries seem to reach the columella a little farther down than the primaries. The tertiaries are very small, but as far as observed are complete in number. All the septa project slightly above the wall, those of the first two cycles noticeably more than the tertiaries. The corallite wall is much thinner than that of *C. wanneri* Felix.

The columella is composed of septal spines; diameter about one-third that of calice.
Exothecal vesicles thick, averaging about 0.5 mm. apart.

This species differs from *C. serailia* (Forskål) by its thick exothecal vesicles, its poorly developed costae which correspond to the third cycle of septa, the fact that the corallites never project as much as 2 mm., and its deep calices. It differs from *C. chalcidicum* (Forskål) in that the corallites do not project perpendicularly from the exotheca, by its very well developed costae with sloping edges, and its large exothecal granulations and deep calices. Good suites of *serailia* and *chalcidicum* are in the U. S. National Museum.

One of the outstanding characteristics of the species is its deep calices.

Eua: No. 406, from deep gorge east of Powells field (Station P).

Genus GALAXEA Oken

Galaxea Oken, Lehrb. Naturg., Th. 3, Abth. 1, p. 72, 1815.
Galaxea Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 223, 1857.
Galaxea Vaughan, Carnegie Inst. Wash., Pub. 213, p. 98, 1918.
Type species: *Madrepora fascicularis* Linnaeus.

Galaxea fascicularis (Linnaeus).

Madrepora fascicularis Linnaeus, Syst. Nat., ed. 12, p. 1278, 1767.

Galaxea haligena Felix, Die fossilen Anthozoen aus der Umgegend von Trinil, Palaeontographica, Stuttgart, vol. 60, p. 339, pl. 26, figs. 1, 2, 2a-c, 1913.

Galaxea fascicularis Matthai, Trans. Linn. Soc. London, 2nd ser., Zool., vol. 17, p. 59, pl. 8, fig. 4; pl. 16, fig. 4; pl. 34, fig. 3; pl. 38, fig. 6, 1914.

Galaxea fascicularis Vaughan, Carnegie Inst. Wash., Pub. 213, p. 98, pl. 33, figs. 2, 3, 3a; pl. 34, fig. 1, 1918.

Two specimens from the 200-foot terrace seem to fit this species very well. In the largest calices there are 4 complete septa but in the smaller ones the 4th cycle is incomplete. *Galaxea haligena* Felix probably belongs to this species also. Felix likens it to *Galaxea irregularis* Milne Edwards and Haime but says it differs from that species by its more prominent costae. Matthai has included *G. irregularis* in the synonymy of *G. fascicularis* and he is probably right in doing so. Many specimens of *G. fascicularis* in the U. S. National Museum possess exceptionally well pronounced costae. The corallite walls may be nearly smooth in one part of the corallum and decidedly ribbed in another part. In the specimen which Dana identified as *Anthophyllum cespitosum,* which Vaughan has placed with *G. fascicularis,* the corallites all over the corallum possess well developed costae throughout their length. Thus this is not a specific characteristic.

Eua: Nos. 165 and 169, seaward edge of 200-foot terrace at Matalanga.

Living: Red Sea; Indian Ocean; Great Barrier Reef; Philippine Islands; Fiji Islands; Samoa.

Fossil: reported by Felix as *G. haligena* from the Pliocene of Java; Gerth (37, p. 89) reports *G.* cf. *fascicularis* (Lin.) and *G. haligena* Felix from the Miocene of Borneo; Umbgrove has found *G. fascicularis* in the Neogene of Sumatra.

Galaxea cf. **lamarcki** Milne Edwards and Haime.

Galaxea lamarcki Milne Edwards and Haime, Hist. Nat. Corall., II, p. 225, 1857.

Galaxea lamarcki Matthai, Trans. Linn. Soc. London, 2d ser., Zool., vol. 17, p. 64, pl. 13, fig. 6; pl. 16, fig. 1; pl. 34, fig. 2, 1914.

The species is characterized by large perithecal vesicles and small corallites, which have three cycles of septa. The septa of the first cycle are much thicker and more prominent than those of the second cycle. In this they resemble *G. explanulata* Quelch, which Matthai places here. In mature corallites most of the secondaries as well as all of the primaries reach the columella. The tertiaries are rudimentary.

Eua; No. 399, deep gorge east of Powells field (Station P). Other localities.

Living: Maldives; Chagos; Sayade Malha; Red Sea; Fiji.

Genus FAVIA Oken

Favia Oken, Lehrb. Naturg., Th. 3, Abth. 1, p. 67, 1815.

Favia Vaughan, Carnegie Inst. Wash., Pub. 213, p. 100, 1918.

Favia speciosa (Dana).

Astraea speciosa Dana, U. S. Expl. Exped., Zooph., p. 220, pl. 11, figs. 1, 1a to 1d, 1846.

Favia speciosa Vaughan, Carnegie Inst. Wash., Pub. 213, p. 103, pl. 36, figs. 1, 2, 2a, 3, 4, 4a; pl. 37, figs. 1, 2, 3, 4, 4a, 1918.

Favia speciosa Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 23, 1925.

Favia speciosa Faustino, Recent Madreporaria of the Philippine Islands, p. 130, plates 25 and 26, 1927.

A small example seems to fit this living species perfectly. There is a large collection of specimens belonging to *F. speciosa* in the U. S. National Museum including Dana's types.

Eua: Deep gorge east of Powells field (Station P).

Recent: Red Sea; Djibouti; Maldives; Chagos; Ceylon; Cocos-Keeling Islands; Great Barrier Reef; Amboina; Fiji Islands; Fanning Island.

Fossil: Neogene of Nias and reported by Umbgrove from Sumatra.

Favia pallida (Dana).

Astraea pallida Dana, U. S. Expl. Exped., Zooph., p. 224, pl. 10, figs. 13, 13a-13e, 1846.

Favia pallida Vaughan, Carnegie Inst. Wash., Pub. 213, p. 105, pl. 38, figs. 1-7 (with synonymy), 1918.

Vaughan (82) has placed Dana's *A. versipora* with *Favia pallida* (Dana) and I believe he is right in doing this.

The original specimen of Dana's *Astraea versipora* (*non* Lamarck) is No. 76 U. S. National Museum. This is nearly identical with a medium sized specimen taken from the living reef at Nukualofa, Tongatabu. A fossil specimen from a deep gorge in the interior of the island of Eua, Station P, also belongs here. The only difference between the living and fossil specimens is in the somewhat deeper calices of the former. This can be explained by the relatively worn condition of the fossil.

One of the main characteristics of *F. pallida* is that the septa are highly exsert. This condition is decidedly noticeable even on the somewhat worn fossil. The columella is weakly developed.

A badly worn specimen, which I have referred to this species with some doubt, comes from the seaward edge of the 550-foot terrace. The septa are thicker than in the other specimens.

Gerth (37, p. 72) lists two forms of *F. pallida* from Borneo, forma *F. doreyensis* E. and H. and forma *Astraea rotulosa* Lamarck. Under the former form he places *F. denticulata* Gardiner (1904), Felix (1913) and Gerth (1920). According to Matthai (59, p. 84) *F. denticulata* Gardiner belongs to *F. doreyensis* E. and H. which Vaughan (82, p. 105) considers the same as *F. pallida* (Dana). This form according to Gerth comes from rocks of Pliocene age. The *rotulosa* form, which Vaughan also has placed under *F. pallida* (Dana) is reported by Gerth to come from the upper Miocene of Borneo.

Stations in Eua: Nos. 417 (Type), 398, and 411, from deep gorge east of Powells field (Station P), altitude about 320 feet; No. 20, top of ravine made by Lakatoha stream at bend east of Ohonua; No. 80, from cliff at Station C, seaward edge of 550-foot terrace, eastern side.

Recent: from the Maldives and Chagos eastward to the Tongan islands.

Fossil: Gerth (36, p. 413) has reported a specimen which he places with some doubt with this species from the upper Miocene of Java; also he reports (37, p. 72) the species from the Pliocene and upper Miocene of

Borneo, and from the Neogene of Nias; reported by Umbgrove (76; 77) from Sumatra and the Plio-Pleistocene of Ceram.

Favia pseudostelligera, new species (pl. 11, *A*).

Corallum massive and rises into hillocks. The type is evidently one of such hillocks which has been broken at its base from the main part of the colony. It tapers somewhat toward the top which is rounded. Height 6 cm.; cross-section of broken base elliptical, its longer axis measuring 44 mm., and shorter 36 mm.

The calices are subcircular, elliptical or decidedly elongate if reproduction is taking place. Diameter of average subcircular calicular opening 3 mm.; longer axis in elliptical ones averages 3.5 mm., and those in the act of reproducing are as much as 5 or 6 mm. long. Distance between corallites 1.5-3.5 mm.; average 2.5 mm. Intercalicular space costate. Costae distinct, alternate in size, larger ones may join those of adjoining corallite furrow.

Septa in fully developed calice in three cycles; those of the first two cycles subequal and reach columella; those of third cycle smaller and reach about half way from wall toward the center of the calice. Septal edges serrate and septal faces somewhat granulate. The inner ends of some of the large septa apparently have paliform lobes.

Columella well developed and composed of twisted ends of the larger septa. Where preserved they are 1 to 1.5 mm. in diameter.

Reproduction by equal or unequal fission.

This species is somewhat similar to *Favia stelligera* (Dana) in growth form and general appearance. The calices are larger and the septa more numerous than in the latter species. Another specimen from the same locality has slightly larger calices.

Station in Eua: Nos. 155 (type), 401, 154, and 394, from deep gorge east of Powells field (Station P).

Genus FAVITES Link

Favites Link, Besch. Nat. Samml., Rostock, 3d pt., p. 162, 1807.
Favites Verrill, Trans. Conn. Acad. Arts and Sci., vol. II, p. 92, 1902.
Favites Vaughan, Carnegie Inst. Wash., Pub. 213, p. 109, 1918.
Favites Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 24, 1925.

Favites cf. **complanata** (Ehrenberg) (pl. 11, *B*).

Favia complanata Ehrenberg, Corall. Roth. Meer., p. 93, 1834.
Astraea tessifera Ehrenberg, Corall. Roth. Meer., p. 97, 1834.
Prionastraea tessifera Klunzinger, Corall. Roth. Meer., iii, p. 37, pl. 4, fig. 9, 1879.
Favia complanata Matthai, Trans. Linn. Soc. London, 2d ser., Zool., vol. 17, p. 109, pl. 30, figs. 1-3, 1914.
Prionastraea tessifera Felix, Paläontologie von Timor. Jungtertiäre und quartäre Anthozoen von Timor und Obi., Teil 1, p. 25, 1915.

I have placed three specimens here with some small doubt. The usual growth form of the species is incrusting, with thin corallum. The Eua specimens have a thickness of about 40 mm. Matthai (59, p. 110) in his treatment of the species says, "This species is variable to even a greater extent than *F. abdita,* all the stages from a light corallum with thin walls and septa to a heavy corallum with thick walls and septa being present."

The number and size of the septa and calices lead me to place the specimens here. There are several good examples from the Red Sea in the U. S. National Museum.

Eua: No. 174, seaward edge of 200-foot terrace at Matalanga; No. 332, seaward edge 340-400 foot terrace at R. (referred here with doubt.); No. 100, seaward edge of 100-foot terrace, east of Monument (Station M).

Reported living in Red Sea. Felix reports it from the Pliocene at Niki Niki in Timor.

Favites magna, new species (pl. 12).

Corallum large, apparently subhemispherical clump. Type is one-half of original specimen; has depth of 15.5 cm. and the greatest diameter measured perpendicular to the direction of corallite growth is 19 cm. No hillocky structure apparent.

The calices are large, polygonal, frequently pentagonal. The greatest diameter of the mature calices is from 15-20 mm. The top of the corallum has been somewhat worn so that it is difficult to tell the original depth of the calices; probably 8-10 mm. Walls of adjoining corallites fused and are about 2 mm. thick when measured in vertical cross section.

The septa are numerous, of medium thickness, and are somewhat thicker at the wall. There are 35 to 40 septa in the mature calices. These are all large and subequal in thickness. About 18-20 reach the columella. Most of the remainder curve and join the longer one just before the latter reach the columella. Occasionaaly a small rudimentary septum may appear between two large ones. The septal edges were evidently originally much serrated. The septal faces are very smooth.

The columella is rather well developed, but relatively narrow; composed of septal trabeculae.

Endothecal dissepiments thin, rather poorly developed, curve downward at about 45° from the wall.

Reproduction by marginal fission.

This species is similar to *Favites vasta* (Ehrenberg) in the size and appearance of the calices but differs in its growth form and character of the septa. *F. vasta* has a flat, thin corallum frequently encrusting, whereas *F. magna* has a large, thick, subhemispherical corallum. Also *F. vasta* nearly always has a cycle of small rudimentary septa alternating with the larger ones. One of the outstanding characteristics of *F. magna* is the subequal septa.

Dana's *Astraea felicosa* (Wilkes Expl. Exped. p. 232), the type of which is in the U. S. National Museum, is similar as regards size of calices and growth form. It differs in that the columella is much broader and consequently the septa shorter. According to Dana (16), "In a vertical section, the part below the center of a cell, for the width of a third of an inch is extremely cellular or filamentous in structure."

The only specimen in the collection was found loose on the slope leading to the Liku beach on the eastern side of Eua at an altitude of about 300 feet.

Genus GONIASTREA Milne Edwards and Haime

Gonistrea Milne Edwards and Haime, Acad. Sci., Comptes rend., vol. 27, p. 495, 1848.

Type species: *Astrea retiformis* Lamarck.

Goniastrea retiformis (Lamarck) (pl. 13).

Astrea retiformis Lamarck, Hist. Anim. sans vert., 11, p. 265, 1816.

Goniastrea parvistella Vaughan, Carnegie Inst. Wash., Pub. 213, p. 114, pl. 44, figs, 2, 2a, 1918.

Goniastrea retiformis Vaughan, op. cit., p. 114, pl. 15, fig. 24; pl. 16, fig. 25 (with synonymy), 1918.

Goniastrea retiformis Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 26 (with synonymy), 1925.

I have placed a large suite of specimens with this species. The typical specimens are characterized by the following features:

Corallum massive with even topped, undulating surface. Calices polygonal; diameter 2 to 4 mm. Intercalicular walls 0.5 mm. to 1 mm. thick. In the average calice there are 20 septa, alternating with which is a cycle of rudimentary septa. From 7 to 11 large septa reach the columella.

Most of these fossil specimens differ somewhat from the recent specimens of this species in the U. S. National Museum by having more numerous endothecal dissepiments. The recent specimens from Murray Island identified by Vaughan have on the average 10 to 11 dissepiments in one centimeter. This is likewise true of those from the living reefs of Eua. In a large number of the fossil specimens there are as many as 20 dissepiments in one centimeter. Also the septal faces of the fossil specimens are somewhat rougher with granules. However, Gardiner's specimen of *G. solida* from the passage at Hulule, which Matthai has placed in *G. retiformis,* has dissepiments as close together and septal faces that are as rough. There is apparently wide variation in these features.

In my report of some recent corals from Samoa and Fiji (42), I placed *G. parvistella* with *G. retiformis* and called it a variety. The only difference between these two forms is in the thickness of the walls. The *parvistella* variety has thicker walls which average 1 mm. in this respect. One specimen (No. 418) from Eua belongs in this variety.

In Eua typical *Goniastrea retiformis* (Lamarck) was collected in the following places: on the 100-foot terrace, east of Monument (Station M), two specimens; on the 200-foot terrace, at ravine (Station Ra.), 4 specimens; at Matalanga, 1 specimen; at Y, 1 specimen; on seaward edge of 340-400-foot terrace, 1 specimen; at Ohonua, altitude 85 feet, 1 specimen; altitude 40 feet, 2 specimens; loose in gully at seaward edge of the 200-foot terrace at Matalanga. *Goniastrea retiformis* variety *parvistella* (Dana) was found in the deep gorge east of Powells field (Station P), one large specimen.

Living: Red Sea; Indian Ocean; Great Barrier Reef; Amboina; Philippine Islands; eastward in Pacific to Samoa.

Fossil: reported from the Pleistocene reefs of the Red Sea, the Pliocene of Ceram and Dutch New Guinea, and the Pliocene or Pleistocene of Timor by Felix (31, p. 28; 32, p. 34); Pleistocene of Christmas Island and from Sumatra.

Goniastrea pectinata (Ehrenberg).

Astraea pectinata Ehrenberg, Corallenth. Roth. Meer., p. 96, 1834.

Goniastrea favus, and *G. pectinata* Felix, Die fossilen Anthozoen aus der Umgegend von Trinil. Paläontographica, Band 60, Stuttgart, pp. 353, 354, 1913.

Goniastrea pectinata Felix, Jungtertiäre und quartäre Anthozoen von Timor und Obi, Teil 1, p. 26, 1915.

Goniastrea pectinata Vaughan, Carnegie Inst. Wash., Pub. 213, p. 114, pl, 42, figs. 3, 3a, 4, 4a; pl. 43, figs. 1, 2, 3, 3a, 4, 5, 5a; pl. 15, figs. 21, 22, 23 (with synonymy), 1918.

Goniastrea favus Felix, Jungtertiäre und quartäre Anthozoen von Timor und Obi, Teil II, p. 11, 1920.

There is one fossil specimen in the Eua collection of this well known species. Two specimens which in all probability belong in this species were taken from the seaward edge of the living fringing reef of the small island of Makahaa in the harbor of Nukualofa, Tongatabu. They differ only in having slightly smaller calices and thinner walls than is typical. Both of these characters seem to be variable, however, as can be seen in the large suite of specimens belonging to the species in the U. S. National Musum.

Eua: No. 197, roadbed at Ohonua, altitude 85 feet.

Living: Red Sea; Great Barrier Reef; southern Philippine Islands; Fiji; Samoa; Makahaa, Tonga.

Fossil: reported from the Pliocene of Java and the Pliocene or Pleistocene of Timor by Felix; reported from Sumatra by Umbgrove and from the Neogene of Nias by Gerth.

Genus **LEPTORIA** Milne Edwards and Haime

Leptoria Milne Edwards and Haime, Acad. Sci., Comptes rend. vol. 27, p. 493, 1848.

Type species: *Madrepora phrygia* Ellis and Solander.

Leptoria cf. **phrygia** (Ellis and Solander).

Madrepora phrygia Ellis and Solander, Nat. Hist. Zooph. p. 162, pl. 48, fig. 2, 1786.

Leptoria phrygia Vaughan, Carnegie Inst. Wash., Pub. 213, p. 117, pl. 45, figs. 4, 5; pl. 46, figs. 1, 2, 3, 1918.

Platygyra phrygia Matthai, Cat. Mad. Corals, Brit. Mus. (Nat. Hist.), vol. VII, p. 112, pl. 1, fig. 3; pl. 10, figs. 5-7, 9; pl. 11, figs. 5-6; pl. 12, figs. 3, 6; pl. 49, figs. 1-2; pl. 50, fig. 1; pl. 65, fig. 4, 1928.

This species is characterized by having 11 to 12 large septa to 1 cm., without or rarely with intermediate septa, septal margins flat across the collines and valleys with a width of 3 to 5 mm. *L. gracilis* (Dana) differs from *L. phrygia* in having more numerous septa. In my Samoan paper (42), I pointed out the similarity between the two species and indicated that eventually they may have to be united, since the number of septa is variable and specimens are frequently found which have an intermediate number to the cm. Also it appears that the position of the septa over the walls, whether they arch or are flat, is variable. At present, however, I am keeping them separate and using the number of septa as the chief distinguishing feature. A few specimens from various stations in Eua seem to belong to *L. gracilis*.

