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RECONNAISSANCE GEOMORPHOLOGY OF RANGIROA ATOLL, TUAMOTU ARCHIPELAGO

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with LIST OF VASCULAR FLORA OF RANGIROA

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RECONNAISSANCE GEOMORPHOLOGY OF RANGIROA ATOLL, TUAMOTU ARCHIPELAGO

by D. R. Stoddart

I. GENERAL DESCRIPTION

A. Introduction

Rangiroa (Figure 1) is the largest atoll in the Tuamotu Archipelago, and since the institution of a regular air service, the most accessible; yet in common with other Tuamotuan atolls it has rarely been visited by scientists and is barely mentioned in the literature. Dana (1849) published brief notes following the Wilkes Expedition; but the only full account is that by Agassiz (1903). Agassiz's descriptions are, however, verbose and imprecise, and marred by misinterpretations of major atoll features. In the study of Tuamotuan atolls, a major reference point is provided by the reports of the 1952 Pacific Science Board Expedition to Raroia Atoll, led by N. D. Newell. Major reports resulting from this expedition are those of Newell (1953, 1956) on geology and geomorphology; Doty and others (1954), Doty and Morrison (1954), and Morrison (1954) on plant and animal systematics and ecology; Harry (1953) on ichthyology; and Danielsson (1954, 1956) on culture and economic life. More recently, Ranson (1962 and earlier papers) has published accounts of Hikueru and other atolls, and detailed work has been carried out in connection with the French weapons tests at Mururoa at the eastern end of the archipelago (Lalou and others 1966, Chauveau and others 1967). Since Agassiz's work at Rangiroa, Tercinier (1956) has published briefly on soils, and Ottino (1965) and Garanger and Lavondes (1966) have issued first reports on culture history. The atoll has been recently visited by Dr. M.-H. Sachet in 1963, and by Professor A. Guilcher and the present writer in 1965. Aubert de la Rüe (1964) has published a general account of the atolls of the Tuamotu Archipelago, though he did not visit Rangiroa.

Because of shortage of time, observations in 1965 were limited to the superficial morphology of the atoll rim at a series of sample locations chosen to illustrate diverse exposure environments. These locations covered the north, west and south rims of the atoll. No observations could be made at the eastern end of the atoll, But Dr. Sachet spent some time there in 1963, and thus information is available for points on the entire perimeter. This report consists of three parts:

(1) a brief general account of the gross form and environment of Rangiroa;

(2) the systematic description of transects around the atoll rim, with emphasis on details of morphology; and

(3) a summary of atoll geomorphology as known at present, with emphasis on the nature and form of carbonate rocks and unconsolidated sediments, and a suggested summary of recent geomorphic development.

B. Acknowledgements

This study would have been impossible without the hospitality and active help of M. Maurice Pomier, Director of the Tiputa station of the Institut de Recherches pour les Huiles et Oléagineux (I.R.H.O.). M. Pomier made it possible to visit all the locations described in this report, and gave a great deal of his time in assisting the work. Dr. Marie-Hélène Sachet first drew my attention to Rangiroa, and was tireless in making arrangements for my visit. Finally, I thank the Royal Society of London, for the opportunity to visit French Polynesia following the Royal Society Expedition to the British Solomon Islands in 1965.

C. Gross Form of Rangiroa

Rangiroa is situated towards the northwestern end of the Tuamotu Archipelago, a chain of atolls 600 miles long in the center of the Pacific Ocean (Figure 1). According to Menard (1964) the Tuamotus lie on the site of part of the foundered Darwin Rise. Rangiroa is 125 miles northeast of Tahiti, the largest of the reef-encircled volcanic Society Islands. Rangiroa is itself large enough to entirely contain the island of Tahiti within its lagoon: it has a maximum length of 54 miles (northwest-southeast) and breadth of 23 miles. Agassiz states (1903, 33) that it is "somewhat pear-shaped" in outline. In quantitative terms the shape may be expressed in a number of indices, of which the Ellipticity Index is most useful. Table 1 gives calculated shape indices for Rangiroa and for a sample of 99 other atolls. Rangiroa is thus rather more elongate or elliptical than the mean for atolls so far measured.

Table 1

Index	Rangiroa Atoll	Mean values for 99 atolls[1/]
I_e	3.59	2.87 (modal class 1.5-2.0)
F	0.22	0.35
R_c	0.43	0.57
R_e	0.53	0.64

[1/] Stoddart (1966)

The size of Rangiroa (Figure 2) is its most immediately striking characteristic: the peripheral reef is 137 miles long, and the atoll has a total area of 633 square miles. This compares with 189 miles and

902 square miles, respectively, for Kwajalein Atoll in the Marshall Islands, the world's largest atoll. Dimentional statistics for Rangiroa, derived from the 1:100,000 chart by Lt. d'Anglejan Chatillon, Mission Hydrographique en Polynésie Française 1959, together with data for Raroia and four Marshall Islands atolls, including Kwajalein, are given in Table 2.

The peripheral reef flats of the atoll vary considerably in width, being generally narrower on the windward and wider on the leeward sides. On the northern rim the flat is 350-700 yards wide; on the west rim 475-700 yards wide; and on the south rim 825-1175 yards wide. The greatest width is found at the eastern end of the atoll, where north and south rims meet in a sharp angle. In common with other Tuamotu atolls, much of the reef rim is covered with islands. As at Raroia, atoll land is most continuous on the narrowest rim, and least continuous where the rim is widest; rim dimensions in both cases are similar, though orientation is not the same (Newell 1965, 330). The 1959 chart of Rangiroa shows 241 islands, of which all except 10 are on the peripheral reef rim. Islands cover one-third of the area of the peripheral rim, compared with 35% at Raroia, and contrasting with less than 10% on some Marshall Island atolls.

There are two passes through the rim, both on the north or windward side. Avatoru, the widest, is 400 yards wide, with depths of up to 10 fathoms; it bifurcates lagoonward. Tiputa Pass is 330 yards wide, with least depths of 9 fathoms; it also has a patch reef with island on the lagoon side. The passes are charted at a scale of 1:15,000 in Admiralty Chart 1175. In both passes there are strong and complex currents; Agassiz found these to reach 4-1/2 - 8 knots (Agassiz 1903, 33-34). There is little information on the lagoon floor. Agassiz (1903, 36, 45) took soundings between Avatoru and Fenuaroa, and found a hard, fairly flat floor, reaching 14-16 fathoms in the center, with a wide area less than 5 fathoms near the south rim. Within the two passes the floor lies at depths of 10-15 fathoms. Scattered soundings during the 1959 survey gave five readings of more than 30 fathoms, with a maximum of 34.4 fathoms; this compares with a maximum of 30.1 fathoms at Raroia. There seem to be few lagoon patch reefs actually breaking surface in the central part of the lagoon, but a greater number rising to about 5 fathoms. Patch reefs are concentrated in the narrow eastern part of the lagoon, and along the western side. Apart from the islands on patches near the passes there are seven small islands on lagoon patch reefs.

Soundings on the outer slopes of the atoll average about 600 fathoms at distances of 2 to 4 nautical miles from the reef. Slopes are steepest to the north (1 in 3 to 1 in 4), east (1 in 3.6), and south (1 in 4), and least steep along the west side (1 in 6 to 1 in 7). Soundings by Agassiz show that the outer slopes on both north and south sides of the atoll are steepest near the reefs, and become gentler at depth.