Stations in Eua: No. 110, seaward edge of 200-foot terrace at ravine (Station Ra.); Nos. 93 and 96, seaward edge 100-foot terrace east of Monument (Station M); No. 5024, seaward edge 200-foot terrace at Y; No. 173, seaward edge 200-foot terrace at Matalanga; No. 392, deep gorge near Powells field (Station P).

Living: Cocos-Keeling Islands; southern Philippines; Ceylon; Samoa (?).

Leptoria cf. **gracilis** (Dana).

Meandrina gracilis Dana, U. S. Expl. Exped., Zooph., p. 261, pl. 14, figs. 6, 6a, 6b, 1846.

Leptoria gracilis Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 407, 1857.

Leptoria gracilis Vaughan, Carnegie Inst. Wash., Pub. 213, p. 118, pl. 46, figs. 4, 4a; pl. 17, fig. 34, 1918.

Platygyra gracilis Matthai, Cat. Mad. Corals, Brit. Mus. (Nat. Hist.), vol. VII, p. 122, pl. 10, fig. 8; pl. 12, fig. 4, 1928.

This species has in its typical form about 19 septa to the cm. For further remarks see under *Leptoria phrygia* (E. and S.). There are three specimens in the collection which I am placing here. They are very similar to the Murray Island ones described by Vaughan.

Eua: Nos. 5009 and 5028, seaward edge of 200-foot terrace at Y; No. 258, doubtfully referred here because of slightly less crowded septa (15-17 to 1 cm.); seaward edge 400-foot terrace at Vaigana.

Living: Indian Ocean; Red Sea; Fiji Islands; Murray Island.

Leptoria setchelli, new species (pl. 14).

This species forms very large, massive heads. The corallum of the type even-topped, undulating, with large pointed knobs shaped like the end of an anvil. Measures 22 cm. in height and has a maximum width of 20 cm. Thin epitheca around base.

Calices indistinct, a system of meandering collines and valleys. Valleys run into each other and seem to have no end. Distance between summits of collines from 3.5 to 6 mm., average 4.5 mm. Depth of valleys, 2.5-3 mm. Septa rather thick and substantial, slightly exsert, 12-14 to every centimeter. Upper margins form broad arches across walls. In most places septa are subequal and reach columella, but here and there a small, rudimentary one is found. They cross walls and usually fuse with corresponding septa of neighboring row. Width of intercorallite wall from 1 to 2.5 mm., average 1.7 mm.

Columella lamellar with plates compressed parallel to the valleys.

This species is somewhat similar to *L. gracilis* (Dana) and *L. phrygia* (E. and S.). It differs from both of these by its wider valleys and thicker intercorallite walls.

Eua: Nos. 407 (type), 405, 408 and 156, from deep gorge east of Powells field (Station P.).

Genus MAEANDRA Oken

Maeandra Oken, Lehrb. Naturgesch., Th. 3, Abth. 1, p. 70, 1815.

Maeandra Vaughan, Carnegie Inst. Wash., Pub. 213, p. 119 (with synonymy), 1918.

Type species: *Madrepora labyrinthiformis* Linnaeus.

Maeandra aspera (Verrill) (pl. 15, *A*).

Goniastrea aspera Verrill, Proceedings of Essex Inst., vol. 5, p. 32, 1866.

Goniastrea aspera Faustino, Recent Madreporaria of the Philippine Islands, p. 141, pl. 33, figs. 1, 2, 1927.

Verrill's co-types of *Goniastrea aspera* from the Loo Choo Islands are Nos. 402 and 403 of the U. S. National Museum. Vaughan pointed out in his Murray Island paper, page 114, that in all probability this species should be placed with *Maeandra* because of its roughly and irregularly dentate septa and slit walls. I believe he is correct in this and so place it.

The following description adds somewhat to Verrill's account:

Corallum evenly convex or hemispherical, adherent at center below; edges thin, inclined to spread out horizontally or curl up. Epitheca well developed, marked by uneven, concentric lines which are roughly parallel to the growing edge.

Calices polygonal, distorted, inclined to meander. Those which are not decidedly elongate have an average diameter of 6 mm.; the elongated ones measure about 9 mm. in length and 5 mm. in breadth. Depth of calices as much as 4 or 5 mm. in deeper calices near top of corallum and as shallow as 2 mm. in calices near edge. Calicular walls usually rather thin, 0.5 to 1 mm. Walls between calices seem to be fused in most places; in worn part of corallum, however, a slit appears between the calices revealing two distinct walls.

Septa in a nearly circular corallite, which measures 6 mm. in diameter, number 44; 22 of these are large and alternate with small, rudimentary ones; 12 reach the columella and two other large ones bend and fuse to these just before the columella is reached; the remainder of the 22 reach from ¼ to ½ way from wall to columella. In the larger, elongated calices the septa are correspondingly more numerous. Septal edges extremely rough with large irregular indentations, the latter covered with fine granulations. Inner ends of edges of septa which reach or nearly reach columella possess large paliform lobes. Septa somewhat exsert above walls; either alternate or join with those of the next calice. Septal faces rough with numerous fine granulations.

Columella moderately developed, composed of fused and twisted septal ends.

There are five specimens of the species from the southern Philippines in the U. S. National Museum. Faustino (29) has pictured one of these.

There are two fossil specimens from Eua which I have placed here. One of them has worn septal edges but the slit walls and other characters show it to belong to this species.

Eua: No. 5000, seaward edge of 200-foot terrace at Y; No. 15, limestone cliff in ravine at Ohonua west of bend, about 30 feet above sea level.

Living: Loo Choo Islands; southern Philippines.

Maeandra cf. **lamellina** Ehrenberg.

Maeandra (Platygyra) lamellina Ehrenberg, Corallanthiere Roth. Meer., p. 99, 1834.

Coeloria arabica Klunzinger, Korall. Roth. Meer., pt. 3, p. 17, pl. 12, figs. 1-3; pl. 9, figs. 10a-10c, 1879.

Maeandra lamellina Felix, Die fossilen Anthozoen aus der Umgegend von Trinil, Palaeontographica, Band 60, p. 358, 1913.

Maeandra lamellina Vaughan, Carnegie Inst., Wash., Pub. 213, p. 119, pl. 45, figs. 2, 2a, 1918.

Maeandra lamellina Gerth, Die Anthozoenfauna des Jungtertiärs von Borneo, p. 77, 1923.

Maeandra lamellina Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 29, 1925.

Coeloria lamellina Matthai, Cat. Mad. Corals, Brit. Mus. (Nat. Hist.), vol. VII, p. 37, pl. 6, figs. 2-6, and many other illustrations, 1928.

A very large specimen from the seaward edge of the 200-foot terrace appears to belong here. It is closer to the specimens in the U. S. National Museum from Murray Island, Australia, identified by Vaughan as this species, than to any other of which I know. They agree in having thick walls and septa. The columella is trabecular and rather well developed as in the Murray Island specimens.

Eua: No. 5632, seaward edge of 200-foot terrace at Y.

Living: Red Sea; Indian Ocean; Murray Island, Australia; southern Philippine Islands; Samoa; Wake Island.

Fossil: reported by Felix from the Pliocene of Java and var. *leptochila* Ehrenberg from the Pliocene or Pleistocene of Timor; reported by Gerth (37, p. 77) from the Pliocene of Borneo.

Maeandra euaensis, new species (pl. 15, *B*).

Valleys winding, tortuous. On the center of the top of the corallum the calices are either circumscribed or form short series 1-1.5 cm. long. Toward the periphery the series become longer with an average length of 2.2 cm. At the periphery they are the longest and some reach 50 mm., although this is unusual. Width of valleys 4-5 mm.; because of the weathered condition of the surface it is impossible to tell the depth. Walls thin, about 0.5 mm. in thickness.

Septa thin, 12 to 14 to centimeter, equal. Only occasionally a rudimentary septum appears between the larger ones. The similarity in size of the septa and the fact that they are placed at equal intervals gives an appearance of neatness to the series.

Columella well developed, trabecular.

A large specimen belonging to the Coeloria division of *Maeandra* was found on the top of Tee Moa, at an altitude of 740 feet. This is the highest point on the island from which a coral was collected.

This species is very similar to an unidentified recent specimen in the U. S. National Museum from the Philippine Islands, collected by J. B. Steere. The more irregular growth form of the latter and slightly more numerous septa to the cm. keeps me from uniting them. One of the outstanding characters of the species is the subequal size of the septa. In this and in some other ways it is very similar to *Maeandra equisepta* (Gregory) from the Pleistocene of Christmas Island. Felix also reported this species from the Pliocene or Pleistocene of Timor. The valleys of *M. equisepta,* however, are usually longer. The figures of both Gregory and Felix are too poor to make identification certain.

Eua: No. 356, top of Tee Moa, altitude 760 feet; No. 337, seaward edge 340-400 foot terrace at R (doubtful reference); Nos. 102, 104, seaward edge of 100-foot terrace, east of Station M (doubtful reference).

Maeandra, species.

A thick-walled species of *Maeandra* is common to the 200-foot and the 340-400 foot terraces. Neither of the two specimens collected were preserved well enough to be identified but there is little doubt about their being of the same species.

Eua: No. 336, seaward edge 340-400 foot terrace at R; No. 5020, seaward edge of 200-foot terrace at Y.

Genus HYDNOPHORA Fischer de Waldheim

Hydnophora Fischer de Waldheim, Mus. Demidoff, vol. 3, p. 295, 1 plate, 1807.

Hydnophora Vaughan, Carnegie Inst. Wash., Pub. 213, p. 121 (with synonymy), 1918.

Hydnophora, species.

A piece of a large stem of a species of *Hydnophora* (No. 223) was found on the seaward edge of the 400-foot terrace at the Matalanga. Cross section of the stem is elliptical; the diameter across the longer axis is 68 mm. and across the shorter is 49 mm. The surface is rather worn.

Genus ACANTHASTREA Milne Edwards and Haime

Acanthastrea Milne Edwards and Haime, Acad. Sci., Comptes rend., vol. 27, p. 495, 1848.

Acanthastrea Vaughan, Carnegie Inst. Wash., Pub. 213, p. 125, 1918.

Type species: *Acanthastrea spinosa* Milne Edwards and Haime = *Astraea echinata* Dana.

Acanthastrea echinata (Dana) (pl. 16).

Astraea echinata Dana, U. S. Expl. Exped., Zooph., p. 229, pl. 12, figs. 1, 1a-1b, 1846.

Favia hirsuta Matthai, Trans. Linn. Soc. London, 2d ser., Zool., vol. 17, p. 100, pl. 24, figs. 7, 8, 1914.

Acanthastrea echinata Vaughan, Carnegie Inst. Wash., Pub. 213, p. 125, pl. 50, figs. 2, 2a, and pl. 51, fig. 2, 1918.

One specimen from the 200-foot terrace agrees perfectly with Dana's type of *A. echinata* which is No. 25, U. S. National Museum.

Eua: seaward edge of the 200-foot terrace at Matalanga.

Living: Red Sea; Maldives; Murray Island; Tongatabu; Fiji; Tuamotu Islands.

Fossil: Felix (32, p. 27) reports *Acanthastrea hirsuta* var. *megalostoma* Klunzinger, which is a variety of this species, from the Sang Kuliran district of Borneo; Gerth (37, p. 73) reports it from the upper Miocene of Borneo.

Genus FUNGIA Lamarck

Fungia Lamarck, Syst. Anim. sans Vert., p. 369, 1801.

Fungia Döderlein, Korallengat. Fungia, Abhandl. Senckenb. naturf. Gesellsch., vol. 27, pt. 1, pp. I-III, 1-162, 25 plates, 1902.

Fungia, species.

An elongated *Fungia* (No. 203) of the same general type as the recent *Fungia paumotensis* Stutchberry, was collected from the roadbed at Ohonua at an altitude of about 65 feet above sea level.

Genus PACHYSERIS Milne Edwards and Haime

Pachyseris Milne Edwards and Haime, Acad. Sci., Comptes. rend., vol. 29, p. 72, 1849.

Type species: *Agaricia rugosa* Lamarck.

The following species of this genus are well represented in the U. S. National Museum: *P. rugosa* (Lamarck), *P. speciosa* (Dana), *P. levicollis* (Dana), *P. valenciennesi* Milne Edwards and Haime and *P. carinata* Brueggemann. The only other living species which I consider valid is *P. involuta* Studer.

Pachyseris speciosa (Dana).

Agaricia speciosa Dana, U. S. Expl. Exped., Zooph., p. 337, pl. 21, fig. 7, 1846.

Pachyseris speciosa Vaughan, Carnegie Inst. Wash., Pub. 213, p. 131, pl. 54, figs. 3, 3a, 4, 4a, 1918.

Pachyseris speciosa Van der Horst., Mad. Siboga Exped., pt. 2, p. 35, 1921.

Pachyseris speciosa Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 36, 1925.

The specimen from Eua has very sharp ridges which are somewhat concave on their sides. It would thus be placed with *P. haimei* Quelch if this could be considered a specific character. Van der Horst (79, p. 35) has discussed the validity of *P. haimei* and has concluded that it should be placed in the synonymy of *P. speciosa* because sharp and rounded ridges are found on the same specimen. The numerous specimens in the U. S. National Museum show that he is right. In all other characters the Eua specimen agrees with typical *P. speciosa*.

Eua: from cliff south side of ravine at Ohonua, altitude 20 feet.

Living: East Indies; Murray Island; Tahiti; Dutch East Indies; Samoa.

Fossil: Reported with some doubt by Gerth (37, p. 113) from the lower Miocene of Borneo and also from the Neogene of Nias.

Genus DIPLOASTREA Matthai

Diploastrea Matthai, Trans. Linn. Soc. London, ser. 2, Zool., vol. 17, p. 72, 1914.

Diploastrea Vaughan, Carnegie Inst. Wash., Pub. 213, p. 142, 1918.

Diploastrea Vaughan, U. S. Nat. Mus., Bull. 103, p. 469, 1919.

Type species: *Astrea heliopora* Lamarck.

Diploastrea heliopora (Lamarck).

Astrea heliopora Lamarck, Hist. Nat. Anim. sans Vert., vol. 2, p. 265, 1816.

Diploastrea heliopora Vaughan, Carnegie Inst. Wash., Pub. 213, p. 143, pl. 59, figs. 5, 5a (with synonymy), 1919.

Orbicella minikoiensis Felix, Jungtertiäre und Quartäre Anthozoen von Timor und Obi., Teil II, p. 6, 1920.

Diploastrea heliopora Gerth, Die Fossilien von Java, Band 1, 2te Abtlg., Heft 3, p. 417, 1921.

This well known species is represented by several specimens from the 200-foot terrace. They differ from the typical form of the species by having the dissepiments somewhat more numerous and by having the septo-costae frequently alternate in passing from one calice to the next. In typical *D. heliopora* the septo-costae of adjacent corallites usually run into each other. I do not believe, however, that these differences are of specific value.

Eua: Nos. 88, 89, 113, from seaward edge of 200-foot terrace at Ravine (Station Ra.).

Living: French Somaliland; Minikoi; New Britain; Fiji Islands; Samoa.

Fossil: reported by Felix from the Pliocene of Dutch New Guinea and the Pliocene or Pleistocene of Timor; Gerth reports it from Java from beds which he doubtfully calls "Miocene and younger?" and from the Neogene of Nias; reported by Umbgrove from Ceram and Sumatra.

Genus PAVONA Lamarck

Pavona Lamarck, Syst. Anim. sans Vert., p. 372, 1801.

Pavona Vaughan, Carnegie Inst. Wash., Pub. 213, p. 132, 1918.

Type species: *Pavona cristata* Lamarck = *Madrepora cristata* Ellis and Solander = *Lophoseris knorri* Milne Edwards and Haime = *Pavona formosa* Dana = *Pavona cactus* (Forskål).

Pavona ostergaardi, new species (pl. 17, *A*).

Corallum an irregular, nodose mass.

Calices small, irregularly placed without any tendency to be arranged in rows. The distance between calicular centers 1 to 2 mm.; in a few cases 2.5 mm.; usually 1.5 mm.

Calices subcircular or slightly elliptical on hillocks, where they are farther apart; distorted or polygonal in valleys, where they are more crowded. Diameter of mature, subcircular calices 1 to 1.5 mm.

Collines flattened, crossed by septo-costae which are crowded and alternate but slightly in thickness. There are 8 or 9 septo-costae in a distance of 2 mm.

Septa number from 13 to 20 for each calice; usual number about 16. In calices with smaller number there are 6 or 7 large ones alternating with smaller ones. In larger calices 8 to 10 large septa alternate with smaller ones. All the primaries and some of the secondaries reach columella.

The edges and faces of the septa and septo-costae are microscopically granulated.

Synapticulae rather numerous, and can be plainly seen between septo-costae.

Columella a compressed tubercle.

The species belongs to the group of *Pavona* which has a massive corallum. *P. clavus* Dana, *P. duerdeni* Vaughan, *P. maldivensis* (Gardiner), *P. gigantea* Verrill and *P. clivosa* Verrill are living species which are members of this group. *P. ostergaardi* is probably closer to *P. duerdeni* Vaughan from the Hawaiian Islands than to any other described species. It differs in having more numerous septa and synapticulae, 8 or 9 septo-costae in 2 mm. as against 6 in *P. duerdeni,* and also by the lack of any definite arrangement in the position of the calices.

P. clivosa Verrill is also somewhat similar but forms large rounded masses and the septo-costae number only 5 or 6 in 2 mm. *P. panamensis* Vaughan, from the Emperador limestone of the Canal Zone which Vaughan (83, p. 431) has stated is closely related to *P. clivosa,* has larger calices than *P. ostergaardi.*

P. malvidensis (Gardiner) has a larger columella and the septo-costae are not so numerous per cm. Felix (30, p. 335) has reported *P. malvidensis* from the lower Pliocene of Java. Vaughan in his Murray Island report, p. 135, says regarding *P. clavus* Dana, *P. duerdeni* Vaughan and *P. malvidensis* (Gardiner), "These three supposed species are probably synonyms of *P. explanulata* Lamarck."

Eua: No. 187, loose in small gulley at seaward edge of 200-foot terrace at Matalanga.

Pavona species.

Some worn specimens of *Pavona* which belong to the same group as the preceding species were collected from three different localities on the 400-foot terrace. I believe they all belong to the same species but are a little too worn to be definitely identified. They may belong to *P. ostergaardi* but the septa are usually more numerous, 18 to 20 in a calice, likewise the columella is more prominent. The number of septo-costae per cm. is the same in the two species. They also bear some resemblances to an undescribed species from Funafuti and the Tuamotus in the U. S. National Museum mentioned by Vaughan (80, p. 136).

Eua: No. 219, seaward edge 400-foot terrace at Matalanga; No. 330, seaward edge 340-400-foot terrace at R; No. 259, seaward edge 400-foot terrace at Vaigana.

Genus **ASTREOPORA** de Blainville

Astreopora de Blainville, Dict. Sci. nat., vol. 60, p. 348, 1830.

Astraeopora Bernard, Cat. Gen. Astraeopora, Cat. Madreporaria Brit. Mus., vol. 2, pp. 77-99, 1896.

Astreopora Vaughan, Carnegie Inst. Wash., Pub. 213, p. 145, 1918.

Type species: *Astrea myriopthalma* Lamarck.

Astreopora cf. **ocellata** Bernard.

Astraeopora ocellata Bernard, Cat. Gen. Astraeopora, p. 95, pl. 29; pl. 33, fig. 16, 1895.

Astreopora ocellata Vaughan, Carnegie Inst. Wash., Pub. 213, p. 147, pl. 17, figs. 36, 37 (with synonymy), 1918.

Vaughan (82) placed *A. ovalis* Bernard and *A. kenti* Bernard in the synonymy of *A. ocellata*. One of the main characteristics of the species is that the septa do not join to form a columella. A specimen from the 200-foot terrace seems to belong to this species and matches the specimen No. 1 from Murray Island mentioned in Vaughan's paper.

Eua: seaward edge 200-foot terrace at Y.

Known living on Great Barrier Reef and at Bandin Island.

Astreopora tongensis, new species (pl. 17, *B*).

Corallum worn, massive, irregular. May originally have been hemispherical. Diameter, 7 by 4 cm.; height, 9 cm.

Calices worn on top so that the original surface is no longer present. Diameter of calicular openings 1.25-2 mm. Distance between calices from 1 to 3 mm., usually about 1.5 mm.

Septa in large calices in two cycles. The primaries are very prominent, rather thick and fuse loosely in the center of the calice to form a weak columella. The secondaries are very small, almost rudimentary; a few of the longer ones reach 0.5 mm. from wall toward center of calice, but this is exceptional.

The columella, made by the fused ends of the primary septa, is rather well developed for a species of *Astreopora*, but weak in comparison to those of some other genera.

The coenenchyma is made of rather stout processes. In vertical cross section thick trabeculae run obliquely from one calicular wall to adjoining wall; the angle with the horizontal may be 45° or 85°. These trabeculae run through successive perforate platforms and probably projected as spines at the surface.

A specimen, no. 333, from the 340-400 foot terrace has somewhat thicker primary septa which fuse to make a stronger columella. This thickening may be of secondary origin.

This species is characterized by having only two cycles of septa with very prominent primaries which fuse loosely to form a columella. *A. listeri*

Bernard has at first sight some similarities but differs by having three cycles of septa and slightly larger calices. *Astreopora horizontalis* Bernard is probably closer than any other described species but differs radically in growth form and also has somewhat smaller calices.

Eua: No. 128 (Type), seaward edge of 100-foot terrace directly east of Station M; No. 206, hill behind store at Ohonua, altitude 50 feet; No. 5022, seaward edge 200-foot terrace at Y; No. 333, seaward edge 340-400 foot terrace at R.

Genus MONTIPORA Quoy and Gaimard

Montipora Quoy and Gaimard, Voy. de l'*Astrolabe,* Zool., vol. 4, p. 247, 1833.

Montipora Bernard, Brit. Mus. (Nat. Hist.), Cat. Mad., vol. 3, pp. 1-166, 177-184, 1897.

Montipora species.

A worn specimen of *Montipora* (No. 404) from the deep gorge east of Powells field belongs to the collection. It is somewhat similar to the recent species *M. venosa* (Ehrenberg) but has smaller calices.

Genus ACROPORA Oken

Acropora Oken, Lehrb. Naturg., Th. 3, Abth. 1, p. 66, 1815.

Acropora Verrill, Trans. Conn. Acad. Arts and Sci., vol. 11, pp. 164-208, 1902.

Acropora Vaughan, Carnegie Inst. Wash., Pub. 213, pp. 159-186, 1918.

Acropora Hoffmeister, Carnegie Inst. Wash., Pub. 343, pp. 54-72, 1925.

Type species: *Millepora muricata* Linnaeus = *Madrepora cervicornis* Lamarck.

The genus *Acropora* is a difficult one to work with in fossil material. Its spongy nature and the fact that many species are delicately branched makes it an easy victim of weathering. At least two species were obtained from Eua. Neither can be definitely identified, however.

Acropora species (pl. 18).

This piece of *Acropora* (No. 125) taken from the seaward edge of the 200-foot terrace at Station Ra. looks somewhat like the basal part of a specimen of *A. gemmifera* (Brook). The branches are not as long (1-2 cm.) as those in the central portion of a corallum of typical *A. gemmifera* (4-6 cm.). Frequently, however, those near the base of the corallum of the latter are shorter and fit the Eua specimen. A specimen in the U. S. National Museum from Murray Island shows the variation in this respect well. Another difference between the Eua specimen and *A. gemmifera* is the slightly more elliptical corallites of the former. *A. gemmifera* is a living species reported from Fiji, the Great Barrier Reef, Torres Straits and Arafura Sea.

Genus PORITES Link

Porites Link, Beschreib. Natur. Samml. Rostock, p. 162, 1807.
Porites Bernard, Porites of the Indo-Pacific Region, pp. 303, 35 plates, 1905.
Porites Bernard, Porites of the Atlantic and West Indies, pp. 144, 17 plates, 1906.
Porites Vaughan, Carnegie Inst. Wash., Pub. 213, pp. 188-206, 1918.

Porites aff. **lutea** Milne Edwards and Haime.

Porites conglomerata Dana, U. S. Expl. Exped., Zooph., p. 561, pl. 55, figs. 3, 3a, 1846.

Porites lutea Hoffmeister, Carnegie Inst. Wash., Pub. 343, p. 73, pl. 21, figs. 2a to 2c, 3, (with synonymy), 1925.

I have discussed the variation within this species in a previously presented paper (42). Two of the Eua specimens appear very similar to typical *P. lutea,* the type of which, together with many other specimens, is in the U. S. National Museum.

Eua: Nos. 5013 and 5019, seaward edge 200-foot terrace at Y.

Living: Fiji; Murray Island; Samoa.

Fossil: Gerth (37, p. 117) doubtfully reports this species from the upper Miocene of Borneo; known from Plio-Pleistocene of Ceram and Christmas Island.

Genus ALVEOPORA Quoy and Gaimard

Alveopora fijiensis, new species (pl. 19).

A specimen of *Alveopora* found loose in a small gully at the seaward edge of the 200-foot terrace seems to be identical with an unnamed specimen in the U. S. National Museum collected by Dr. A. G. Mayor from the living reef at Suva, Fiji. I am here describing it as a new species.

Corallum massive, even topped, undulating with rounded knobs rising above the general surface. Maximum length 13 cm., maximum width 9 cm., maximum height 12 cm. The largest knob has a height of about 3 cm., and a diameter of 3 cm. Thin epitheca covers base near edges.

Calices are polygonal, average diameter 2 mm.; depth 2-3 mm. Walls rather thick and substantial for *Alveopora;* thickest around basal portions of corallum; perforate, the pores arranged in longitudinal rows; usually two rows on each side of the polygonal calice.

Septa in two cycles, irregular in size, spine-like; those in basal calices thicker than those in calices on upper surface. Primaries and some secondaries frequently meet irregularly in center. Short, thick septal spines line sides of calices between septa and top.

The fossil specimen from Eua is small but has all the characteristics of the type. The species is distinguished from *A. verilliana* Dana, the type of which is in the U. S. National Museum, by its thicker walls and septa and uniformly larger calices.

Eua: loose in a small gully at the seaward edge of the 200-foot terrace at Matalanga.

Living. The specimen collected by Mayor from Fiji is the type.

EOCENE FORAMINIFERA

By G. Leslie Whipple

INTRODUCTION

Dr. J. Edward Hoffmeister, while making a geological reconnaissance of the Tonga Islands in 1926, made an extensive collection of rocks containing foraminifera which he forwarded to the Scripps Institution of Oceanography, La Jolla, California, for examination and report. A list of tentative determinations was published in 1929 (46), but as a detailed study had not been made at that time several additions are included in the present paper.

Much of the material is rock from which individual specimens cannot be separated either because the fossils are too fragile or because the rock is too hard. Many of the determinations, therefore, had to be made in thin sections. The matrix of all the specimens is calcareous and in many specimens both rock and the fossils have been so highly altered that the original structure has been completely obliterated.

Acknowledgments are due to Dr. T. Wayland Vaughan, Scripps Institution of Oceanography, La Jolla, California, for his suggestions and criticism. The writer is also greatly indebted to Dr. B. L. Clark of the University of California for much assistance while at the University and since, and to Mr. E. M. Thorp for assistance in making the photographs.

AGE OF THE LIMESTONES

The base of the island of Eua is volcanic, and over it has been deposited a coating of Eocene foraminiferal limestone. The elevation of the island has been attained by a series of uplifts with periods of quiescence long enough for the cutting of terraces and the deposition on the seaward edge of more recent deposits. Hoffmeister has described six well defined terraces: 1, 100-foot; 2, 200-foot; 3, 340-foot; 4, 400-foot; 5, 550-foot; 6, 760-foot. (See pp. 48-55.) Above these rises a high ridge which in places may have a maximum height of about 1,000 feet. At the seaward edge of several of these terraces are deposits containing only recent species. Some of these have been reported by Sherlock (73), who recorded several recent genera and species from the first and second terraces and the inner valley, but other than this there seems to be no record of foraminifera from Eua. Eocene foraminifera occur abundantly at the base of the terraces where they have been collected from localities ranging in altitude from near sea level to 860 feet above sea level.

The older limestone is referable to the upper Eocene, or to the Tertiary-*b* of Van der Vlerk and Umbgrove (78). *Discocyclina fritschi* was described by Douvillé (23) from the upper Eocene of Java associated with *Camerina pengaronensis*. *D.* (*Asterocyclina*) *stella* has been reported from New Caledonia by Deprat (20) in deposits assigned by him to upper Eocene. Douvillé (22) records *A. stellata* from southeastern Borneo and it occurs in material from the same region in the Scripps Institution collections. *Pellatispira rutteni* was first described by Umbgrove (75) from Tidoengsche Landen (northeastern Borneo), associated with *Discocyclina* and *Camerina*, and is reported by the same author from southeastern Borneo. These associations would appear to be rather characteristic of the Tertiary-*b* in the Pacific region. The association of *Discocyclina* and *Asterocyclina*, to the writer's knowledge, occurs only in this horizon.

FAMILY CAMERINIDAE

Genus CAMERINA Brugière

Camerina pengaronensis (Verbeek).

Nummulites pengaronensis Verbeek: Neues. Jahrb., p. 3, pl. 1, figs. 1 a-k, 1871.

Nummulites nanggoelani Verbeek et Fennema, Descr. géol. de Java et Madoura, p. 1152, pl. 8, figs. 111-113, 1896.

Nummulites pengaronensis Verbeek et Fennema, 1. c. p. 1153.

Nummulites pengaronensis Douvillé, H., Geol. Reichs-mus. in Leiden Samml., Ser. 1, Bd. 8, pp. 262, pl. 20, fig. 1; pp. 284-285, pl. 24, fig. 6, 1912.

Nummulites pengaronensis Yabe, Tohoku Imp. Univ. Sci. Rep., 2d ser., vol. 5, no. 4, p. 104, pl. 18, fig. 3, 1921.

As shown in Table 5, specimens referable to this species were collected at several localities on the island. The specimens are somewhat smaller than those from the Nanggoelan horizon of Java but in other characters they agree very closely with that form. The largest individual in the collection measures 5.1 mm. in diameter and 3.5 mm. in thickness. The surface is smooth and the alar prolongations of the septa are but slightly curved.

A small form is present in a section of rock collected from the vicinity of Station 115 (E-67*) and also on the east side it was collected from E-107 and E-390.

Genus PELLATISPIRA Boussac

There are at the present time nine species of *Pellatispira* known to occur in Eocene rocks of the East Indies, and the following table is an attempt to give in outline form some of the general surface characters of these different species. As comparatively little is known about the microspheric

* Numbers preceded by letter E refer to localities as given in Table 5.

forms, they were not taken into consideration. Such a table must necessarily include only general characteristics and for specific discrimination reference must be made to the published description of the species. Also, variation within several of the species, such as noted by Umbgrove, can be discussed only in detailed descriptions. (See Umbgrove, 75, pp. 1-60.)

Table 6. Synopsis of East Indian species of Pellatispira (based on the megalospheric forms)

- Test 3 to 6 mm. in diameter
  - Shape lenticular
    - Ratio of horizontal to vertical diameter 3:1
      - Pillars decrease in size toward the periphery........ **P. orbitoidea** (Provale)
      - Pillars thick (150 to 200μ)........ **P. crassicolumnata** Umbgrove
    - Ratio of horizontal to vertical diameter 5:1
      - Pillars of two sizes........ **P. madaraszi** var. **provalei** Yabe
  - Shape globular to ellipsoid
    - Ratio of horizontal to vertical diameter 1:1.
      - Pillars small and sparse........ **P. inflata** Umbgrove
    - Ratio of horizontal to vertical diameter 1.5:1.
      - Pillars absent........ **P. glabra** Umbgrove
      - Pseudo-pillars present as knobs on the surface........ **P. irregularis** Umbgrove
- Test 6 to 10 mm. in diameter
  - Shape lenticular.
    - Ratio of horizontal to vertical diameter 5:1
      - Pillars thick (150-200 μ)........ **P. hoffmeisteri** Whipple
    - Ratio of horizontal to vertical diameter 8:1.
      - Pillars present (100 $\pm$ μ in diameter)........ **P. fulgeria** Whipple
  - Shape lenticular or umbonate
    - Pillars present (100 $\pm$ μ in diameter)........ **P. rutteni** Umbgrove

Pellatispira rutteni Umbgrove (pl. 21, 6).

Pellatispira rutteni Umbgrove, Wetensch. Meded. No. 10, pp. 20-21, figs. 57-61, 1928.

The test is lenticular to umbonate, 5 to 6 mm. in diameter, 3 mm. thick, surface strongly granulate, with each granule surrounded by large pores.

Initial chamber about 300 μ in diameter usually followed by one or two chambers somewhat smaller than the initial chamber though larger than those chambers immediately following. This is followed by the typical *Pellatispira*-type of coiling with the walls between successive whorls increasing in thickness.

Walls coarsely tubulate, those tubules in the outer wall extending to the surface of the test where they form the pores surrounding the granules.

The ratio of horizontal to vertical diameter in the specimens from Eua is about 2:1 with little variation from this ratio. Umbgrove finds the variation in specimens from Borneo rather large, the ratio there being 2 to 8:1. He reports the species from N. E. Borneo, Tendoengsche Landen, and Sg. Singko (S. E. Borneo).

This species occurs abundantly at an altitude of 840 feet (E-390), associated with *Camerina pengaronensis* on the highest ridge of the island.

Pellatispira hoffmeisteri Whipple, new species (pls. 20, 5; 21, 4, 5).

Test flat, 7 to 8 mm. in diameter, 1.5 mm. thick, surface coarsely granulate, the granules being the ends of pillars, 150 to 200 μ in diameter, of dense shell material which extend outward from the chamber layer and are surrounded by pores about 24 μ in diameter.

Initial chamber 200 to 300 μ in diameter, followed by a second chamber subequal to the initial, or intermediate in size between it and the succeeding chambers. The first 2 or 3 whorls are of the typical loosely coiled *Pellatispira*-type, with the chambers regularly arranged and the walls between each whorl increasing in thickness. These are followed by chambers which are very irregular in size, shape, and arrangement, and continue as such to the edge of the test. This irregularity obscures any evidence of coiling which may have taken place during the later growth of the test and shows the chambers promiscuously arranged in a plane.

In vertical section is shown a single layer of chambers, in some specimens those toward the periphery appearing to be subdivided due to the irregular arrangement. The walls are coarsely tubulate, the tubules forming pores which surround the pillars at the surface of the test.

A single broken individual of the microspheric form of this species, collected at E-369, is much larger than the megalospheric form, measuring about 15 mm. in diameter, but in other features the two seem identical.

Type locality: Rock Point (R. P.), altitude 860 feet. At this locality fragments of *Discocyclina* are abundant in most sections studied. It also occurs at the base of Tee Moa (E-369) where it is associated with *Discocyclina fritschia D.* (*Asterocyclina*) *stellata,* and *D.* (*Asterocyclina*) sp.

Pellatispira fulgeria Whipple, new species (pl. 20, 2, 3, 4, 6, 7.)

Test flat, 7 to 9 mm. in diameter, 1 mm. in thickness, in many specimens the periphery is as thick as or thicker than the center; surface granulate with the granules 80 to 120 μ in diameter.

Initial chamber about 200 μ in diameter, followed by the typical planispirally coiled chambers with the walls between each whorl increasing rapidly in thickness. The outer walls appear to be made up of two types of shell material, the denser of which occurs as coarse fibers arranged both radially and transversely, giving a reticulate structure to the walls.

Pillars are shown in vertical section originating at or near the central plane and extending to the surface of the test. The reticulate structure may be observed in vertical as well as horizontal section, although it is more pronounced in the latter. In many cases this reticulate structure gives rise to the appearance of lateral chambers.

Type locality: east side of Eua 3¼ miles from southern end. "From 1. s. cave in volcanic area, 10 chains S. W. of Bush (B). Alt., 700 feet" (E-458). It also occurs at a limestone contact at Ana Aha, where it is associated with *Discocyclina, Camerina,* and *Heterostegina.*

The thickened periphery together with the reticulate structure shown in thin section serves to distinguish this species.

Genus OPERCULINA d'Orbigny

Operculina pacifica Whipple, new species (pl. 20, 1, 8).

Test flat, slightly umbonate, greater diameter 4 to 6 mm., lesser diameter 3 to 4 mm., thickness 0.5 to 0.75 mm.; composed of about 3 whorls, the last-formed of which usually contains about 16 chambers. Early chambers slightly embracing, later ones becoming less so; sutures slightly raised, early ones moderately recurved, later ones becoming more recurved, and all of them merging into the rounded periphery.

The last-formed whorl increases very rapidly in height. In the typical specimens it is 8 to 10 times as high as the first whorl and 4 to 5 times as high as the second whorl.

Type locality: near the center of the island on the east coast. "In conglomerate at the base of the 100-foot terrace, 10 feet above sea level. North of Pinnacle" (E-316). Here it occurs associated with *Discocyclina euaensis* n. sp., *Discocyclina* sp., and *D.* (*Asterocyclina*) *stellata.* It also occurs at E-318 and 319.

Genus HETEROSTEGINA d'Orbigny

Heterostegina species indeterminate (pl. 20, 9).

Specimens of this genus occur abundantly at nearly all localities on the island. The Eua species appear rather close to *H. reticulata* Rutimeyer but the specimens are so poorly preserved that specific determination cannot be made with certainty.

Localities from which it was collected are as follows: E-21A, E-67, E-313, E-319, E-361, E-373-376, E-390, and E-348.

FAMILY ORBITOIDIDAE

Genus DISCOCYCLINA Gümbel

Subgenus DISCOCYCLINA Gümbel

Discocyclina (Discocyclina) fritschi (H. Douvillé).

Orthophragmina fritschi Douvillé, Geol. Reichs-Mus. in Leiden Samml., Ser. 1, Bd. 8, pp. 288-289, pl. 24, fig. 2, 1912.—Yabe, Tohoku Imp. Univ. Sci. Rep., 2d ser., vol. 5, no. 4, p. 106, pl. 27, fig. 12; pl. 28, fig. 1, 1921.

Abundant specimens of this species were collected from the 600-foot terrace at the base of Tee Moa (E-369). The test is large, 20 mm. in diameter with a central portion of 3 to 4.5 mm. in thickness and 4-5 mm. in diameter surrounded by a thin flange 6-9 mm. wide, surface granulate. The granules on the Eua specimens are poorly preserved, but in a few instances they appear to increase in size toward the periphery.

The Eua species agree very closely with specimens from the Nanggoelan Eocene of Java whence it was first described.