Table 2

Atoll	Perimeter miles	Length miles	Breadth miles	Total area sq. miles	Lagoon area sq. miles	Reef area sq. miles	Island area sq. miles	Number of islands
RANGIROA1/	137	54	23	633	583	50	16.6	241
Raroia2/	56	27	9	154	131	23	8	280
Kwajalein3/	189	804/	204/	9024/	880	(c.22)	5.64/	924/
Rongelap3/	93	33	20	4264/	396	34	2.54/	584/
Eniwetok3/	72	25	20	3954/	360	32	2.54/	394/
Bikini3/	66	26	15	2674/	243	30	2.8	294/

Sources:

1/ 1:100,000 chart by Lt. d'Anglejan Chatillon, 1959.

2/ Newell 1956, 329-330.

3/ Emery, Tracey and Ladd 1954, 22.

4/ Fosberg 1956, 34 and Figure 10.

D. Climate and tides

The following summary of wind conditions in the Taumotus is taken from the Geographical Handbooks Series: Pacific Islands, volume 2 (1943), p. 195-196.

> "The trade winds blow over the archipelago throughout the year but are often disturbed; they are most regular from May to October and then blow freshly. Their mean direction is east, drawing to east-south-east from June to October, and then to east-north-east from November to May. At this latter period they are often light, and may alternate with heavy unstable squalls from north to south-west, these squalls being more frequent by night than by day. Strong winds from the south-east are liable to occur from May to September, but especially in August, when they are apt to last from four to eight days. From November to May, gales from north to south-west are relatively frequent, especially in January to March. In January a gale arising in the north-west usually shifts to north and north-east; at other times the tendency is for it to shift from north-west to south-west.
>
> "The Tuamotu group is subject to hurricanes, which occur as a rule towards the end of the year, or in January or February. Normally, however, they occur less than once in two years. Hurricanes (tropical cyclones) of particular force have been recorded in September 1877, February 1878, January 1903, and February 1906."

Climatic data for the I.R.H.O. Station at Tiputa, Rangiroa, are available since 1959. The mean annual rainfall for 1959-64 was 57 inches (1449 mm), but this figure conceals considerable variation from year to year. Rainfall tends to be highest in November-January, when it is also least reliable, and lowest in April-May and again in September. The scatter diagram of monthly rainfall over the period of record (Figure 3) shows this vividly. The range of actual monthly rainfalls recorded in each month even over this short period gives a similar impression, as shown in Table 3. Exceptionally high monthly figures appear to result largely from the rainfall received during single storms: in each of the years of record there was one storm yielding more than 100 mm of rainfall in a single day, with a maximum of 159.1 mm in one day in January 1965. These exceptional storms are well-distributed throughout the year (Figure 4), though with minima in May and September.

Other climatic data are less complete. Mean annual temperature in 1963 was 27.7°C and in 1964, 27.6°C. The variation in monthly means is approximately 3°C: from a minimum of 25.7-26.2° in July to a maximum of 28.8-29.3°C in February-March. Insolation is greater than 200 hours per month in all months except November and December, and totals between 2500 and 3000 hours per annum (1963: 2671 hours; 1964: 2893 hours). No wind or pressure records are kept at Rangiroa.

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Table 3[1/]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
A:	370.8	292.5	224.5	212.5	340.2	248.0	98.8	171.0	94.7	286.5	496.1	321.4
B:	62.5	44.3	54.1	27.0	11.9	9.0	11.9	25.0	24.7	16.0	36.4	33.7

1/ Source: Rainfall records, I.R.H.O., Tiputa.

A. Maximum recorded for each month, mm, 1959-65

B. Minimum recorded for each month, mm, 1959-65

Newell (1956) summarized sea conditions affecting the Tuamotu atolls as follows:

(1) Prevailing trade winds from the east give heavy seas on the northeast or windward sides of atolls.

(2) Southern Ocean swell breaks heavily on the south or swellward sides of atolls.

(3) Occasional hurricanes or tropical storms strike atolls in their northwest or stormward quarter.

This framework may be conveniently used for categorizing the rims of Rangiroa.

According to Wiens (1962, 214) the spring tide range at Rangiroa is 2.1 feet; this compares closely with a little under 2 feet at Raroia (Newell 1956, 329).

II. THE NORTHERN OR WINDWARD RIM

A. General Characteristics

The northern reef flat varies in width from 350 to 700 yards, reaching a maximum of 1050 yards at its eastern end. It is approximately 50 miles long, and is surmounted by islands for some 85% of this length. Five of the islands are more than a mile long: most of the rest are between 200 and 600 yards in length, but show clear evidence of being dissected fragments of formerly longer islands. The two deep-water passes (*ava*) are found on the northern rim, to the west of the islands of Avatoru and Tiputa, respectively; on each of these two islands there is a village of about 300 people. At the lagoonward entrance of each pass there is a reef patch with a small island. The characteristics of the flat are described, first, with an island, and second, without.

(1) Reef rim with island.

The characteristics of the reef rim with island are shown schematically in Figures 5 and 6A. A cross-section of reef rim with island falls into three main divisions: (a) the seaward flat, (b) the island, and (c) the lagoon reef. The width of the seaward flat varies from 50 to 200 yards, and occupies roughly one-fifth of the width of the rim. It consists of a raised outer rim, with surge channels and living Porolithon to seaward (the "algal ridge" *sensu lato*): and a bare rock flat, partly drying at low water. Detailed transects of the seaward flat are given in Section IIB.

The islands (*motu*) are generally 250 to 400 yards wide. They are built almost entirely of shingle, with massive shingle and rubble ridges rising to heights of 10-15 feet above the reef flat on the seaward side. Lagoonward of these ramparts the surface falls fairly rapidly to a level of 6-8 feet above the flat, and declines lagoonwards.

The lagoon shore is formed by steep ridges of finer shingle. The lower part of the seaward shore almost invariably consists of an erosion ramp of worn, smooth conglomerate, sloping seawards at angles of 5-7° (Plates 1 and 2), and in many places overlain by topographically recognizable beachrock (Plate 3). The beachrock, with dips of 3-7° (maximum recorded 11-20°) normally follows the shore, but in places trends across the seaward flat at an angle to the shore to form outliers up to 80 yards distant from it. Seaward beach angles vary considerably: the beach face of rubble beaches may reach 14-18°, though angles as small as 6-1/2° were measured on small patches of sand beach. On the lagoon shore, though the relief is much less, angles remain steep: lagoon-facing slopes of successive beach ridges at Tiputa have angles of 10-13°, while the backslope of the ridges reaches 19° in places. At some points the lagoon ridges are being oversteepened by erosion, to give angles as high as 39° on the lagoon shore of Maheretetiae. In many islands, particularly towards the west, the steep lagoon ridges enclose an area of standing water or marshy ground (tairua pape): at Avatoru this measures 170 x 700 yards (Plate 8). After heavy rain the low-lying area surrounding the pools may be covered with two to three inches of standing water for a period of days. In addition to the pools surface depressions are also found in the form of taro pits (maite), formerly used for cultivation but now serving as depositories for organic rubbish and the growing of bananas and other plants.