Associated forms at this locality are *Discocyclina* (*Asterocyclina*) *stellata, D.* (*Asterocyclina*) species, and *Pellatispira hoffmeisteri,* new species.

Discocyclina (Discocyclina) euaensis Whipple, new species (pl. 22, 3-7.)

Test lenticular, 5 to 8 mm. in diameter, 1 to 1.5 mm. in thickness, slope from the center to the periphery usually gradual although a central boss sometimes may be developed, surface papillate.

Embryonic apparatus consists of an initial chamber nearly surrounded by a second larger chamber (fig. 6). Diameter of the nucleoconch 500 $\mu \pm$.

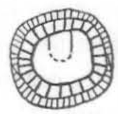


FIGURE 6.—Embryonic apparatus of *Discocyclina euaensis* Whipple.

Equatorial chambers rectangular, those of the first cycle larger than those immediately following. After the first four or five cycles the chambers increase in radial diameter until the ratio of radial to transverse diameters is about 1:5. Near the periphery the radial diameter measures about 120 μ and the transverse 24 μ. Equatorial layer may or may not increase in height toward the periphery.

In vertical section there are 15-18 layers of lateral chambers over the center on each side of the equatorial plane. Chambers small, usually irregular in size and arrangement, and may or may not be arranged in tiers between the pillars. Pillars, small, conical, averaging about 40 μ in diameter at the surface, some of which appear to have their origin at the equatorial layer and extend to the surface where they form the papillae.

Type locality: at the base of a high limestone peak (Pinnacle) on the east coast near the center of the island (E-318 and E-319). At this locality it occurs with *Discocyclina* sp., *D.* (*Asterocyclina*) *stellata, Operculina pacifica,* new species, and *Heterostegina* species indeterminate. Other localities are E-313, conglomerate north of limestone pinnacle, 10 feet above sea level; and E-361, west of Tee Moa on the 600-foot terrace.

Discocyclina species indeterminate (pl. 22, 1-2).

Several specimens of a *Discocyclina* which are different from the above species were collected in material from E-313 and E-318-319. They seem to have characters relating them to *D. varians* (Kaufman) but the material is so poorly preserved that they can not be identified.

Subgenus ASTEROCYCLINA Gümbel

Discocyclina (Asterocyclina) stellata (d'Archiac) (pls. 21-22).

Calcarina stellata d'Archaic, Soc. géol. Fr. mém., Sér. 2, vol. 2, p. 199, pl. 7, fig. 1a, 1846.

Orbitoides (*Asterocyclina*) *stellata* Gümbel, K. bayer. Akad. Wissen. Abh., cl. 2, Bd. 100, pp. 135-137, pl. 2, figs. 115 a-e; pl. 4, figs. 4-7, 1868.

Orthophragmina stellata Schlumberger, Soc. géol. Fr. Bull., Sér. 4, vol. 4, pp. 126-128, pl. 5, fig. 31-36; pl. 6, figs. 37-40, 1904.

Asterodiscus stellata Douvillé, Soc. géol. Fr. Bull., Sér. 4, vol. 12, pp. 78-79, 1922.

Test stellate, rather small, the largest specimens from Eua measure 8 mm. in diameter and 1.5 mm. in thickness. There are usually five rays radiating out from a central boss, surface covered with granules, those between the rays small and in some specimens indistinct.

The embryonic apparatus is somewhat smaller than in the typical *A. stellata* but the chambers are similarly arranged. The initial chamber, 90 $\mu \pm$ in diameter, is half surrounded by a second chamber and the entire nucleoconch measures about 180 μ in diameter. Following the embryonic apparatus are several large equatorial chambers usually corresponding in number and position to the rays of the test. At the proximal end of each ray there are two or three elongated equatorial chambers, this number increasing toward the periphery producing the fan-like arrangement of the chambers within the ray. Within the ray itself there is a gradual increase in height of the equatorial chambers toward the periphery, but little or no increase in height of those between the rays.

Lateral chambers rather small, 15-20 over the center on each side of the equatorial plane, usually arranged into tiers between conical pillars which extend from the equatorial plane to the surface of the test where they form the granules.

D. (*Asterocyclina*) *stellata* occurs very abundantly in the collection from Eua. The forms from localities E-313 and E-319 are smaller than those from E-369 where specimens are typical of the species, but in other characters appear to be identical.

Discocyclina (Asterocyclina) species cf. **A. stellata** (Gümbel) (pl. 21).

Hymenocyclus stella Gümbel, Geogn. Besch. d. bayer Alp., p. 653, 1861.

Orbitoides asteriscus Kaufmann, Beitr. z. geol. Schweiz., vol. 9, p. 155, pl. 9, figs. 11-16, 1867.

Orbitoides (*Asterocyclina*) *stella* Gümbel, K. bayer Akad. Wissen, Abh., Cl. 2, Bd. 10, abt. 2, p. 138, pl. 2, figs. 117 a-c; pl. 4, figs. 8-10, and 19, 1868.

Orthophragmina stella Schlumberger, Soc. géol. Fr. Bull., Sér. 4, vol. 4, p. 132, pl. 6, figs. 47-50, 52-56, 1904.—Deprat, Soc. géol. Fr. Bull., Sér. 4, vol. 5, p. 508, pl. 19, fig. 28, 1905.

Asterodiscus stella Douvillé, Soc. géol. Fr. Bull., Sér. 4, vol. 12, p. 93, 1922.

A few specimens which may belong to this species were collected from the 100-foot terrace (E-107). The test is small, usually about 3 mm. in diameter and 2-2.5 in thickness, stellate with five rays. Although the individuals from Eua are somewhat weathered, the surface appears to be papillate.

The only other form from this locality is *Camerina pengaronensis*.

Discocyclina (Asterocyclina) species (pl. 21).

A single broken specimen of a large *Asterocyclina* occurs in the material from the base of Tee Moa (E-369). It measures 20 mm. in diameter and has a central boss about 4 mm. in diameter, from which radiate 9 raised arms; surface papillate with the papillae more or less regularly spaced and each surrounded by 4 or 5 lateral chambers.

Equatorial chambers long and narrow and seem to increase in length (radially) and height along the direction of the ray.

This specimen corresponds rather closely to that figured by Schlumberger (71, pl. 3, fig. 8), although the granulations on Schlumberger's form may be somewhat coarser than on the above individual. It is also possible that this is the microspheric of *D.* (*Asterocyclina*) *stellata* with which it is associated at this locality, but due to the lack of material no conclusion is warranted at this time.

BIBLIOGRAPHY

1. Agassiz, Alexander, Exploration of the *Albatross* in the Pacific Ocean: Am. Jour. Sci., 4th ser., vol. 9, pp. 33-43, 1900.
2. Agassiz, Alexander, The coral reefs of the tropical Pacific: Mus. Comp. Zoology, Harvard Coll., Mem., vol. 28, pp. 1-410, 1903.
3. Andrews, C. W., A monograph of Christmas Island (Indian Ocean), physical features and geology, London, 1900.
4. Bernard, H. M., The genera Turbinaria and Astraeopora: Cat. Madreporarian Corals in the British Mus. (Nat. Hist.), vol. 2, 1896.
5. Bernard, H. M., The genera Montipora and Anacropora: Cat. Madreporarian Corals in the British Mus. (Nat. Hist.), vol. 3, 1897.
6. Bernard, H. M., Porites of the Indo-Pacific region: Cat. Madreporian Corals in the British Mus. (Nat. Hist.), vol. 5, 1905.
7. Bernard, H. M., Porites of the Atlantic and West Indies, with the European fossil forms: Cat. Madreporarian Corals in the British Mus. (Nat. Hist.), vol. 6, 1906.
8. Blainville, H. M. D. de, Les Madrépores: Dictionnaire des Sciences Naturelles, vol. 60, pp. 297-364, Paris, 1830.
9. Brook, George, The genus Madrepora: Cat. Madreporarian Corals in the British Mus. (Nat. Hist.), vol. 1, 1893.
10. Chamberlin, R. T., The geological interpretation of the coral reefs of Tutuila, American Samoa: Carnegie Inst. Washington, Pub. 340, pp. 145-178, 1924.
11. Chubb, L. J., The geology of the Austral or Tubuai islands (southern Pacific): Geol. Soc. London, Quart. Jour., vol. 83, pp. 291-316, 1927.
12. Chubb, L. J., Mangaia and Rurutu, a comparison between two Pacific islands: Geol. Mag., vol. 64, pp. 518-522, 1927.
13. Cook, James, A voyage to the Pacific Ocean, vol. 1, p. 259, London, 1784.
14. Crossland, Cyril, Coral reefs of Tahiti, Moorea, and Rarotonga: Linnean Soc. London, Jour. Zoology, vol. 36, pp. 577-618, 1928.
15. Daly, R. A., Geology of American Samoa: Carnegie Inst. Washington, Pub. 340, pp. 93-143, 1924.
16. Dana, J. D., Zoophytes: U. S. Expl. Exped., vol. 7, Philadelphia, 1846.
17. Dana, J. D., Corals and coral islands, London, 1872.
18. Darwin, Charles, The structure and distribution of coral reefs, 3rd ed. (appendix 2, by T. G. Bonney), London, 1889.
19. Davis, W. M., The coral reef problem: Am. Geog. Soc., Special Pub. 9, pp. 1-596, 1928.
20. Deprat, J., Les dépôts eocenes néo-caledoniens: Soc. Géol. France, Bull., sér. 4, vol. 5, pp. 485-516, 4 pls., 1905.
21. Döderlein, Ludwig, Die Korallengattung Fungia: Senckenb. Naturf. Ges., Abh., vol. 27, pt. 1, 1902.
22. Douvillé, H., Les foraminiferes dans le Tertiaire de Borneo: Soc Géol. France, Bull., sér. 4, vol. 5, pp. 435-464, 1 pl., 1905.
23. Douvillé, H., Quelques foraminiferes de Java: Reich Geol.-Min. Mus., Leiden, Samml., sér. 1, Band. 8, pp. 279-294, 3 pls., 1912.
24. Edwards, H. M., and Haime, J., Note sur la classification de la deuxième tribue la famille des Astréides: Acad. Sci. Paris, Comptes Rendus, vol. 27, pp. 490-497, 1848.

25. EDWARDS, H. M. and HAIME, J., Mémoires sur les polypiers appartenants à la famille des Oculinides, au groupe intermédiare des Pseudastréides et à la famille des Fongides; Acad. Sci. Paris, Comptes Rendus, vol. 29, pp. 67-73, 1849.

26. EDWARDS, H. M. and HAIME, J., Histoire naturelle des corallaires, vol. 2, p. 663, Paris, 1857.

27. EHRENBERG, C. G., Die Corallenthiere . . . des Rothen Meeres . . .: K. Preussische Akad. der Wissensch. Berlin, Abh., 1834.

28. ELLIS, JOHN, and SOLANDER, DANIEL, The natural history of many curious and uncommon zoophytes, London, 1786.

29. FAUSTINO, LEOPOLDO, Recent Madreporaria of the Philippine Islands: Bur. Sci. Manila, Mon. 22, 1927.

30. FELIX, JOHANNES, Die fossilen Anthozoen aus der Umgegend von Trinil: Palaeontographica, Band 60, Stuttgart, 1913.

31. FELIX, JOHANNES, Jungteriäre und Quartäre Anthozoen von Timor und Obi, 1 Teil: Paläontologie von Timor, Lief. 2, Stuttgart, 1915.

32. FELIX, JOHANNES, Fossile Anthozoen von Borneo: Paläontologie von Timor, Lief. 9, Stuttgart, 1921.

33. FISCHER VON WALDHEIM, G., Minéraux et Pétrifications: Muséum-Demidoff, tom. 2, Moscou, 1806.

34. FORSKÅL, PETRUS, Descriptiones animalium, avium, amphibiorum, piscium, insectorum, vermium, quae in itinere Orientali observavit . . ., Hauniae, 1775.

35. GARDINER, J. S., Madreporaria, pt. 3, Fungida, pt. 4, Turbinolidae: Fauna and Geography of Maldive and Laccadive Archipelagoes, vol. 2, supplement 1, Cambridge, 1905.

36. GERTH, H., Die Fossillien von Java, Band 1, 2te Abt., Heft 3, 1921.

37. GERTH, H., Die Anthozoenfauna des Jungteriäres von Borneo: Beitr. Geol. Ost-Asiens und Australiens, Band 10, Heft 3, pp. 37-136, 1923.

38. GERTH, H., Jungtertiäre Korallen von Nias, Java, und Borneo, nebst einer Übersicht über die aus dem Känozoikum des indischen Archipel. bekannten Arten: Leidische Geol. Mededeel. 1, 1925.

39. HARKER, ALFRED, Uralitized gabbro from Eua, Tonga Islands: Geol. Mag., vol. 8, pp. 172, 250, 1891.

40. HARKER, ALFRED, Notes on a collection of rocks from the Tonga Islands: Geol. Mag., vol. 8, pp. 250-258, 1891.

41. HOFFMEISTER, J. E., Brief report of geologic work, Tonga expedition of 1926: Science, new ser., vol. 64, pp. 141-142, 1926.

42. HOFFMEISTER, J. E., Some corals from American Samoa and the Fiji islands: Carnegie Inst. Washington, Pub. 343, 1925.

43. HOFFMEISTER, J. E., LADD, H. S., and ALLING, H. L., Falcon Island: Am. Jour. Sci., 5th ser., vol. 18, pp. 462-471, 1929.

44. HOFFMEISTER, J. E., Erosion of elevated fringing coral reefs: Geol. Mag., vol. 67, pp. 549-554, 1930.

45. HOFFMEISTER, J. E., Some reef corals from Tahiti: Washington Acad. Sci., Jour., vol. 19, pp. 357-365, 1929.

46. HOFFMEISTER, J. E., and WHIPPLE, G. L., Eocene foraminifera from Eua, Tonga (abstract): Fourth Pacific Sci. Congress, Proc., Java, 1929.

47. KLUNZINGER, C. B., Die Korallanthiere des Rothen Meeres, Teil 2, p. 80, Teil 3, p. 100, Berlin, 1879.

48. LADD, H. S., and HOFFMEISTER, J. E., Recent negative shift in the strand line in Fiji and Tonga: Jour. Geol., vol. 35, pp. 542-556, 1927.

49. LADD, H. S., and HOFFMEISTER, J. E., Geological work in Tonga and Fiji: Science, new ser., vol. 69, pp. 272-273, 1929.

50. LAMARCK, J. B. P. DE, Système des animaux sans vertèbres, Paris, 1801.

51. LAMARCK, J. B. P. DE, Histoire naturelle des animaux sans vertèbres, tome 2, Paris, 1816, 2nd ed., tome 2, Paris, 1836.

52. LINK, H. F., Beschreibung der Naturalien-sammlung der Universität zu Rostock, Abth. 3, 1807.

53. LINNAEUS, CARL VON, Systema naturae, 12th ed., Holmiae, 1767.

54. LISTER, J. J., Notes on the geology of the Tonga Islands: Geol. Soc. London, Quart. Jour., vol. 47, pp. 590-617, 1891.

55. MARSHALL, P., Geology of Mangaia: B. P. Bishop Mus., Bull. 36, 1927.

56. MARSHALL, P., Mangaia and Rurutu—a comparison between two Pacific islands: Geol. Mag., vol. 66, pp. 385-389, 1929.

57. MARSHALL, P., Geology of Rarotonga and Atiu: B. P. Bishop Mus., Bull. 72, 1930.

58. MARTIN, J. K. L., Die Tertiärschichten auf Java, Leiden, 1879-1880.

59. MATTHAI, GEORGE, A revision of the recent colonial Astraeidae possessing distinct corallites: Linnean Soc., London, Trans. Zoology, 2nd ser., vol. 17, pt. 1, 1914.

60. MATTHAI, GEORGE, A monograph of the recent Meandroid Astraeidae: Cat. Madreporarian Corals in the British Mus. (Nat. Hist.), vol. 7, 1928.

61. MAYOR, A. G., Growth rate of Samoan corals: Carnegie Inst. Washington, Pub. 340, pp. 51-72, 1924.

62. MAYOR, A. G., Rose Atoll, American Samoa: Carnegie Inst. Washington, Pub. 340, pp. 73-79, 1924.

63. MAYOR, A. G., Structure and ecology of Samoan reefs: Carnegie Inst. Washington, Pub. 340, pp. 1-25, 1924.

64. MAYOR, A. G., Causes which produce stable conditions in the depth of the floors of Pacific fringing reef flats: Carnegie Inst. Washington, Pub. 340, pp. 27-36, 1924.

65. MAYOR, A. G., Inability of stream water to dissolve submarine limestones: Carnegie Inst. Washington, Pub. 340, pp. 37-49, 1924.

66. OKEN, LORENZ, 1. Zunft. erdkorallen, steinkorallen: Lehrbuch der Naturgeschichte, Teil 3, Zoologie, Abth. 1, Fleischlose Thiere, Leipzig und Jena, 1815.

67. OLDHAM, C. F., Eua Island, Tonga group: Nature, vol. 42, pp. 85-86, 1890.

68. QUELCH, J. J., Report on the reef corals collected by H. M. S. *Challenger* during the years 1873-1876: Chal. Rep., vol. 16 (Zoology), pt. 3, London, 1886.

69. QUOY, J. R. C., and GAIMARD, J. P., Zoophytes: Voyage de découverte de l'*Astrolabe,* Zoologie, vol. 4, p. 390, Paris 1833.

70. REED, W. W., Climatological data for the tropical islands of the Pacific Ocean (Oceania): U. S. Dept. Agr. Weather Bur., Monthly Weather Rev. supplement no. 28, 1927.

71. SCHLUMBERGER, C., Quatrième note sur les orbitoides: Soc. Géol. France, Bull., sér. 4, vol. 4, p. 133, pl. 3, fig. 8, Paris, 1904.

72. SETCHELL, W. A., Nullipore versus coral in reef formation: Am. Philos. Soc., Proc., vol. 65, pp. 136-140, 1926.

73. SHERLOCK, R. L., The foraminifera and other organisms in the raised reefs of Fiji: Mus. Comp. Zoology, Harvard Coll., Bull., vol. 38, pp. 359-360, 1903.

74. SKEATS, E. W., The chemical composition of limestones from upraised coral islands, with notes on their microscopical structure: Mus. Comp. Zoology, Harvard Coll., Bull., vol. 42, pp. 53-126, 1903.

75. UMBGROVE, J. H. F., Het genus Pellatispira in het indo-pacifische gebied: Wetensch. Meded., no. 10, pp. 20-21, 1929.

76. UMBGROVE, J. H. F., Report on Pleistocene and Pliocene corals from Ceram: Results of explorations from 1917-1919 in the island of Ceram by L. Rutten and W. Hotz, 2nd ser., no. 1, 1924.

77. UMBGROVE, J. H. F., Neogene en Pleistocene koralen van Sumatra: Wetensch. Meded., 1926.

78. VAN DER VLERK, I. M., und UMBGROVE, J. H. F., Tertiaire gidsforaminiferen van Nederlandsch Oost-Indie: Wetensch. Meded., no. 6, pp. 1-31, 24 pls., 1927.

79. VAN DER HORST, C. J., Madreporaria of the Siboga Expedition, pt. 2: Siboga-Expeditie, Mon. 16*b*, Leiden, 1921.

80. VAUGHAN, T. W., Recent Madreporaria of the Hawaiian islands and Laysan: U. S. Nat. Mus., Bull. 59, 1907.

81. VAUGHAN, T. W., The platform of barrier coral reefs: Am. Geog. Soc., Bull., vol. 46, pp. 426-429, 1914.

82. VAUGHAN, T. W., Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island: Carnegie Inst. Washington, Pub. 213, 1918.