The islands are separated by shallow, narrow channels known as hoa (Plate 4). These are clearly erosional, and represent breaks in formerly more extensive islands. In the walls of islands transected by hoa, conglomerate rock is exposed underlying the island clastics and rising above the level of the reef flat. This conglomerate forms a ledge in the walls, and also floors the hoa itself. Channels cut in the conglomerate by water passing from sea to lagoon are extending seaward by headward erosion, often terminating in small waterfalls with plunge pools. Erosion of the conglomerate is generally fronted by a flat erosion ramp representing the extent of marine planation. The height of the conglomerate varies: between Tiputa and Tepaetia, where the seaward beach ridges are not higher than 8 ft., the conglomerate stands three feet above the inner reef flat at the seaward end of the hoa, falling gradually to 1 ft. at the lagoonward end. The general dip of the upper surface of the rock is about 0.5; at the seaward end, stratification planes in the rock dip lagoonward at up to 1°. No seaward dips were seen. Much of the rock surface in the hoa is undergoing onion-skin spalling of plates less than 6 inches in thickness, which once loosened are at times torn off bodily by wave action. Neither the conglomerate rock nor the erosion ramp immediately to seaward extends beyond the general line of the seaward or lagoonward shores of islands. In places similar rock forms horizontal outcrops 1-2 feet high and of small extent on the lagoon shores of islands. The lagoonward mouths of hoa are often almost closed by spits and bars of fresh small coral shingle. On Mahereretiatae a relict hoa was seen in the process of being recolonised by vegetation, after being sealed at both ends by beach ridges.

The lagoon reefs on the northern rim are poorly developed. A rather sparse growth of corals extends from the beach foot to the edge of the lagoon slope, a distance of only 15-50 yards, where the bottom falls steeply to the lagoon floor at depths of 10-15 fathoms.

(2) Reef rim without island.

Reef rim lacking island was investigated between Moao and Hararu. Although no land is shown on the chart, the whole of this section resembles a normal hoa. The seaward flat is the same as that off islands, with seaward rim and bare rock-floored reef flat, together with occasional large reef blocks. The place of the island is taken by a platform of conglomerate rock, with a general level of less than 2 feet above the flat. The seaward edge of the conglomerate forms a low cliff overlooking an abrasion platform. Channels through the conglomerate are shallower and less clearly defined than in the hoa, and are often discontinuous; near the lagoon edge, however, they may become deeper, V-shaped scour notches only partly interrupted by bars. Along the seaward edge of the conglomerate platform there is no accumulation of rubble or shingle; but along the lagoon edge there is a zone 50 yards wide of high steep shingle ridges. The inner part of the conglomerate platform and the lagoonward ridges are covered with vegetation, mainly Pemphis acidula and Suriana maritima growing directly on the bare rock surface; the plant cover is sufficiently dense that, seen from the sea, the inter-island flat appears to be a vegetated island.

This description applies specifically to the 1-1/2 miles long Maoa-Hararu gap, which is one of the longest on the northern rim; whether other inter-island areas on this rim are comparable remains to be seen.

B. Reef flat profiles

The northern rim of Rangiroa was investigated at Avatoru, Tiputa, Tepaetia, Mahereretiatae, and eastwards to Hararu in the Moao-Hararu gap. Measured profiles of the seaward flat at these locations are given in Figure 7.

Profile 1

Avatoru, north shore, west end of the island. The reef flat has an average width of 170 yards, and the seaward beach of 20 yards. The following zones are recognized:

(a) Porolithon zone of encrusting pink algae. The algae form a 'paint' over the surface of surge channels and inter-channel areas; the channels themselves pass seawards into the reef-front groove system. Apart from small and scattered Porites and Acropora in the surge channels, corals are absent. Slate-pencil urchins are conspicuous on the algal surface. In the channels the Porolithon forms small, smooth-surfaced bosses up to 6 inches high and 6 inches in diameter; the channels themselves are 10-15 yards apart. From the inner limit of continuous Porolithon to the wave break line the zone is 30-40 yards wide. At low water the zone emerges during backwash, but is covered by up to 2 feet of water during swash.

(b) Orange zone. This name is given to a highly distinctive zone of eroded rock at the same level as or slightly higher than the Porolithon zone; it consists of rimmed pools and holes coated with an orange alga. Zones (a) and (b) together comprise the outer ridge or, in a wide sense, the algal ridge, of the seaward flat. The orange zone is 20-25 yards wide. Its inner boundary is irregular, serrated by erosion channels formed by water pouring over the lip onto the flat itself. There are no growing corals in this zone.

(c) Reef flat. A rock-floored flat deepening from land to sea. The inner half dries completely at low water, when the outer part still carries up to 1.5 feet. Potholes near the junction with zone (b) contain a few small corals such as Pocillopora and Porites, but otherwise there are no growing corals on any part of the flat. The planed rock surface is very sparsely covered with a thin layer of mobile sand. Total width 100-110 yards.

(d) Beach-foot beachrock: a massive conglomerate, dipping seaward, forming a plate 5 yards wide and 1.5 feet thick along the foot of the beach; resting on an inclined rock surface which passes under the beach sediments and which is formed of a similar conglomerate to the beachrock.

(e) Beach face: white, unweathered coral shingle, 14 yards wide and rising to 8 feet above the level of the inner flat.

(f) Beach crest of blackened shingle with a hedge of Suriana maritima.

Profile 2

Tiputa, north shore, west end of the island. The reef flat is only 90 yards wide, and the rubble beach is correspondingly higher and steeper.

(a) Porolithon zone of smooth pink encrusting algae between surge channels, with small boss-like growths on channel walls. No growing corals; a few patches of green algae. When observed wave action was greater here than elsewhere on the reef edge: in very calm conditions waves at breaking reached heights of 1.5 to 2 yards, at times throwing spray to heights of 6 yards. The zone is at least 30 yards wide.

(b) Orange zone of eroded rock with large potholes and some sharp residual pinnacles. No pink algae. There are some corals in the deeper potholes. The zone is 10-25 yards wide, and rises 2 feet above the outer reef flat.

(c) Reef flat: a planed rock floor with a thin discontinuous cover of sand and no corals. Strong longitudinal currents move westwards towards Tiputa pass to remove water pouring over the raised rim. The flat deepens slightly from land to sea, and the inner part dries at low water, 35 yards wide.

(d) Beach-foot beach conglomerate: a rather heavily eroded massive conglomerate, dipping seaward, 5 yards wide.

(e) Beach face, 12 yards wide, rising steeply to 10 feet above the flat; built of white shingle with pockets of foraminiferal sand in the lee of the beachrock.

(f) Beach crest of dark unvegetated shingle - mostly coral fragments 3-9 inches long, recognisable to genus. The surface slopes gently upwards from the top of the beach face to a crest 17 yards inland, and then falls landwards to the vegetation hedge of Tournefortia argentea and Suriana maritima.

Profile 3

Tiputa, east of Profile 2, where the reef flat narrows to approximately 65 yards.

(a) Porolithon zone and surge channels. No corals.

(b) Orange zone of eroded rock; zones (a) and (b) together form a rim at least 30 yards wide (Plate 9).

(c) Rock-floored reef flat, possibly just drying in places at low water. No corals on the rock surface. In places there are linear residuals of rock which are probably old patches of beachrock. Width 35 yards.

(d) Beach-foot beachrock (Plate 3): a smooth inclined plate rising up to 3 feet above the inner flat level and passing under beach sediments. The rock contains large coral fragments, but hand specimens have the appearance of moderately infilled beachrock. Structural dip seawards.

(e) Beach face: a rather complex feature 30-40 yards wide, rising to a maximum height of 15 feet above the inner flat, mostly formed of grey shingle 4-6 inches long, with sand on the lower face.

(f) Beach crest of dark shingle, coarsening landwards. Declining in height towards the vegetation hedge which here consists mainly of Tournefortia argentea, with coconuts farther inland.

Profile 4

Tepaetia, north shore, midway along the island. The profile is narrow and comparable to Profile 3.

(a) Porolithon zone of pink encrusting algae 25 yards wide, with surge channels 5-10 yards apart.

(b) Orange zone, width 30 yards. The outer two-thirds of this zone is similar to that in Profiles 1-3: smoothly rounded potholes and ridges are covered with an orange-colored alga. The inner, landward third is formed of sharper pinnacles and ridges, with a local relief of 3-6 inches.

(c) Bare rock reef flat, 25-30 yards wide, lacking growing corals or other large colonial organisms, with only a thin, discontinuous sediment cover.

(d) Beach-foot beachrock: a massive, very stony conglomerate in two distinct bands, each with 2-3 layers, dipping seaward, 8-10 yards wide, and rising up to 1.5 feet above the inner flat.

(e) Seaward beach face: a shingle beach 15 yards wide, with most particles less than 2 inches long, and patches of foraminiferal sand, particularly in the lower part.

(f) Beach crest, forming a wide flat of shingle, with particle length greater than 9 inches, mostly corals but with blocks of beach conglomerate, presumably carried by storm waves. The crest stands 9 feet above the inner flat level. The outer part of the crest is covered with a low hedge of *Suriana maritima*: 35-40 yards inland this is replaced by a solid stand of *Guettarda speciosa*.

Profile 5

Mahereretiatae, north shore, west end of the island. The reef flat here is wide (160-180 yards) and thus comparable to Profile 1.

(a) *Porolithon* zone of pink algae with many close-set groove-like surge channels averaging only 4 yards apart. Nodular *Porolithon* is conspicuous at lower levels.

(b) Orange zone, 25 yards wide: the landward edge potholed and grooved, and clearly undergoing erosion.

(c) Rock-floored reef flat with a total width of 115 yards. Its outer part lies 2 feet below the level of the orange zone, but rises landward. No corals.

(d_2) In places on the reef flat there is a discontinuous zone of rock up to 1.5 feet high, jagged and eroded, forming narrow linear bands parallel with the shore. No structure is apparent, but these are probably relict bands of beachrock.

(g) The inner part of the reef flat is formed by a dark-colored bare rock platform, drying at low water, 20-25 yards wide, and of erosional origin. It stands up to 1 ft. above the general level of the reef flat, but there is not sharp line of demarcation between the two.

(d) Beach-foot beachrock: a conglomerate rock overlying the erosion platform; 4-5 yards wide, up to 1.5 feet high, and dipping seawards.

(e) Beach face, 20 yards wide and 6 feet high from the inner flat to the first vegetation hedge. The lower part of the face is sand and fine gravel; the upper part of medium shingle.

(f) Beach crest: a flat expanse of very coarse blackened rubble 40-50 yards wide and up to 9 feet above the flat, separated from the beach face by a narrow hedge of Suriana maritima and disappearing inland under a thicket of Tournefortia, Guettarda, Scaevola and Hedyotis.

Profile 6

Mahereretiatae, north shore, east end of the island. The reef flat is again wide and comparable with Profile 5.

(a) Porolithon zone: as in Profile 5.

(b) Orange zone: as in Profile 5.

(c) Rock-floored reef flat, 90 yards wide, 1.5-2 feet below the level of the orange zone in its outer half, and rising towards the shore. There are some large reef blocks of storm-tossed origin, up to 5 feet high and 18 feet long on the flat from Mahereretiatae eastwards; one reef block in this profile stands 110 yards from the reef edge. There are no growing corals on the flat.

(g) The inner part of the reef flat is covered with coral rubble to form a boulder carpet up to 25 yards wide, overlying the erosional rock platform seen in Profile 5.

(d) Beach-foot beachrock, here a degraded conglomerate outcrop only 5 yards wide, with no clear form or structure, and largely covered with rubble blocks up to 1.5 feet in diameter.

(e) Beach face and crest. The unvegetated beach area here has a total width of up to 170 yards. The outer face, 6 feet high and 12 yards wide, is built of coarse shingle of 3-12 inch calibre; it is topped by a discontinuous fringe of Suriana and Tournefortia. A 50 yard wide back slope of grey rubble, horizontal and unvegetated, is followed by a steep rise to a second ridge, 6 feet higher than the first, of blackened rubble. The backslope of this has a slight landward slope, and is formed of rough large coral blocks, tightly packed. The vegetation hedge (Tournefortia, Guettarda, Hedyotis and some Pandanus) lies 60-100 yards back from the second beach crest.

III. THE WESTERN OR LEEWARD RIM

A. General characteristics

The western rim of Rangiroa is 17 miles long: of this distance 60% is covered with islands. The basic pattern is similar to that on the northern rim, with the division into seaward flat, island, and lagoon reef. Typical conditions were seen at Motutii and Tereiao (Section IIIB). Here the seaward flat, with a total width of about 120 yards, consists of an outer raised rim, bounding a rock-floored reef flat which towards the seaward shore of the island is covered by a platform of conglomerate rock. The islands are approximately 500 yards wide; five of them are considerably longer than the rest, which are separated by hoa. The seaward beach ridges, facing away from the prevailing winds, are lower, less steep, and built of finer debris than the ramparts on the northern rim. Thus at Motutii the beach of fine shingle rises to 4-7 feet above the flat and has a mean slope of 6-9°. In places where the shore approaches closer to the reef edge, however, as on parts of Tereiao, the seaward ridge is higher (up to 10 feet), steeper (in places up to 20°), and built of coarser shingle. Lagoonward of the seaward beach crest, the surface declines fairly gently towards the lagoon shore: the seaward part is built of blackened gravel, the lagoonward part of sand. The lagoon beach is low and narrow, of either sand or fine shingle, and may enclose a narrow pool or marshy area (Plate 13). The main contrast in island form between the northern and western rims, therefore, is in the absence of sand-size material in the former and its importance in the latter. A further major difference is in the nature of the lagoon reef. On the western rim the lagoon reefs face 10-20 miles of open lagoon, in contrast to the sheltered leeward lagoon reefs of the northern rim. On the west rim the lagoon reefs form a sandy shelf at least 1 foot deep at low water, edged with living coral, and up to 200 yards wide.

At the areas investigated, the islands are separated by hoa in the sides of which conglomerate platforms outcrop. These are closely comparable to similar features on the northern rim. Thus at Motutii, where the seaward beach is 6 feet high, the conglomerate platform underlying it stands 1 foot above the flat. To the south, on Tereiao, where the seaward beach reaches 10 feet in height, the conglomerate platform rises to 3 feet at its seaward edge. In both cases the rock surface declines lagoonward. No conglomerate rock or beachrock was seen on the lagoon shore here; but at Tivaru, where the lagoon shore is sandy and up to 5 feet high, there are outcrops of beachrock trending at a slight angle to the modern beach.

This description applies to 'typical' islands of the western rim. This rim, however, is subject to hurricanes and resulting catastrophic modification. Such changes were seen at Maeherehonae, and may exist elsewhere. Here the seaward flat (Section IIB), of normal width, is littered for a distance of 1 mile with large reef blocks (Plate 18). Most of these are 6-10 feet high; the largest is a huge fragment of reef rock 18 feet high, 18 feet long, and 15 feet wide. The seaward beach is formed by a shingle rampart 6 feet high, and the seaward hundred yards of the island surface by a sea of boulders and coarse rubble, probably hurricane-deposited. The rest of the island surface, almost to the lagoon shore, is formed by a flat plain, partly of stripped conglomerate rock (exposed by overtipping wave scour?), partly of thin sand and gravel with discontinuous vegetation.