83. VAUGHAN, T. W., Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and recent coral reefs: U. S. Nat. Mus., Bull. 103, pp. 189-524, 1919.

84. VAUGHAN, T. W., Coral reefs and submerged platforms: Pan-Pacific Sci. Congress, 1923, Proc., vol. 2, pp. 1128-1131, Melbourne, 1924.

85. VERRILL, A. E., Corals and polyps of the North Pacific Exploring Expedition, with descriptions of other Pacific species: Essex Inst., Proc., vol. 5, pp. 17-50, 1866, 1867.

86. VERRILL, A. E., Variations and nomenclature of Bermudian, West Indian, and Brazilian reef-corals, with notes on various Indo-Pacific corals: Conn. Acad. Arts and Sci., Trans., vol. 11, 1902.

PLATE LEGENDS

PLATE 1.—SHORE FEATURES OF EUA.

A, recently elevated reef near Tufu (looking south); *B*, view looking north along coast near Tufu showing basinlike structure of Lithothamnion ridge; *C*, view looking south along "Liku" beach showing recently elevated reef (left) and dikes in the middle background.

PLATE 2.—FEATURES OF THE EASTERN RIDGE, EUA.

A, Parkers Hill viewed from vicinity of Tee Moa; *B*, top of Eastern Ridge showing "rocky backbone," view looking southeast; *C*, southern part of the summit of Eastern Ridge, showing jagged limestone pinnacles, view looking south, Station R. P. in the right background. (See figs. 3, 4.)

PLATE 3.—TOPOGRAPHIC FEATURES, EUA.

A, summit of Eastern Ridge, looking north from Parkers Hill showing Tee Moa in middle ground and 550-foot terrace beyond; *B*, surface of the 550-foot terrace as seen looking north from Tee Moa; *C*, Central Valley, Eua, as seen from a point on the Western Ridge (W. P. fig. 3) looking toward the Eastern Ridge.

PLATE 4.—FEATURES OF THE EASTERN SIDE OF EUA.

A, view looking south from the summit, showing limestone wall (foreground), and the 200-foot and 100-foot terraces (background); *B*, the 100-foot and 200-foot terraces; *C*, view looking south toward Matalanga.

PLATE 5.—ROCK FEATURES OF EUA.

A, view looking west from the seaward edge of the 400-foot terrace at Vaigana showing contact between the volcanic nucleus (the slope) and the Eocene limestone (the vertical cliff); *B*, the main dike, facing the "liku" beach; *C*, the pinnacle (Manake) as seen from the "liku" beach.

PLATE 6.—PHOTOMICROGRAPHS OF ROCKS, EUA.

A, dike no. 5 showing cored phenocrysts of plagioclase (H291); *B*, main dike exhibiting inclusion of earlier, more basic portion (H294); *C*, dike no. 3 showing zonal plagioclase phenocrysts; *D*, limestone-pyroclastic agglomerate showing carlsbad twinned plagioclase phenocryst from boulder in brown clay (H3); *E*, foraminifera in limestone-pyroclastic agglomerate, 8 mm. objective, × 10 eyepiece (3128a); *F*, limestone-pyroclastic agglomerate showing phenocryst of plagioclase (H3) from boulder in brown clay in ravine on summit of Eastern Ridge; *G*, diabasic norite, showing late phase magnetite with poikilitic texture, 3-minute exposure with Silverman illuminator to bring out surface of magnetite and 15 seconds exposure with 100-watt bulb to show the transparent minerals (3120), from boulder on east coast; *H*, typical diabasic norite, showing uralization of pyroxene (3113), from boulder on the east coast; *I*, fine grained andesitic phase of diabasic norite, showing twinning of plagioclase phenocrysts (3123) from boulder on the east coast. (Photomicrographs except *E* and *G* taken with polarized light. All except *E* taken with 166 mm. objective, × 10 ocular.)

PLATE 7.—ORBICELLA.

Orbicella tongensis Hoffmeister. *A*, *B*, type (no. 177): *A*, top of corallum, natural size; *B*, calices × 2. *C*, no. 189, natural size.

PLATE 8.—ORBICELLA.

Orbicella mansfieldi Hoffmeister. *A*, *B*, *C*, type (no. 5016): *A*, top view, natural size; *B*, side × 2; *C*, calices × 4. *D*, no. 61, top view, natural size.

PLATE 9.—ORBICELLA.

A, Orbicella parksi Hoffmeister, type (no. 90): *a*, corallum, natural size; *b*, calices × 4. *B, Orbicella laddi* Hoffmeister, type (no. 166): *a*, corallum, natural size, *b*, calices × 2.

PLATE 10.—CYPHASTREA.

Cyphastrea vaughani Hoffmeister, type (no. 406): *A*, corallum, natural size; *B*, calices × 4. *C, Cyphastrea cymotoma* Felix. no. 213, Eua, corallum, natural size.

PLATE 11.—FAVIA AND FAVITES.

A, Favia pseudostelligera Hoffmeister, type (no. 155): *a*, corallum, natural size; *b*, calices × 4. *B, Favites* cf. *complanata* (Ehrenberg), no. 174, top view, natural size.

PLATE 12.—FAVITES.

Favites magna Hoffmeister, type (no. 464): *A*, top view, natural size; *B*, top view × 2; *C*, side view × 2.

PLATE 13.—GONIASTREA.

Goniastrea retiformis (Lamarck), no. 471: *A*, top view, natural size; *B*, calices × 4.

PLATE 14.—LEPTORIA.

Leptoria setchelli Hoffmeister, type (no. 407): *A*, corallum, natural size; *B*, calices, natural size; *C*, calices, × 2.

PLATE 15.—MAEANDRA.

A, Maeandra aspera (Verrill), no. 5000: *a*, corallum, natural size; *b*, calices × 2. *B, Maeandra euaensis* Hoffmeister, type (no. 356): *a*, calices × 2; *b*, calices, natural size.

PLATE 16.—ACANTHRASTREA.

Acanthrastrea echinata (Dana), no. 161: *A*, calices × 2; *B*, top view, natural size; *C*, cross section of another fragment, natural size; *D*, top view of same fragment *C* × 2; *E*, top view of fragment *C*, natural size.

PLATE 17.—PAVONA AND ASTREOPORA.

A, Pavona ostergaardi Hoffmeister, type (no. 187): *a*, corallum, natural size; *b*, calices × 8. *B, Astreopora tongensis* Hoffmeister, type (no. 128): *a*, corallum, natural size; *b*, calices × 4; *c*, side view × 4.

PLATE 18.—ACROPORA.

Acropora, sp.: *A*, corallum, natural size; *B*, branches × 2.

PLATE 19.—ALVEOPORA.

A, B, Alveopora fijiensis Hoffmeister, type, recent specimen from Suva, Fiji: *A*, corallum, natural size; *B*, calices × 4. *C, Alveopora fijiensis* Hoffmeister, no. 188, corallum, natural size.

PLATE 20.—OPERCULINA AND PELLATISPIRA.

1, 8, *Operculina pacifica* Whipple: 1, horizontal section, × 16; 8, surface view × 10 (locality E-316). 2-4, 6, 7, *Pellatispira fulgeria* Whipple: 2, surface view × 10; 3, portion of horizontal section × 16; 4, portion of vertical section × 16; 6, horizontal section × 5; 7, vertical section × 5 (locality E-458). 5. *Pellatispira hoffmeisteri* Whipple: vertical section × 16 (locality E-369). 9, *Heterostegina* sp.: horizontal section × 16 (locality E-21A).

PLATE 21.—DISCOCYCLINA AND PELLATISPIRA.

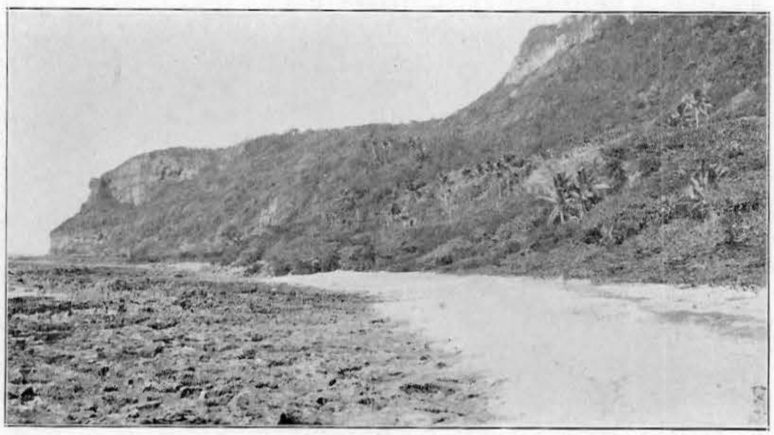
1, *Discocyclina* (*Asterocyclina*) sp.: broken specimen showing some equatorial chambers and part of the surface × 5 (locality E-369). 2, *Discocyclina* (*Asterocyclina*) sp. cf. *A. stella* (Gümbel), surface view × 10 (locality E-107). 3, *Discocyclina* (*Asterocyclina*) *stellata* (d'Archiac) surface view × 5 (locality E-369). 4, 5, *Pellatispira hoffmeisteri* Whipple: 4, broken specimen of microspheric form showing arrangement of chambers × 10 (locality E-369); 5, horizontal section showiing irregular arrangement of the chambers × 16 (locality E-373). 6, *Pellatispira rutteni* Umbgrove, horizontal section × 16 (locality E-390).

PLATE 22.—DISCOCYCLINA AND ASTEROCYCLINA.

1, 2, *Discocyclina* (*Discocyclina*) sp.: 1, horizontal section × 16 (locality E-318); 2, vertical section × 16 (locality E-319). 3-5, *Discocyclina* (*Discocyclina*) *euaensis* Whipple: 3, horizontal section × 16 (locality E-318); 4, vertical section, × 16 (locality E-313); 5, surface view × 10 (locality E-318). 6, rock section showing vertical section of *Discocyclina euaensis* Whipple (large specimen) and four vertical sections of *D.* (*Asterocyclina*) *stellata* (d'Archiac) (small specimens) × 16 (locality E-318). 7, same as 6, showing vertical sections of *Discocyclina euaensis* Whipple and one section of *D.* (*Asterocyclina*) *stellata* (d' Archiac) (center) × 16.

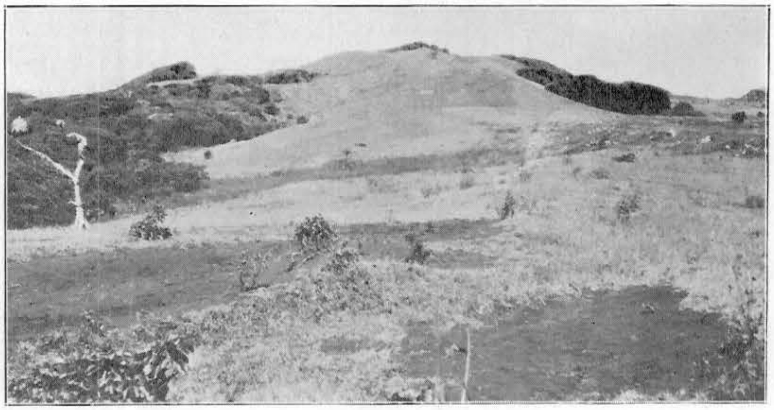
A

B

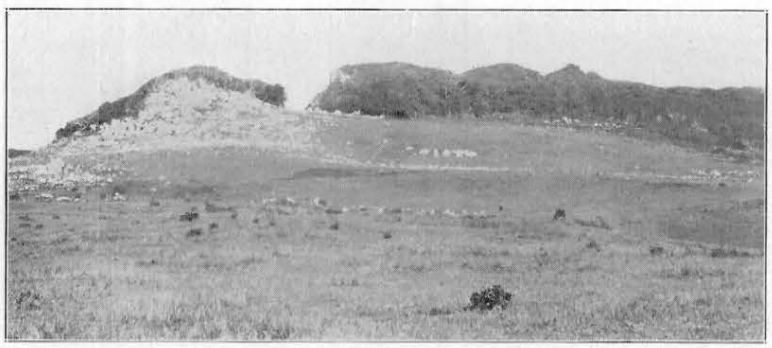


C

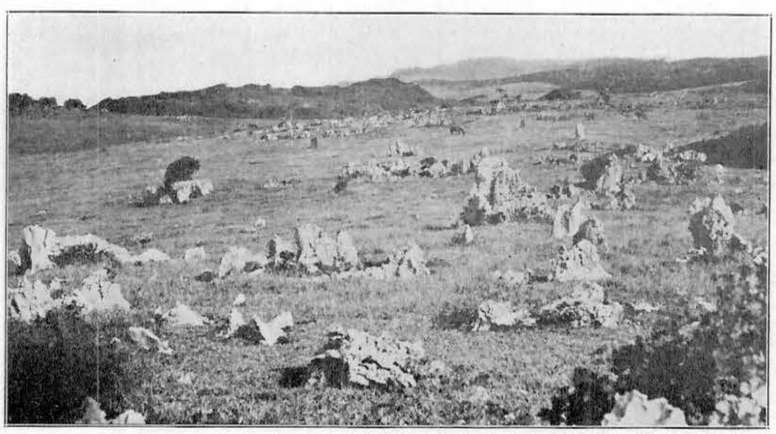
SHORE FEATURES OF EUA.



A

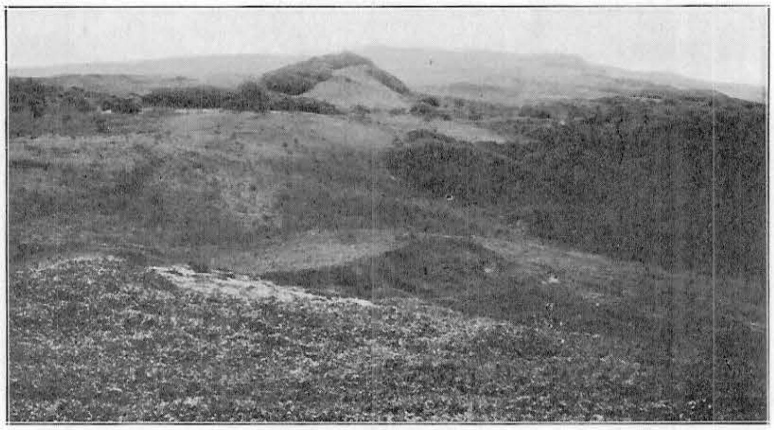


B

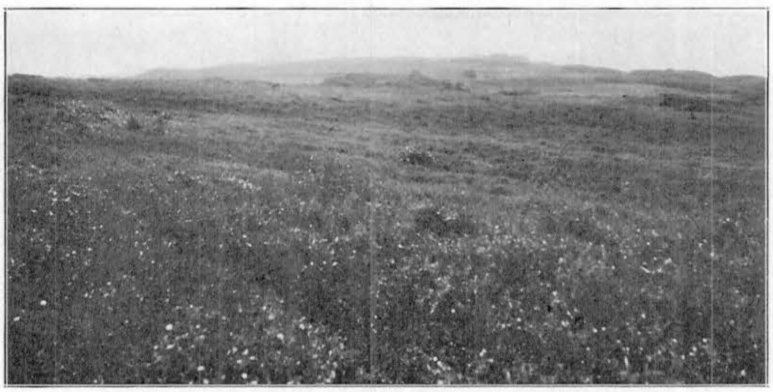


C

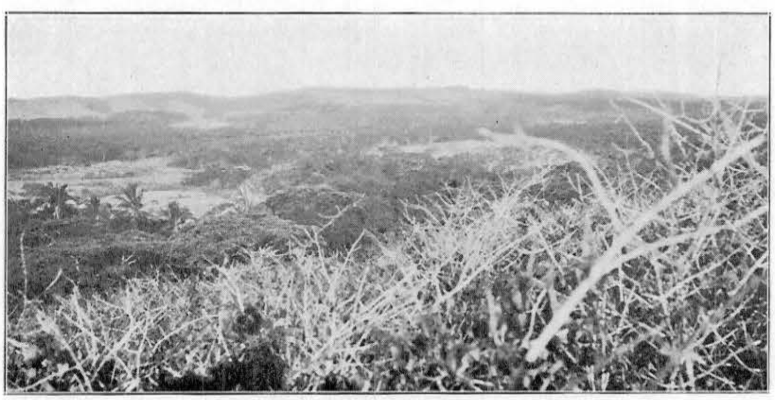
FEATURES OF THE EASTERN RIDGE, EUA.



A

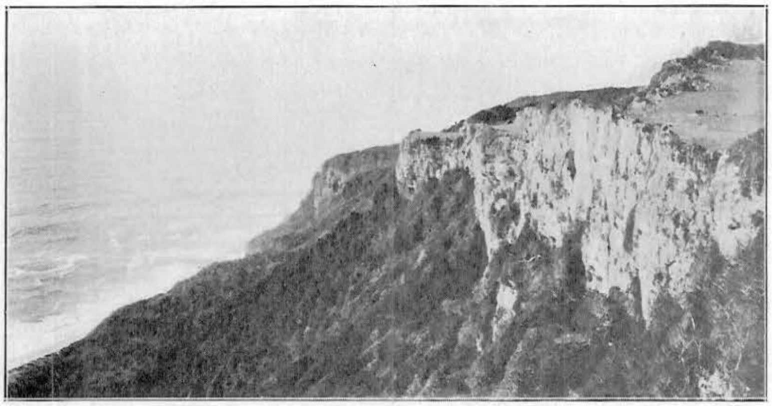


B

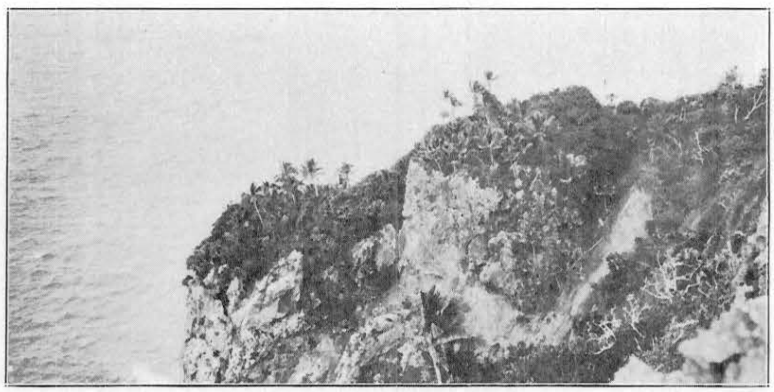


C

TOPOGRAPHIC FEATURES, EUA.