The lagoon shore of Maeherehonae is of especial interest. As at Tereiao it is sandy, faces a wide lagoon sand flat edged with reef, and encloses an extensive marsh area, up to 75 yards wide, with standing brackish to fresh water (Plate 14). At a distance of 150-200 yards from the lagoon shore, however, there is an extensive area of high dunes (one teitei), probably reaching a height of 30 feet and thus forming the highest land on the atoll (Plates 15 and 16). Conglomerate rock pavements can be seen beneath the dunes (Plate 17), and in places in the pools near the lagoon shore; and farther cemented horizons can be seen in swales (often containing water) within the dune system itself. Gaps in the dunes are floored by shingle overlying the conglomerate platform. No lagoon shore dunes have been seen elsewhere. The dunes are vegetated, with Pandanus and Tournefortia, but with no continuous ground cover except dead Pandanus leaves. The Maeherehonae dunes thus represent an addition to the generalized island type shown in Figures 5 and 6.

No inter-island sections of reef flat (other than hoa) were seen on the west rim.

B. Reef flat profiles (Figure 8)

Profile 7

Tereiao, west shore, near the north end of the island.

(a) Porolithon zone, up to 60 yards wide (Plate 10). Three subzones can be distinguished: a lower part with grooves in the area of wave-break; a seaward-sloping section 30 yards wide of rather irregular topography, with erosional pillars and potholes and local relief of 1 foot, covered in pink algae but lacking surge channels; and a flat, regular, uneroded pink algal pavement 25 yards wide, with many scattered small encrusting Porites. The surge channels are here clearly much less extensive in the upper, inner part of the Porolithon zone than they are on the northern rim.

(b) Orange zone, 40 yards wide. The outer ten yards (b_2) is a strip of bare rock, without pink algae but with orange coloration; the rest is typically irregular, with potholes and ridges.

(c) Rock-floored reef flat 95 yards wide, with no growing corals but with a sparse gravel and sand cover.

(d) Conglomerate rock platform, 45 yards wide, rising up to 3 feet above the inner flat, and passing landward beneath the seaward beach. The rock is horizontal and shows no seaward dip (Plate 11).

(e) Seaward beach face, up to 7 feet high and 20 yards wide, of fine white shingle.

(f) Seaward beach crest, of blackened gravel (Plate 12), mean length about 6 inches, falling slightly lagoonward, with a covering of Guettarda and Tournefortia and a seaward fringe of Suriana and scattered Scaevola. Height 4-9 feet.

Profile 8

Maeherehonae, northwest shore, near the north end of the island. This profile differs considerably from the others reported here, presumably as a result of hurricane effects.

(a) Reef edge. The margin here is very irregular and broken: there are no surge channels and no algal ridge or similar feature. The surface lies at a lower level than in other profiles, and is covered with dead Pocillopora colonies coated with pink algae, to a distance of 30 yards from the edge.

(c) Reef flat. The reef flat proper is about 100 yards wide. It is littered with large reef blocks jumbled together; the largest is 18 feet high, the rest mostly 6-10 feet high. Between the blocks the surface is covered with living Pocillopora growing so closely together that it is difficult to see the underlying surface. To landward of the blocks, in calmer water, the Pocillopora is replaced by encrusting Acropora and Porites covering perhaps 10% of the total area.

(e) Seaward beach, 25 yards wide, built of boulders and shingle, rising 6-9 feet above the flat. There is no beach-foot beachrock or conglomerate.

(f) Beach crest: a boulder field with scattered Tournefortia.

IV. THE SOUTHERN OR SWELLWARD RIM

A. General characteristics

The southern rim of the atoll, facing the Southern Ocean swells, is 57 miles long; only one-third of this length is covered by islands, the smallest proportion of the three atoll rims. The southern rim, in addition, has characteristics not found at other parts of Rangiroa: these are shown schematically in Figures 9 and 6B, and elaborated in the detailed profiles 9-11 (Section IVB; Figure 10).

(1) Reef rim with island.

From observations at Porahu, Peari, Vaihoa and Utoto, a basic fourfold division may be made in the morphology of reef rims with islands on the south side of Rangiroa, into (a) the seaward reef flat; (b) the feo; (c) the island; and (d) the lagoon flat and reef. The southern rim is appreciably wider than the northern one, ranging from 800 to almost 1200 yards. The seaward reef flat itself is 100-120 yards wide: its outer edge, with its Porolithon and Orange zone margin, is similar to that elsewhere; but there is no well-developed rock-floored reef flat at or near low water level, as on the north and west rims. Instead, the inner part of the reef flat is occupied by bare swells of exfoliating reef rock, spalling off concentric sheets up to 1 foot in thickness (Plates 22 and 23). This is seen on a much smaller scale on conglomerate rock in some of the northern hoa. The exfoliating rock rises perhaps 2-3 feet above low water level, and is succeeded landward by a narrow and discontinuous rock-floored moat. The feo, lagoonward of the seaward flat, is a strip of elevated reef rock 80-120 yards wide, which evidently extends along the whole of the southern rim of the atoll (Plates 19, 20, 26, 27). It is deeply and intricately eroded, and intersected by narrow, deep and winding channels. The general level of its summit is 6 feet above the flat; some pinnacles reach 9 feet. Characteristically, on its seaward side there is a low platform 10-45 yards wide of eroded feo, presumably cut down towards the level of the flat by marine erosion. The seaward flat and the feo together, with a width of more than 200 yards, account for about a quarter of the total width of the southern rim.

Islands account for rather less than half the width of the rim where observed (though some of the larger islands, such as Fenuaroa, Otepipi and Ovete are much wider). The seaward beach is usually lodged on the upper surface of the feo (Plate 26), though infrequently, as in Profile 9, there is a low area of rock-floored moat between feo and island (Plate 19). The seaward beach is usually narrow, low and sandy: incipient dunes were seen capping it at Utoto, where the crest rises to about 13 feet above the reef flat. The island surface and lagoon shore are mainly sandy, with fine gravel in places. At Porahu, under dense vegetation, the surface is covered with 3-6 inches of humus overlying phosphate rock within 40 yards of the shore. In the hoa between islands, conglomerate rock is exposed in the walls, dipping gently lagoonward, as elsewhere on the atoll rim. In the Peari-Vaihoa hoa (Plate 24) this conglomerate rock reaches to within 60 yards of the feo, and outcrops in the hoa walls for some 500 yards. The islands themselves are generally low, and the conglomerate platform is consequently a foot or less in height. Beach rock is found on the lagoon shore in places, though probably often covered by fresh sand spits and bars. Pools of standing water are ponded in places by the lagoon beach ridges.

The lagoon reef flat is exceptionally wide, reaching 250 yards: coral grows over much of its surface, and edges the flat. The approach to the islands is consequently difficult.

(2) Reef rim without island.

The only extensive inter-island tract seen was that between Porahu and Topitiiti. Here the seaward flat and feo are the same as elsewhere on the southern rim, but the rest of the rim surface carries at least 2 feet of water at low tide, has a sandy bottom, and is covered with large microatolls. Near the lagoon edge the floor shoals and is covered with linear sandbores. This is the only sector of reef flat seen on the Rangiroa rim with appreciable coral growth and no conglomerate platform.

B. Reef flat profiles (Figure 10)

Profile 9

Porahu, south coast, west end of the island.

(a) *Porolithon* zone, with grooves outside the wave-break line and small surge channels inside it. The pink algae form both small knobs and a paint-like coating on the surface; scattered large gastropods are also coated with pink algae. The inner part of the zone forms a slight moat. Width 35 yards.

(b) Orange zone, 25 yards wide, rising about 1 foot above the *Porolithon* zone: the surface is irregular, with ridges and potholes, and sinuous deeper channels cutting back into and through the zone from the seaward side.

(j) Zone of smooth exfoliating reef rock, light grey in color, with white patches where spalling rock shells have been dislodged by wave action. Width 50 yards.

(k) Narrow, rock-floored moat 5 yards wide and up to 1.5 feet deep: no corals.

(h_2) Zone of abraded *feo*, 44 yards wide, forming a low, rough-surfaced platform up to 3 feet in height, extending upwards from the moat to the *feo* proper.

(h_1) *Feo*, zone of elevated reef rock (Plate 20), dissected by deep through-channels, and intricately eroded into spires and pinnacles. The general elevation of the tops of the spires is 6 feet; some rise to 9 feet. Width 55 yards.

(h_2) Narrow zone of degraded *feo*, 12 yards wide, lagoonward of the *feo* similar to that on the seaward side.

(c) Moat, 40 yards wide and up to 1 foot deep at low water. The floor is bare rock with patches of gravel and numerous black holothurians; there are no growing corals (Plate 19).

(g) Intertidal conglomerate platform with small patches of mobile sand, drying at low water, and passing inland beneath the beach. 55 yards wide.

(e) Seaward beach face, 14 yards wide, sandy in its lower part, topped by coarser gravel, with a hedge of *Scaevola*, *Tournefortia* and *Guettarda*.

Profile 10

Peari, south shore, near the center of the island.

(a) *Porolithon* zone of knobby and paint-like algae. 40 yards wide from the wave-break line. Surge channels are present but are very narrow; they are spaced 4-5 yards apart.

(b) Orange zone. This zone is here narrow (14 yards wide) and undergoing active dissection.

(b_1) Inner part of the Orange Zone. Width 11 yards. This has a rough microtopography, with potholes up to 4.5 feet in diameter and 1.5 feet deep: the actual orange area (mainly on the rims) is thus much reduced.

(j) Zone of smooth exfoliating reef rock, 38 yards long, standing 2-3 feet above the Porolithon zone (Plates 22 and 23).

(k) Rock-floored moat, containing water at low tide, but without corals; width 30 yards.

(h_2) Zone of degraded feo 40 yards wide, similar to that in Profile 9.

(h) Feo: zone of elevated reef rock up to 9 feet high. Bare rock is exposed for a width of 54 yards: on the inner part there are scattered shrubs of Pemphis acidula growing directly on the rock.

(e) Seaward beach face, perched on the feo, with pinnacles of reef rock protruding through the beach sands. The beach is built of sand with some shingle and is 20 yards wide. On the face itself there are scattered Pemphis and Guettarda; and at the crest a hedge of Guettarda and Scaevola.

Profile 11

Utoto, south shore, center of the island.

(a) Porolithon zone, 35 yards wide, with closely spaced surge channels, similar to Profile 10.

(b) Orange zone, 21 yards wide, and at the same level as the inner Porolithon zone. Unusually the rims and potholes are absent, and instead there is a flat pavement, through which a few surge channels extend into zone (b_1).

(b_1) High fretted zone, separated from zone (b) by a scalloped clifflet 1 foot high: the surface is rough and eroded. 25 yards wide.

(j) Zone of smooth exfoliating reef rock. Doming is very pronounced, but at this point the zone is only 12 yards wide. Occasional reef blocks up to 4.5 feet high and 9 feet long are found along the reef edge.

(k) Rock-floored moat, with up to 1 foot of water at low tide, but with no living corals; width 40 yards.

(h_2) Strip of degraded feo 15 yards wide.

(h) High feo, 35 yards wide and up to 9 feet high, with scattered Pemphis acidula, passing landward under beach sands (Plates 26 and 27).

(e) Seaward beach face, perched on the feo, 35 yards wide, and rising to 13 feet above the flat. The beach is sandy, topped by incipient dunes, with a vegetation cover of Scaevola, Pandanus, Guettarda and coconuts.

V. PROBLEMS OF RANGIROA GEOMORPHOLOGY

A. Consolidated sediments

1. The problem of the Feo.

In the history of the surface features of Rangiroa, the problem of the nature and origin of the feo is crucial. The chief facts about the feo are as follows:

(1) It is restricted to the southern rim of the atoll, where it is reported to extend from at least Tehaare in the west to the eastern end of the southern rim, a distance of 44 miles: it is not found on the northern or western rims.

(2) It is restricted to a narrow band with a mean width of about 120 yards, situated on the outer part of the reef rim some 120 yards from the reef edge.

(3) The mean height of the upper part of the feo is 6-7 feet above the inner reef flat (approximate low water level), and the highest parts 10 feet.

(4) Since exposure, marine abrasion has formed lower erosional platforms up to 50 yards wide on the seaward side of the feo and up to 10 yards wide on the lagoon side.

(5) The main body of the feo has been eroded into a tough delicate tracery of spires and pinnacles. When struck with a hammer, the rock rings. In hand specimens the rock is so recrystallized as to be structureless.

The Rangiroa feo was described by Dana (1849, 75), who stated that "the reef stood eight feet or so out of water, and was worn into a range of columns, or excavated with caverns, so as to look very much broken, though quite regularly even in the level of the top line." Agassiz later described it as "a wall of old reef rock from 10 to 14 feet in height ... (which) varies in width from 250 to 500 feet" (1903, 45). Elsewhere he gives the height as "from 8 to 15 feet" (1903, 50), "12 to 14 feet" (1903, 16), and "15 to 16 feet" (1903, 20). Agassiz studied the feo at Fenuaroa, where

> "...the great wall of ancient elevated reef rock ... was fully 12 feet high, and is the remnant of the ancient coralliferous limestone ridge which flanked the southern side of Rangiroa. ... This old ledge is deeply pitted and honeycombed and eroded into all kinds of fantastic spires and pinnacles and walls cut through by crevasses extending from low-water mark to the summit, which is more or less covered by the high sand beach accumulated behind it on the lagoon side. This beach completely conceals the extension of the old ledge under the island" (1903, 46).

Recently Tercinier (1956, 39) published a section showing the feo outcropping near the seaward shore of an island and continuing lagoonward beneath the island surface, well above sea level for the greater part of the width of the island.

The identification of the feo as ancient elevated reef rock is probably correct. In hand-specimen characteristics and erosional features it is closely comparable to the rock of undoubted elevated reefs at New Georgia, Solomon Islands, where, however, similar erosional fretting only occurs in areas subject to salt spray (Stoddart, in litt.) Agassiz's speculations that the feo is a remnant of a previous atoll-wide or even archipelago-wide sheet of Tertiary limestone lacks evidence; and the suggestion by both Agassiz and Tercinier that the feo underlies most of the island surfaces on the southern rim seems to be mistaken; Agassiz in particular wrongly identifies feo and island conglomerate as the same. The narrowness of the feo is one of its most striking characteristics: approached from the lagoon side it presents a wall as steep as that on the seaward side. Hence it does not form a cuesta tilted lagoonward; and the small width of the abrasion platform on its lagoonward side demonstrates that its form has not been greatly modified by recent marine erosion. This narrowness, and its localization on the flat, together form the chief problem of the feo; no erosional mechanism seems to explain it adequately.