A

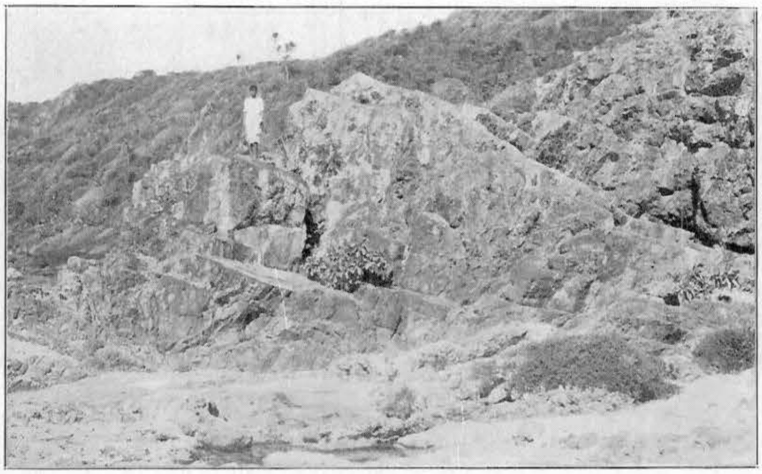


B

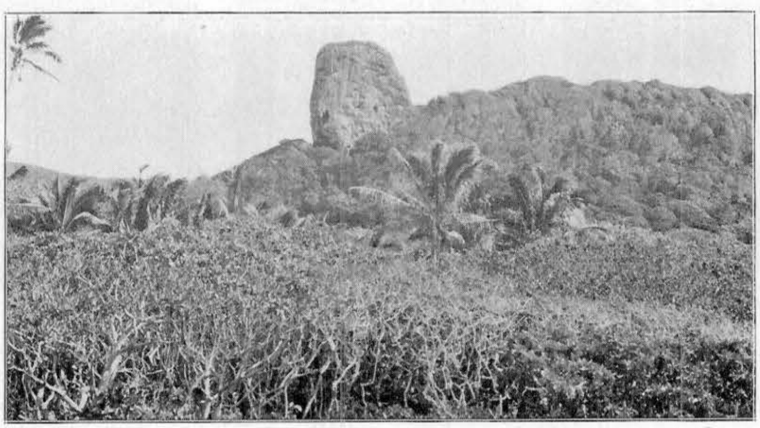
C

FEATURES OF THE EASTERN SIDE OF EUA.

A

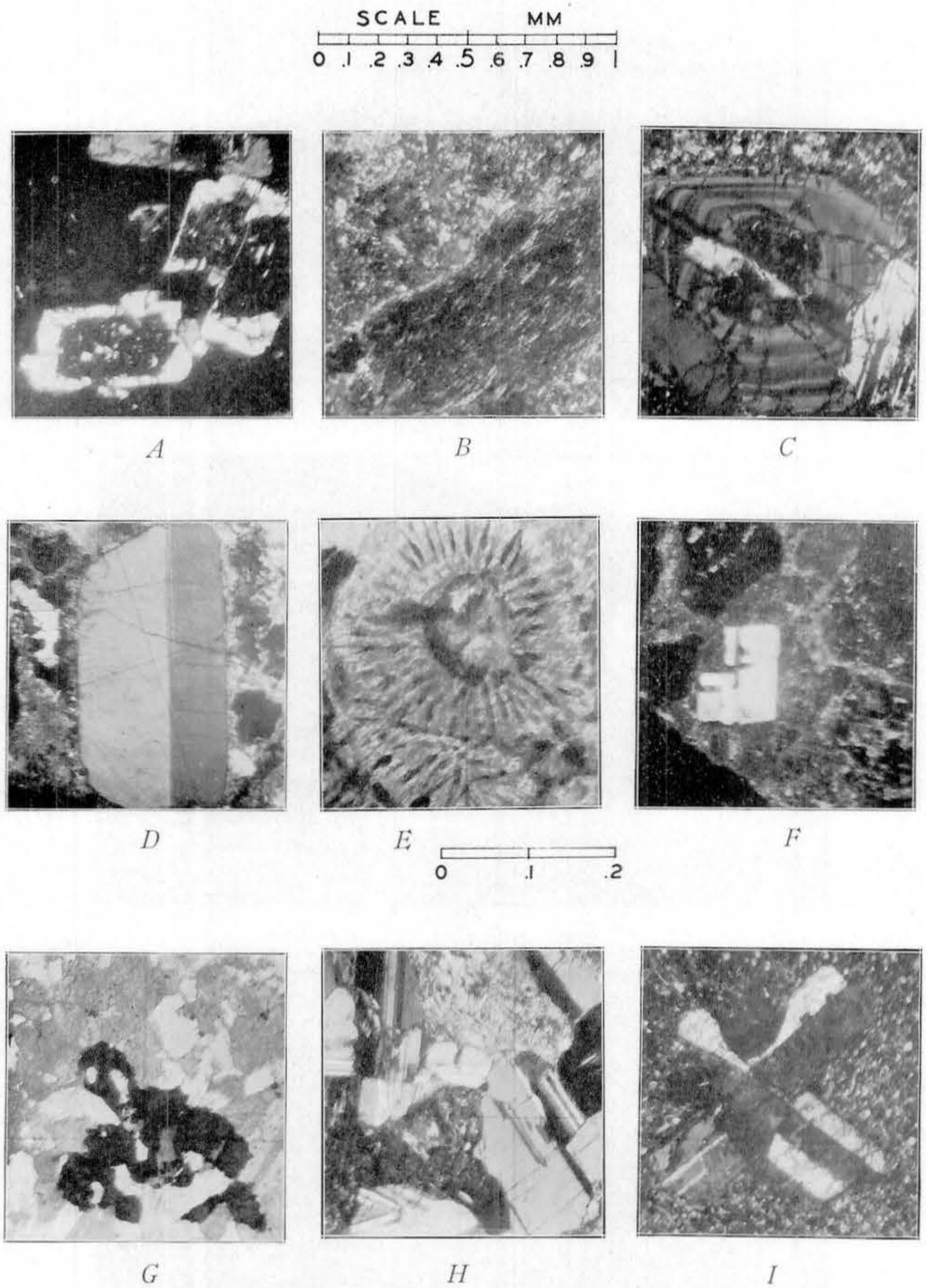


B



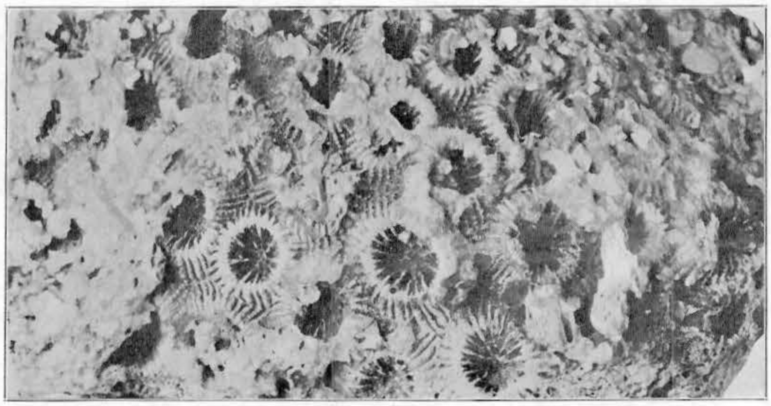
C

ROCK FEATURES OF EUA.

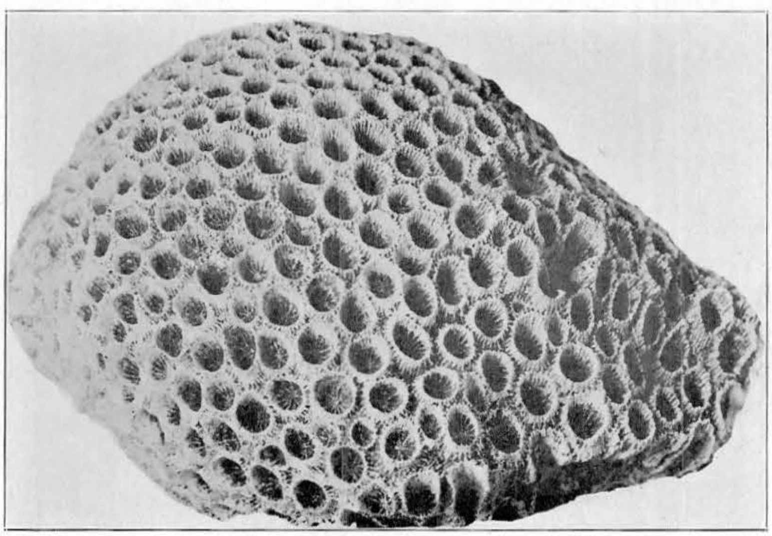


Photomicrographs of Rocks, Eua.

A

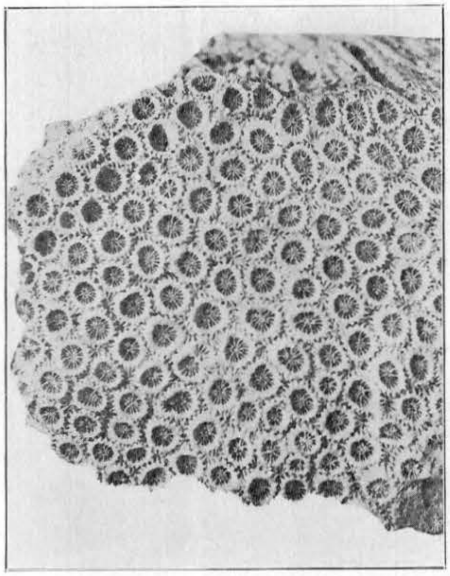


B



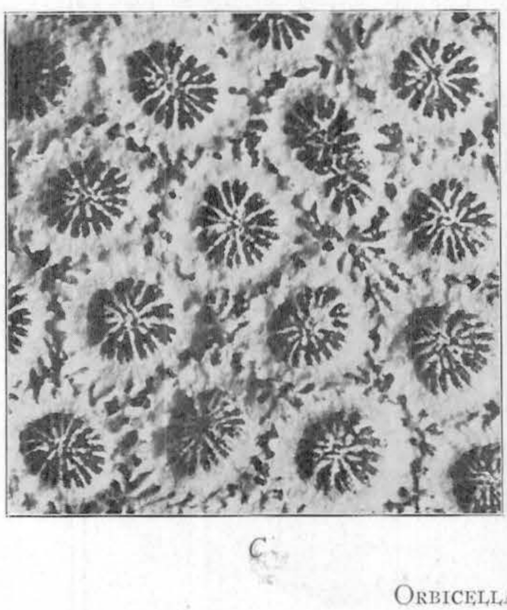
C

ORBICELLA.

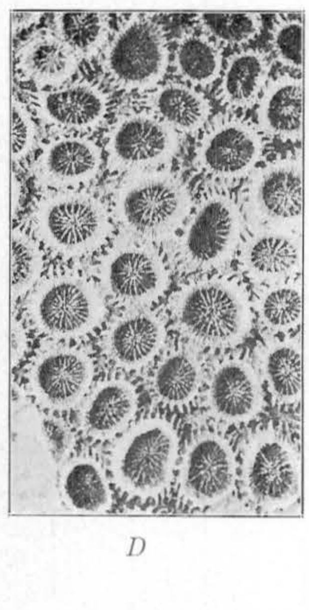


A

B

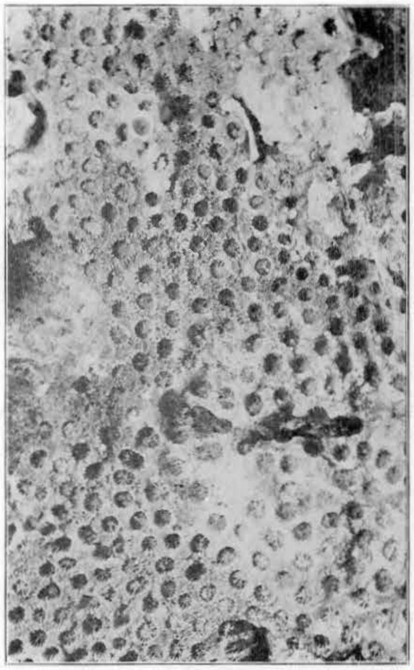


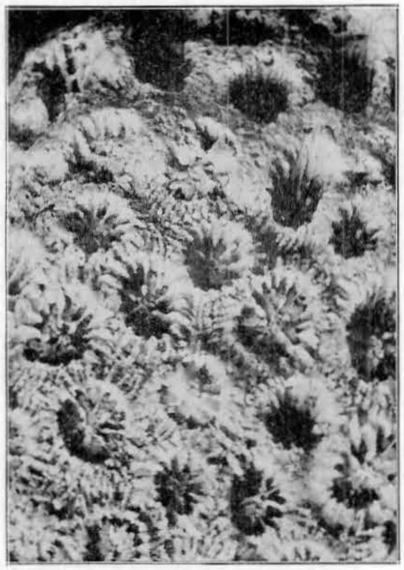
C



D

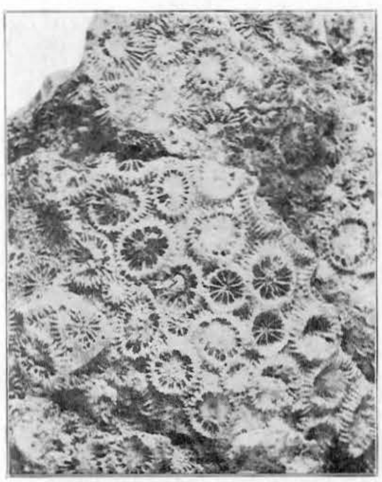
Orbicella.

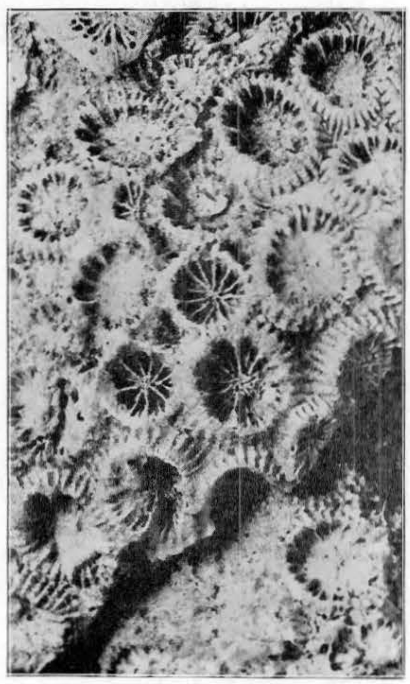




b

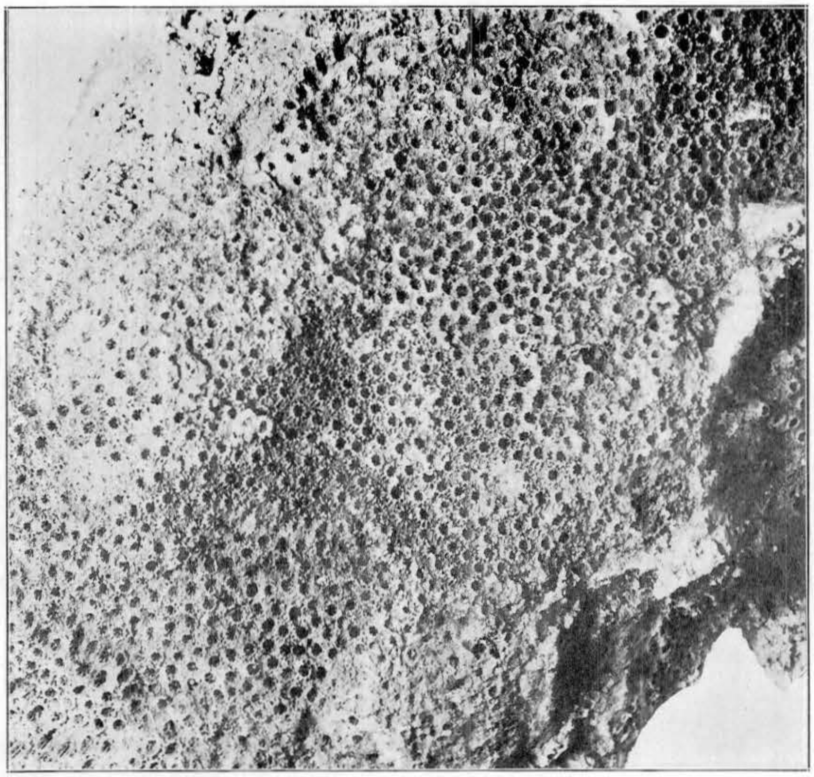
a *A*



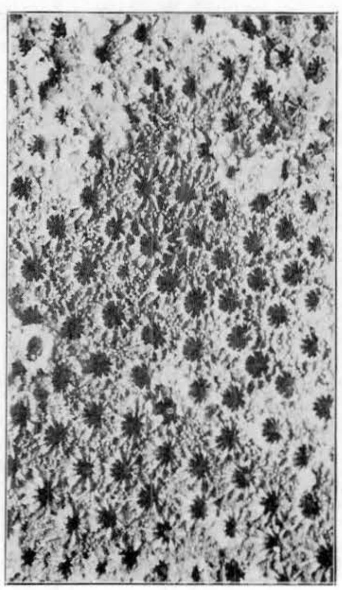


a *B* *b*

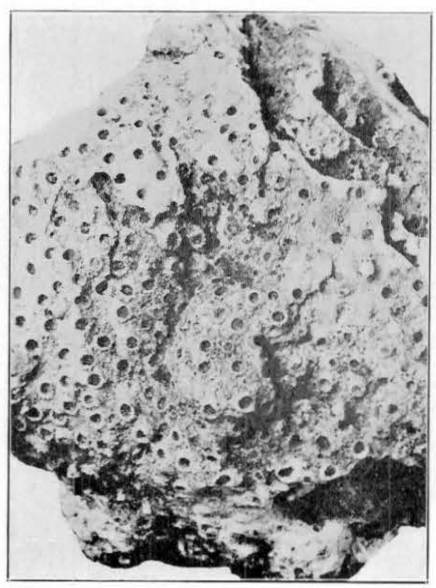
Orbicella.



A

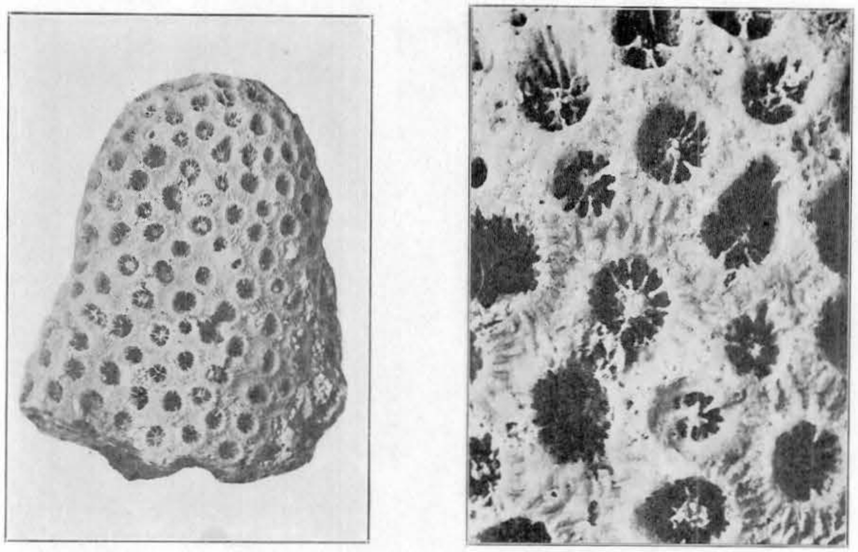


B



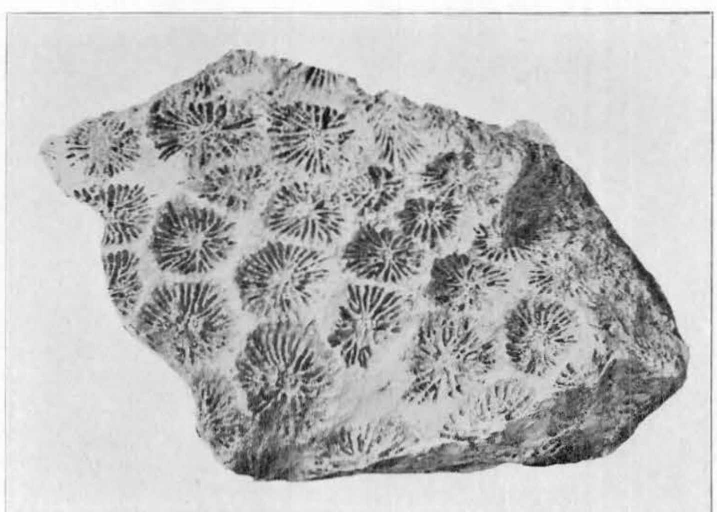
C

CYPHASTREA.