The second problem of the feo is its restriction to the southern rim. Three alternative models may be proposed to account for this:

(1) Feo formerly existed all around the atoll rim, as a result of relative movement of land and sea, but has since been entirely removed on the windward side by marine erosion. It is not possible to explain the complete absence of feo on the west rim by this model, for apart from storms the west rim is the most protected side of the atoll.

(2) Slight local tilt of the atoll raised the southern rim: solution fretting, recrystallization and case-hardening of the emerged reef limestone was followed by marine abrasion on both seaward and lagoonward (i.e., windward) sides, before island clastics began to accumulate. Such local movement would explain the absence of feo elsewhere on the rim; but the explanation of the narrowness of the feo is strained. Observations in the Bahamas (Newell 1961) and the Solomons suggest that the amplitude of marine erosion of limestones is very limited.

(3) Regional tilting within the Tuamotu Archipelago. Feo is reported elsewhere in the Tuamotus, particularly on the south side of the chain, as at Anaa, where the feo reaches 18 feet (Newell 1956, 326), Kaukura (15 feet: Ranson 1962, 18), and other atolls. In other places, as at the intensively investigated Raroia, feo is absent. The existence of feo at different heights on several atolls, the localized distribution of feo within individual atolls, and its nonoccurrence on others render unlikely a simple eustatic sea-level shift as an explanation of its origin. More data are required on the distribution of feo in the Tuamotus before regional explanations can be accepted.

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2. Problem of island or motu conglomerate.

Second to the problem of the feo is that of the origin of the sheets of conglomerate which underlie many of the islands and characteristically outcrop in the walls of every hoa. The relationship of these sheets and the feo, with reef-flat reef rock, and with beachrock require clarification. Wherever seen, the motu conglomerate consisted of worn coral fragments in a sandy matrix; it is a detrital rock, and is in no sense a reef rock which has suffered relative elevation. Agassiz is wrong when he states that this conglomerate, together with the feo, is "the remnant of a bed of tertiary coralliferous limestone which at one time covered the greater part of the area of the lagoon" (1903, 16; also 44); it is hard to see how he could have reached this conclusion. Ranson (1962) also mistakenly states that the conglomerate indicates a former higher sea level.

In no place was the conglomerate seen in contact with the feo. In the Peari-Vaihoa hoa conglomerate is found in the island walls only 53 yards from the feo wall (Plate 24). Conglomerate is intimately associated with islands: it is not found either seaward or lagoonward of the general width of the islands, except in places where recent shore erosion is reasonably inferred (Plates 3 and 11). This is strikingly shown in the hoa, where the island sediments have been eroded, leaving the underlying conglomerate (Plate 4). The conglomerate is formed of similar materials to the islands themselves, generally becoming finer lagoonward, and nowhere contains corals in the position of growth or indeed any sedimentary structures indicative of submarine deposition. On the west shore of Porahu the conglomerate stands up to 2 feet above sea level, and unconformably overlies an eroded reef surface, with truncated corals several feet in diameter standing about six inches above low water level (Plate 21). The elevation of the top of the conglomerate platform everywhere strikingly follows that of the island surfaces, being higher to seaward and declining gradually lagoonward. Typically its seaward edge forms a low cliff up to 3 feet high; lagoonward it falls to three feet or less.

The Rangiroa island conglomerate appears similar to that described by Newell at Raroia, where the pakaota is

> "clearly bioclastic throughout and does not contain in situ reef material. It is not an elevated platform of planation, a reef flat, but it is a depositional surface ... (which) could have been formed at or near the existing sea level" (Newell 1956, 332).

The formation of conglomerate platforms beneath islands and their subsequent exposure by erosion and shoreline migration, as outlined by Newell (1961, 103-4), appears adequately to explain all features of the Rangiroa conglomerate, though Newell does not discuss mechanism. The conglomerate is probably a water-table, calcite-cemented rock, forming beneath islands at the present time. Newell's excavations at Garumaoa, Raroia, failed to demonstrate incipient rock. At Rangiroa, however, an I.R.H.O. soil pit at Tepaetia, dug to a depth of 2 meters, wholly in coarse coral rubble, some of it apparently imbricate, revealed that the top meter was uncemented, the next 80 cm moderately cemented, and the last 20 cm above the water table very well cemented. A pit dug at Tiputa during the construction of the schoolhouse also showed the following section:

0 - 1 meter	unconsolidated rubble
1 - 1 m 50	cemented rubble
1 m 50 - 2 m	unconsolidated rubble
2 m +	cemented rubble (at water table).

The widespread existence of the conglomerate platform beneath islands is shown by the surface sand stripping at Maeherehonae.

In topography and probably origin the Rangiroa conglomerate is similar to the cay sandstones (calcarenites rather than calcirudites) previously described in the Caribbean (Stoddart (1963, 108-110) and the Maldive Islands (Stoddart, Davies and Keith 1966).

3. Problems of beachrock.

A distinction is made here between the island conglomerate and beachrock, although the two are similar in lithology and often rather difficult to distinguish in the field. Beachrock is invariably found forming a strip 5-10 yards wide at the foot of seaward beaches, dipping seaward at 5-10° and even occasionally at up to 20°. It is usually a conglomerate with two or three layers, and overlies a smooth rock platform of similar composition and appearance but doubtful status which passes under the beach sediments. In the entrances to hoa, the stratigraphic distinction between seaward-dipping beachrock and the underlying planed reef flat is clear: but no satisfactory and crucial exposures were seen of the relationship between the beachrock and the island conglomerate. Beachrock is generally absent within the hoa itself.

As at Raroia, relict beachrock is found, especially on the northern rim of Rangiroa, e.g., at Tiputa, trending at an angle to the present beach and isolated on the seaward reef flat, indicating recent retreat of the shoreline. Very little fresh beachrock was seen, and much was quite heavily eroded. Almost no beachrock was seen on lagoon shores (one case was seen at Tivaru), perhaps because these are generally prograding. The horizontal outcrops of rock found on many lagoon shores up to 2 feet above low water level, as at Mahereretiatae, Tepaetia and Tiputa, are all island conglomerate rather than beachrock (Plate 7).

4. Other lithified sediments at Rangiroa.

Phosphate rock was seen underlying raw humus within 40 yards of the shore at Porahu, on the southern rim of the atoll. It is here disturbed by human activity and is on the site of an old settlement. Phosphate is also reported from Putehue, Ahorehore and Tepau, on the southern rim, and at Maufano at the eastern end of the atoll. According to M. Pomier, *Pisonia grandis* is present at, or has recently been cleared from all of these locations. Further study is needed of the nature of the phosphate, its vegetational associations, and its apparent restriction to the southern rim [and east end--Ed.] at Rangiroa.

Cemented horizons in the sand dunes at Maeherehonae add a fifth type of lithified material at Rangiroa. These are probably associated with local water tables in the dunes, are thin and friable, and, unusually at Rangiroa, are calcarenites.