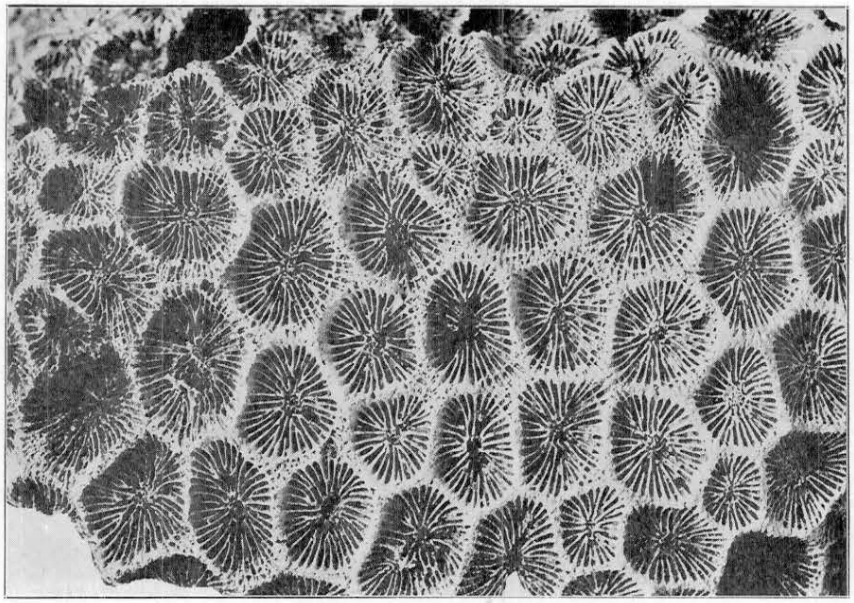
a *b*

A

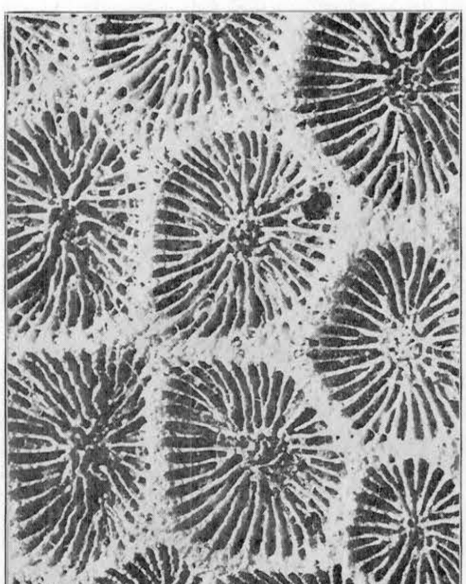


B

FAVIA AND FAVITES.



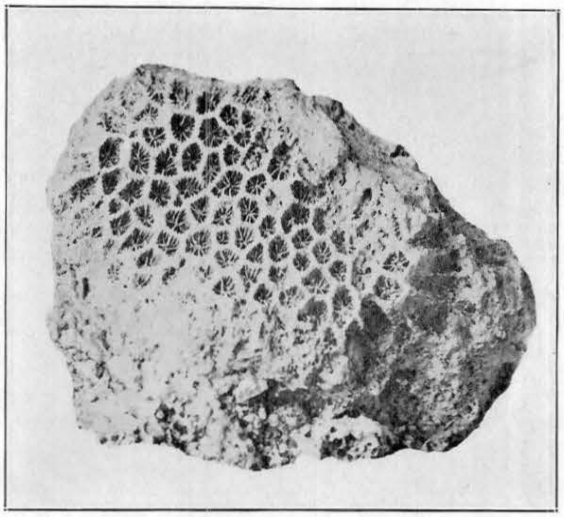
A



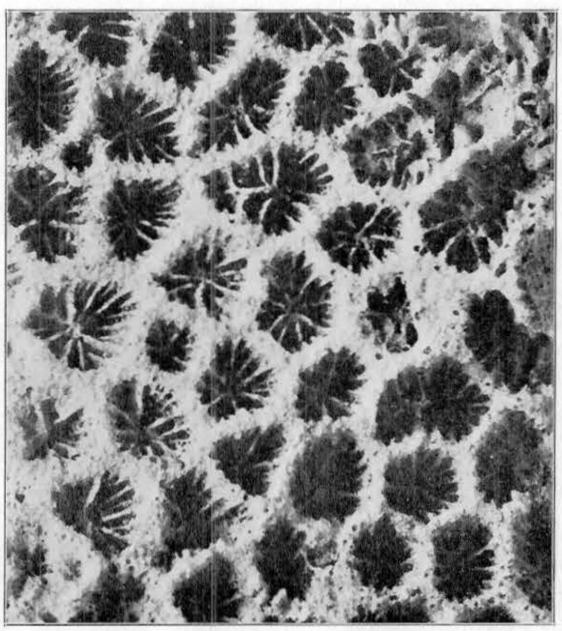
B

C

FAVITES.

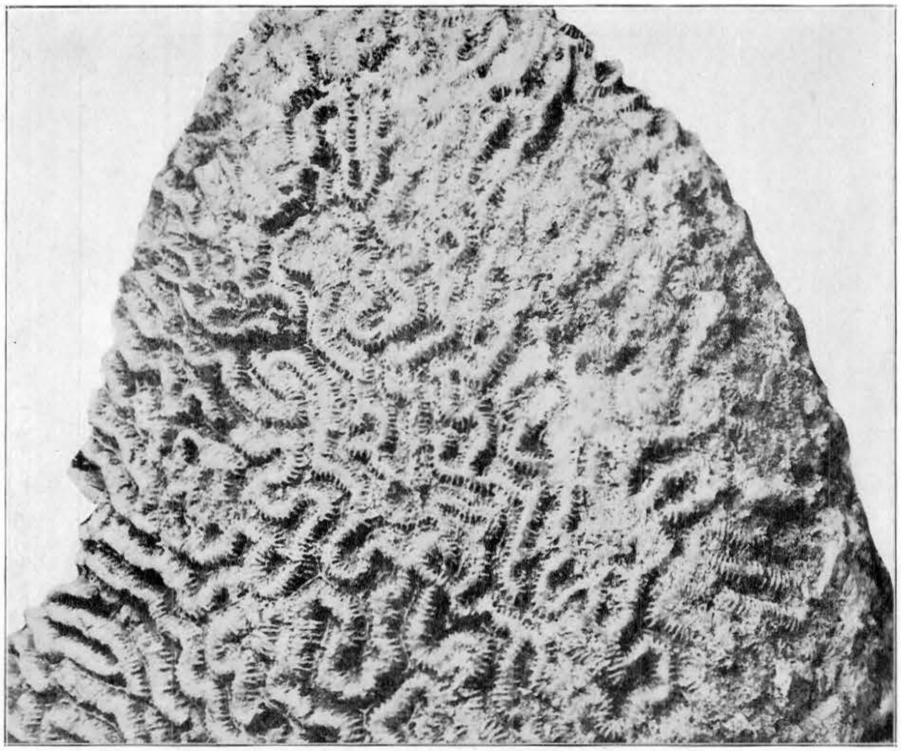


A



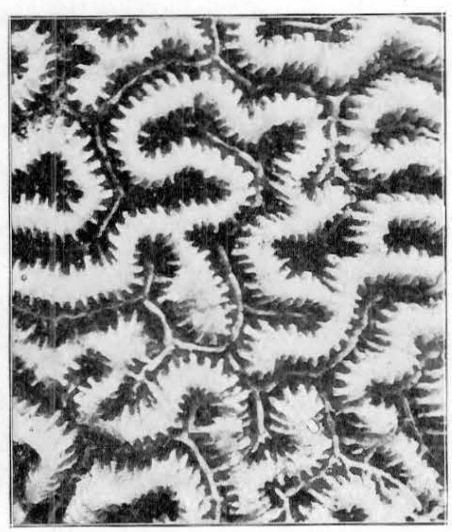
B

Goniastrea.



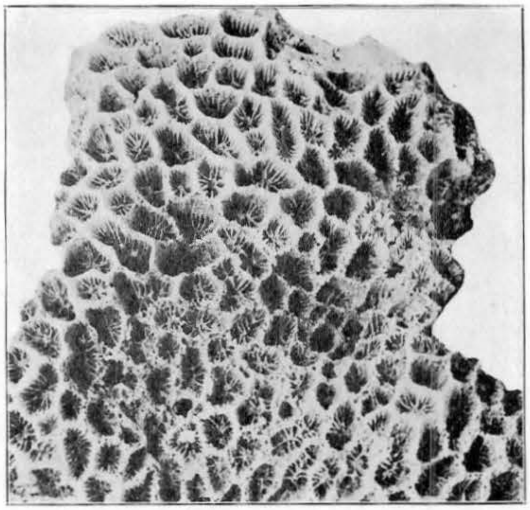
A

B

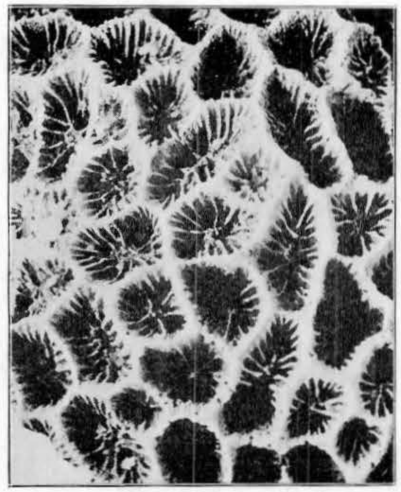


C

LEPTORIA.

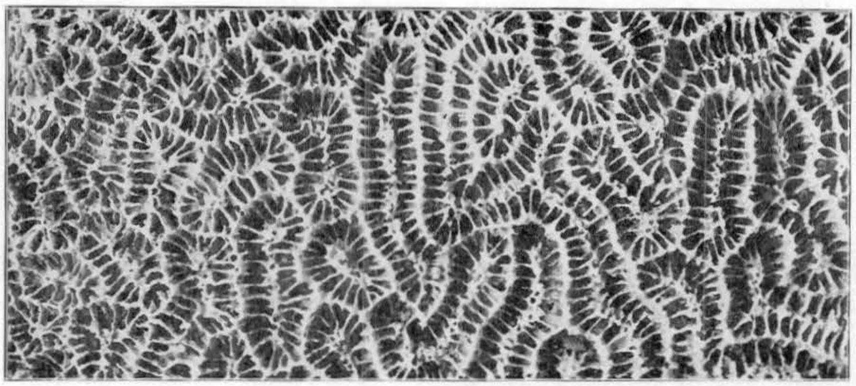


a



b

A



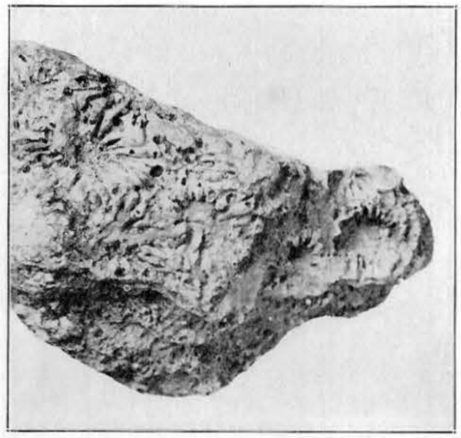
a

b

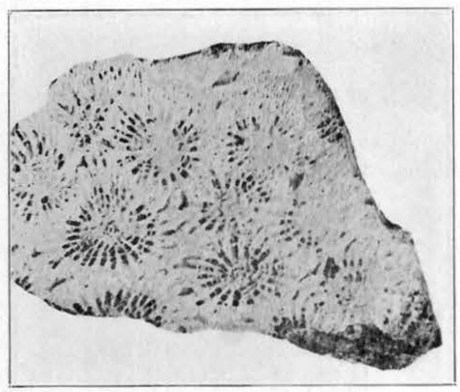
B

Maeandra.

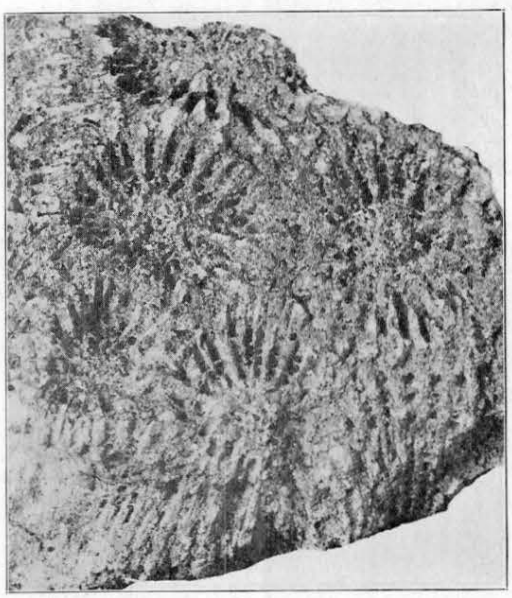
A



B



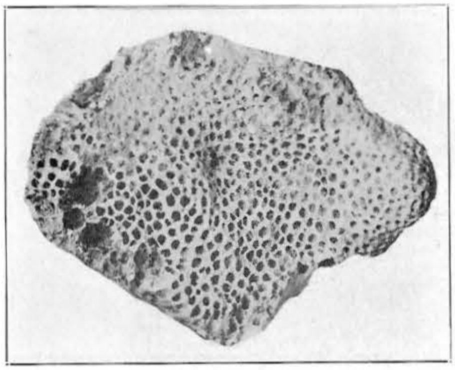
C



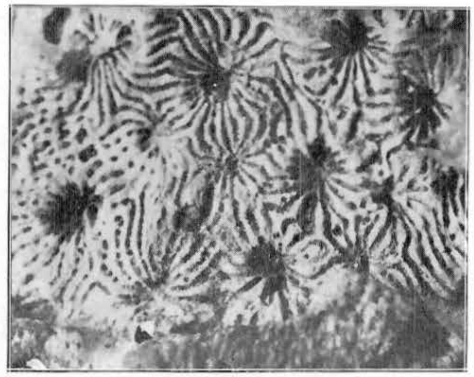
D

E

ACANTHASTREA.

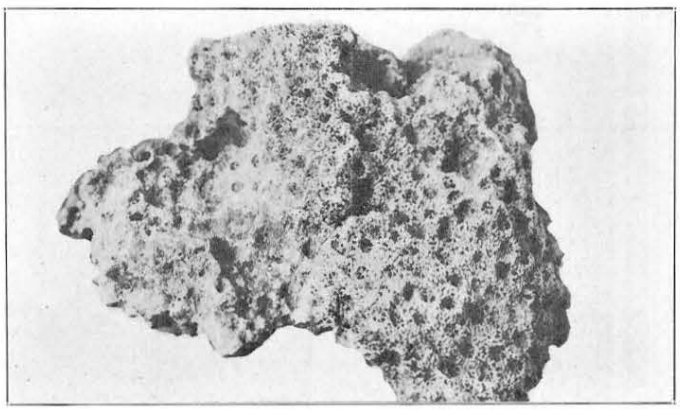


a

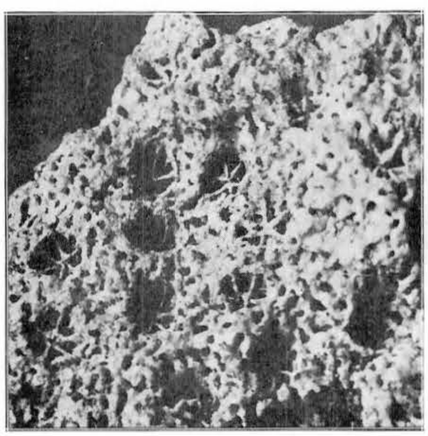


b

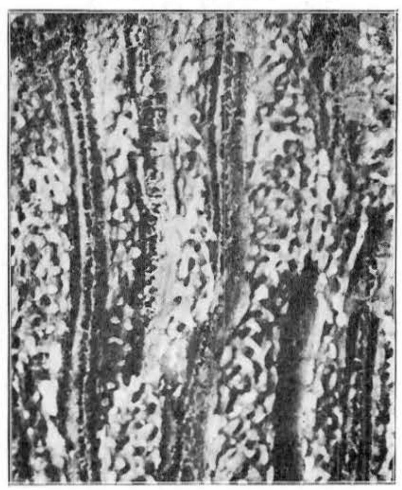
A



a



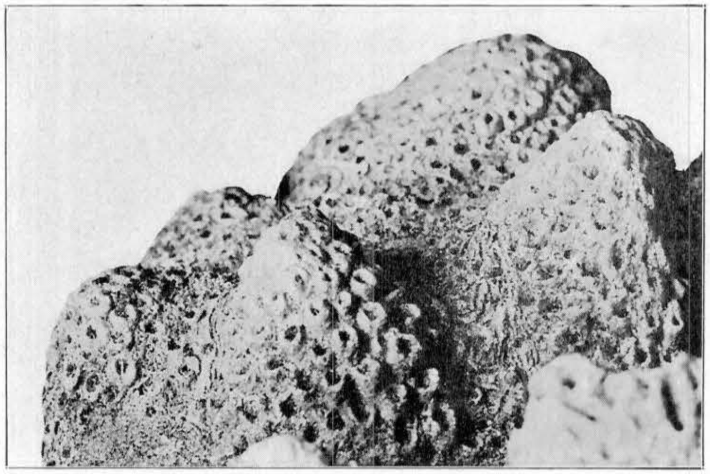
b



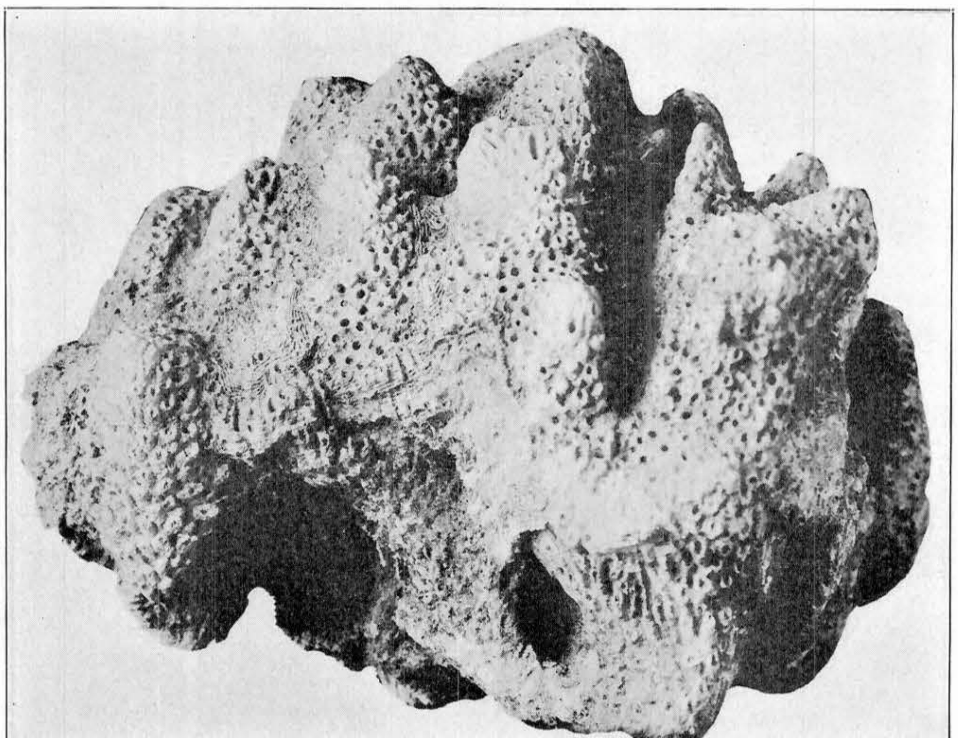
c

B

PAVONA AND ASTREOPORA.

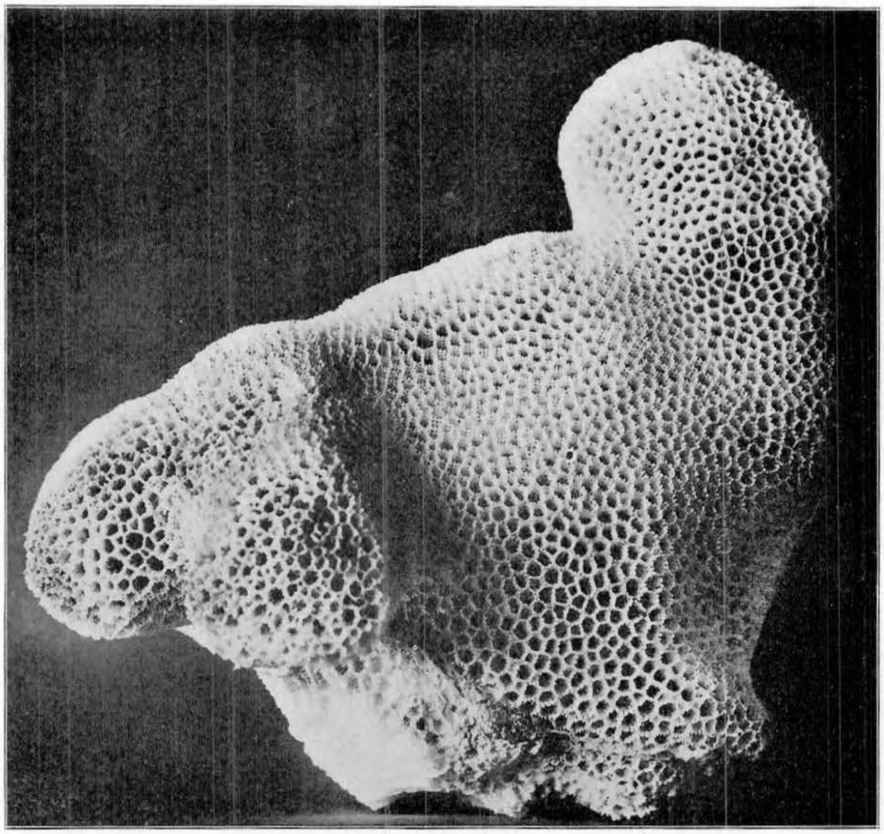


A

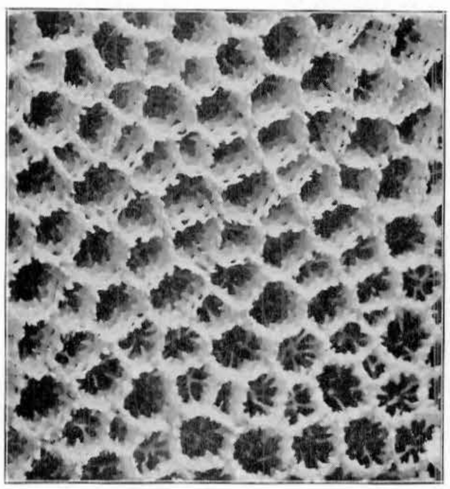


B

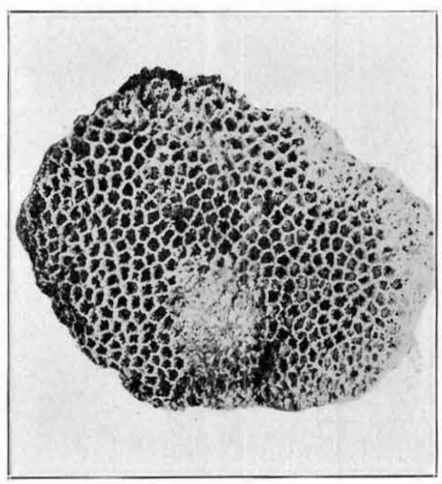
ACROPORA.



A

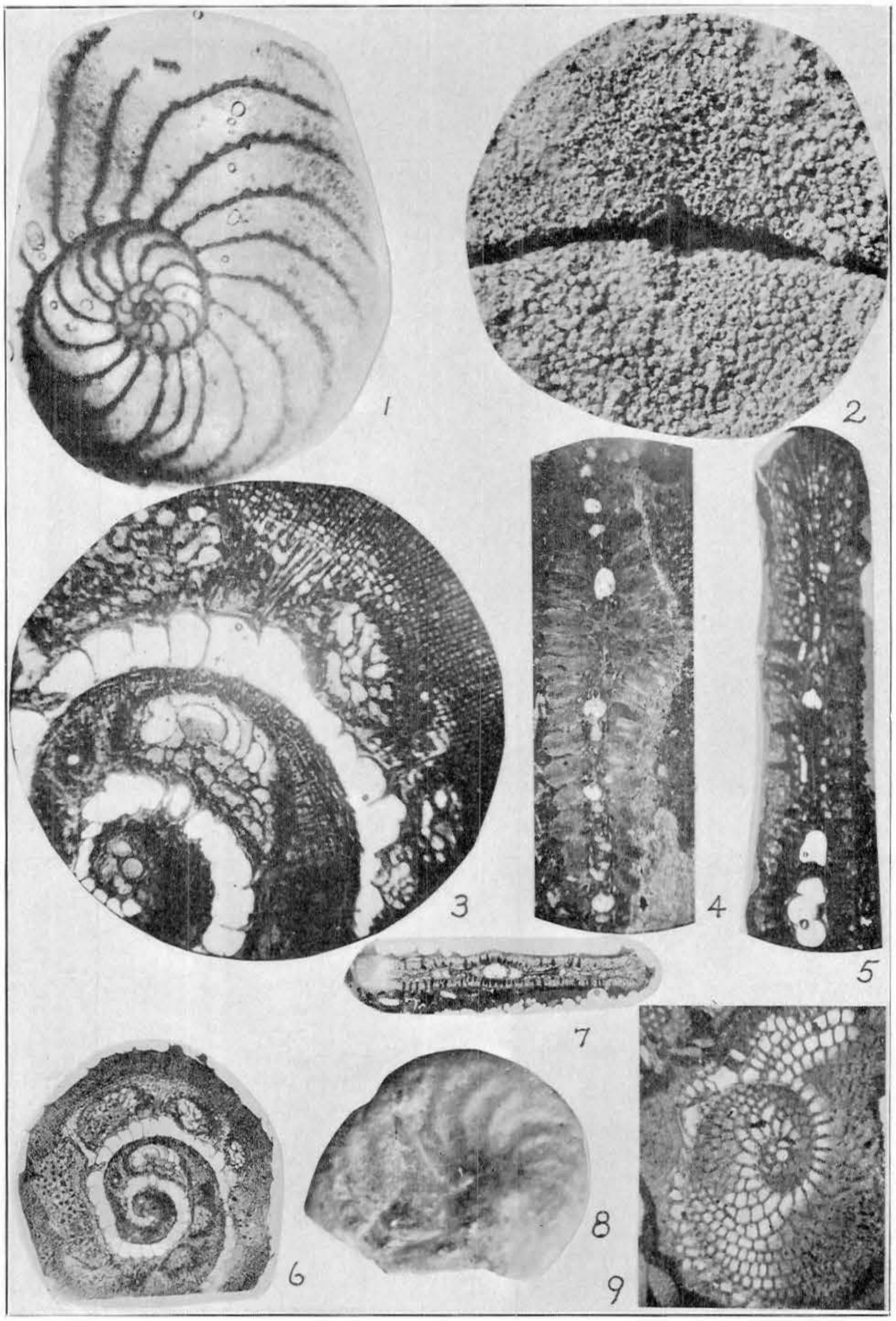


B

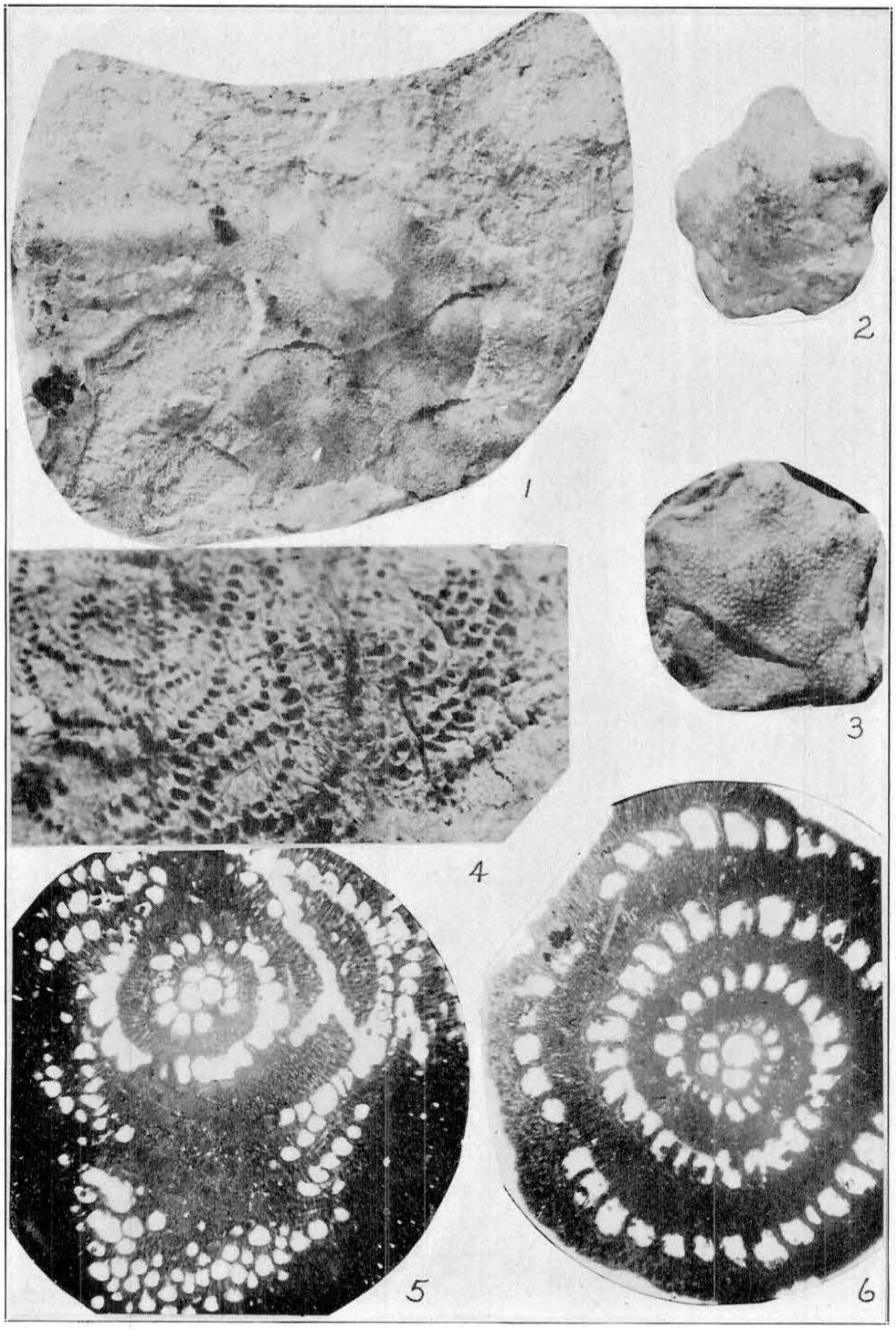


C

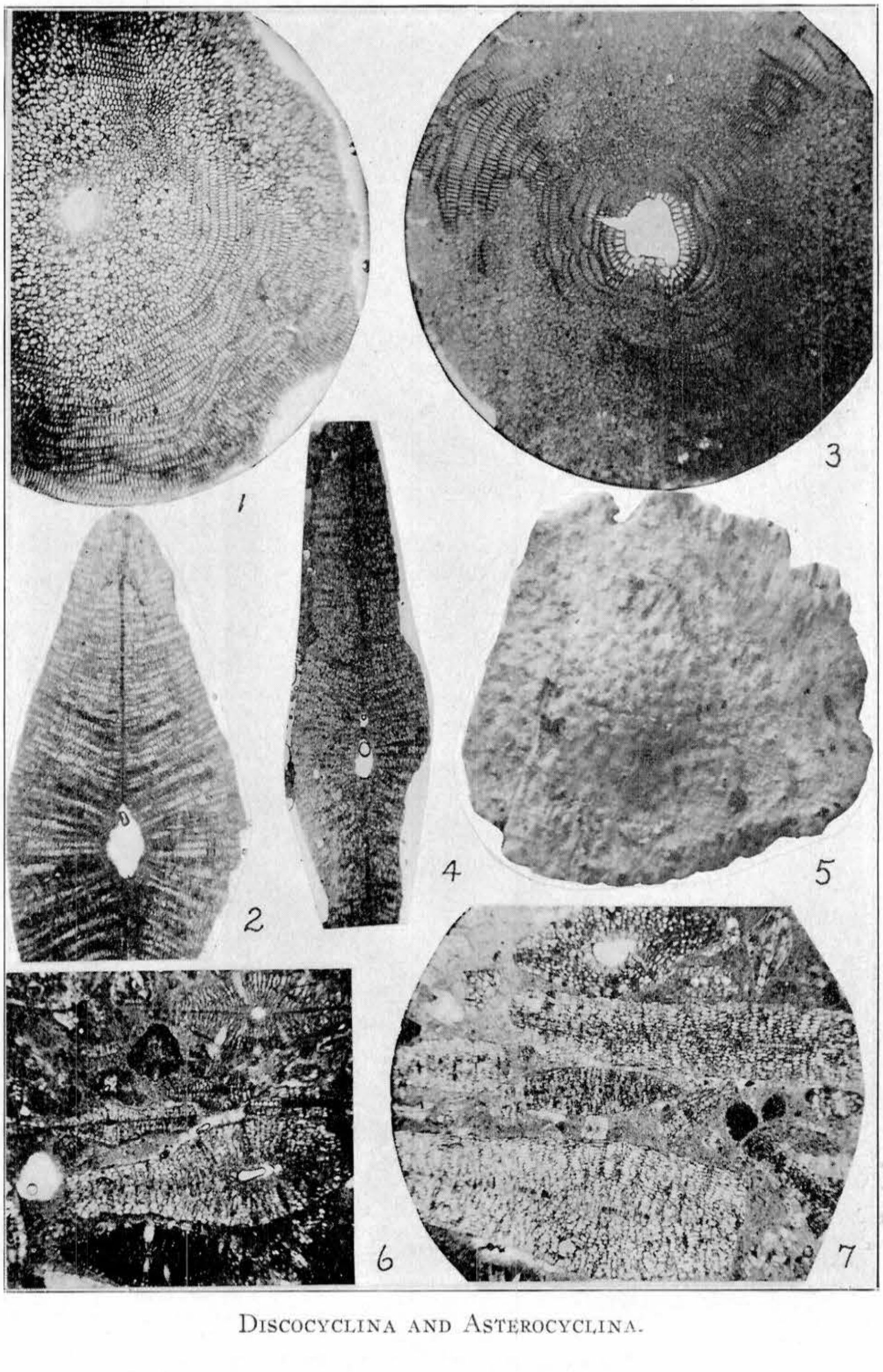
Alveopora.



Operculina and Pellatispira.



Discocyclina and Pellatispira.



Discocyclina and Asterocyclina.

TABLE 5. LIST OF SPECIES AND LOCALITIES

	1A[a]	21A	35A	35AA	57	58	67	103	107	138	147	152	276	309	313	316	318	319	347	348	349	354	357	359	361	362	364	366	369	373	374	375	376	390	402	458	459
EOCENE SPECIES																																					
Camerina pengaronensis (Verbeek)			?				X		X					?						X	?	?												X			
Pellatispira rutteni Umbgrove		?																																X			X
Pellatispira hoffmeisteri Whipple, n. sp.																												X	X	X	X	X	X				
Pellatispira fulgeria Whipple, n. sp.			X							X																										X	
Operculina pacifica Whipple, n. sp.																X	X	X																			
Heterostegina sp. indet.		X	X				X			X				X	X			X		X			X		X		X	X		X	X	X	X	X		X	
Discocyclina (Discocyclina) fritschi (Douvillé)																								X	?	?	X		X								
Discocyclina (Discocyclina) euaensis Whipple, n. sp.															X	X	X	X																			
Discocyclina (Discocyclina) sp. indet.															X		X	X		?	?			X													
Discocyclina (Discocyclina) sp. (small specimens)			X																																		
Discocyclina (Asterocyclina) stellata (d'Archica)		?					X							X	X	X	X	X			?	X	X		X		X	?	X	X	X						
Discocyclina (Asterocyclina) sp. cf. A. stella (Gümbel)									X																												
Discocyclina (Asterocyclina) sp.																													X								
RECENT SPECIES—In the younger limestones																																					
Operculina sp. cf. O. bartschi Cushman						X																															
Heterostegina depressa d'Orbigny						X																															
Cycloclypeus gumbelianus H. B. Brady					X							X	X						X																X		
Peneroplis pertusus (Förskål)					X																																
Sorites marginalis (Lamarck)	X										X	X																									
Amphisorus duplex (Carpenter)					X	?						X																									
Marginopora vertebralis Quoy and Gaimard	X			X	X			X			X	X																									
Amphistegina lessoni d'Orbigny					X	X		X				X	X						X																		
Calcarina mayori Cushman						X																															
Baculogypsina sphaerulata (Parker and Jones)						X																															
Gypsina vesicularis (Parker and Jones)						X																															

[a] The numbers refer to localities at which specimens were collected as follows: 1 A, seaward slope of Western Ridge near Tufu; 21 A, one-half mile north of Station 105; 35 A, limestone at volcanic-limestone contact at Ana Aha; 35 AA, middle of Central Valley east of Ohonua; 57, 58, western slope of Western Ridge in the vicinity of Tufu; 67, Station 115 at southern tip of Eastern Ridge; 103, seaward edge of 100-foot terrace, east of station Ra; 107, base of the 100-foot terrace north of Pinnacle; 138, from limestone at volcanic-limestone contact at Ana Aha; 147, 152, seaward edge 340-foot terrace; 276, cliff at extreme northern tip of island; 309, landward side of 100-foot terrace at Ra; 313-316, base of 100-foot terrace north of Pinnacle; 318, 319, base of Pinnacle; 347, cliff flanking eastern side 550-foot terrace west of station R; 348, 349, middle of 550-foot terrace one mile north of Tee Moa; 354, 357, 359, ¼ way up Tee Moa; 361, middle of 550-foot terrace, west of Tee Moa; 362, 364, 366, middle of 550-foot terrace, 3 chains west of Tee Moa; 369, base of Tee Moa; 373-376, Rock Point (R.P.) altitude 860 feet; 390, Nipple Tree (N.T.), altitude 840 feet; 402, ?; 458, 459, limestone cave southwest of Bush (B), altitude 700 feet.