B. Surface features of the seaward reef flats

There are broad similarities between all the seaward reef flats at Rangiroa. The flat itself is a rock-floored feature, sloping gradually from the seaward shores of the islands towards the raised rim. Growing corals are everywhere scarce, even in the deeper seaward section, and there is only an intermittent and thin cover of mobile sand and gravel. The growth of small algae gives the submerged floor a pink color, in contrast to the higher inner part, often drying at low water, which is dark brown. The higher, more exposed parts of the flat often show truncated corals in section, together with coral branches weathering out: the flat is clearly erosional, deriving from a previously higher level. The strength of longitudinal water currents produced by water pouring over the rim in the process of draining out suggests that lowering is still in progress. No parts of the reef flat as here defined rise more than a few inches above low water level.

The raised rim at the seaward edge of the flat (Guilcher and others 1966) is a problematical feature. It corresponds in location and in general form with the Lithothamnion or algal ridge described from other Pacific atolls. Living pink algae are restricted, however, to the outer face of the rim, which slopes seaward at about 5° and is furrowed by surge channels. This is normally 30-50 yards wide. The rest of the rim, of a similar width, has been here termed the Orange Zone, because of the distinctive color given to it by algal growth. The topography of the Orange Zone is quite clearly erosional (Plates 9 and 10): it is furrowed by grooves and cut by potholes, often leaving only a tracery of curving sharp ridges. The inner, landward-facing edge of the Orange Zone, locally rising 2-3 feet above the reef flat floor, is clearly being cut back by erosion, giving a grooved and scalloped pattern in plan. The rock underlying the Orange Zone, where sampled, appears to contain more recrystallized coral than algal material. In places coral fragments are recognizable in the weathering patterns. This is, therefore, not a true algal ridge, at least as this term is understood in the Pacific literature: it is rather a relict rim of reef rock, which has been colonized and presumably added to on its seaward side by pink algae, at the same time undergoing continuous erosion on its upper surface and inner edge by marine action. The upper part of the Orange Zone currently lies too high for colonization by pink algae. On this interpretation, the origin of the abrupt break of slope between the ridge and the reef flat floor is of interest: presumably solution and mechanical erosion are deepening the flat and cutting back the rim from land to sea, and as the flat is itself deepened the break of slope forms automatically.

On the southern rim a further feature of interest is the zone of exfoliating reef rock (Plates 22 and 23) tens of yards in width between the Orange Zone and the feo, from which it is separated by a moat. The phenomenon of exfoliation in reef limestones does not seem to have been closely studied: here it is striking, and has the appearance of an exfoliating igneous rock. Tentatively, it may be interpreted as part of the slightly raised reef rock not yet removed by marine erosion: the difference between northern and southern rims being the result of the greater exposure and hence more rapid erosion on the former.

The similarity of surface features of the seaward flats implies a common history, and the widespread evidence of vertical erosion calls for a fairly recent slight negative shift in the relative level of land and sea.

Other surface features of the reefs were not closely investigated. Surge channels were found, passing seaward into spur-groove systems, on all sides of the atoll, though developed most strongly on the northern side, where the reef front is also said to slope more steeply than on the south. Newell found spur-groove systems around the whole atoll perimeter at Raroia also. The great variation in development of lagoon reefs, between the narrow fringe on the northern rim (facing leeward) and the 200-300 yard wide platforms on the west and south rims (facing windward) is also noteworthy. Similar variations are described from some of the Marshall Island atolls (Emery, Tracey and Ladd 1954).

C. Unconsolidated sediments

The unconsolidated sediments of the islands at Rangiroa are overwhelmingly coarse. On the northern rim coral shingle is dominant across the whole width of islands, while elsewhere on the rim shingle forms the seaward beaches and the seaward part of the island surface. On the beach face itself the material is generally fresh, white in color, and fine, with longest dimensions of less than 6 inches; but on the beach crest, especially on the north side, the longest dimension of the rough blackened coral blocks is commonly greater than 12 inches. No more detailed observations were made on shingle-caliber material. Sand-size sediments are restricted on the northern rim to pockets of sand along the seaward beach, often sheltered by outcrops of beachrock, and also along the lagoon beach. Elsewhere on the atoll rim the lagoon beach of islands and the lagoonward part of the island surface is dominantly sandy, with patches of shingle. Nine sand samples were taken from the seaward and lagoonward beaches of Tiputa on the northern rim. Median diameter ($[\phi 16+\phi 50+\phi 84]/3$) varied from -1.18ϕ (very fine gravel) to $+1.05\phi$ (medium sand), and averaged $+0.48\phi$. All samples had a high foraminiferal content: the coarsest sands are dominated by a white discoid foram, and the fine ones by a small brown foram which gives the sand a distinct color cast. Sorting ($\sigma_I = [\phi 84+\phi 16]/4 + [\phi 95+\phi 5]/6.6$) is moderately good (0.45 to 0.90 ϕ), averaging 0.75.

D. Tentative geomorphic history of Rangiroa

Evidence for the reconstruction of the geomorphic history of Rangiroa is sparse, and much detailed work remains to be done. Agassiz, for example, reports many data from the islands in the lagoon which, if confirmed, would materially affect a geomorphic chronology. Because many of his observations and interpretations are doubtful, this section attempts to place only my own observations into logical order. The observations reported here clearly do not do justice to the complexity of so large an atoll, and on many aspects of atoll geomorphology, such as the lagoon floor and submarine topography, we have virtually no data at all. There is need not only for the checking of Agassiz's observations but for the extension of those reported in this paper.

The early history of the Tuamotu atolls on the Darwin Rise is at present largely conjectural: there is no reason to doubt the applicability of Darwin's own subsidence model, which was in fact being formulated as he sailed through the Tuamotus in 1835 (Darwin 1962). Deep drilling at Mururoa Atoll in the Southeast Tuamotus has revealed a basalt substrate to coral limestone at depths of 438 and 415 meters, clearly demonstrating subsidence (Lalou and others 1966, Chauveau and others 1967): presumably Rangiroa similarly was formed and achieved its present plan through the Tertiary. Subsequent history based on known geology and geomorphology may be summarized as follows:

(1) The first event to affect the present surface feature of the atoll was the formation and exposure of the feo. The distribution of feo on the atoll and through the archipelago suggests that its uplift was caused by tilting of regional extent but of locally variable amplitude. Exposure was followed by case-hardening and recrystallization of the limestones, marine abrasion of the margins, and the beginning of superficial salt-spray solution. The total uplift at Rangiroa cannot have been greatly in excess of 10 feet. Veeh (1965, 53; 1966) has recently published uranium-series dates on elevated reef limestones from Anaa Atoll, Tuamotus, standing 2-4 meters above mean low tide land, which range from 80,000 to 150,000 years. However, dating of the cores from Mururoa Atoll has revealed a major discontinuity at -20 meters, below which the limestone ages are greater than 500,000 years, and at -6 meters, overlying limestones 100,000 ± 10,000 years old. Limestones above -6 meters, have ages of less than 5,000 years. The lower discontinuity is referred to the penultimate interglacial, and the higher to the last interglacial; the higher correlates in depth and age with that described from Eniwetok in the Marshall Islands (Thurber and others 1965). The emerged feo dated at 80,000 years by Veeh may thus correlate with the last interglacial discontinuity found in cores and dated at 100,000 years: if so, it would form an uneroded residual blanketted by recent (less than 5,000 years) reef limestones.

(2) Following the exposure of the feo, which in extent of lithification and erosion is probably the oldest rock on Rangiroa, the reef rim of the atoll was exposed, more or less uniformly, by a relative change in level of land and sea. This resulted in the

formation of raised reef flats up to about 2 feet, perhaps less, above low water. After elevation, planation by marine erosion began, and has proceeded farthest on the windward side. Here rock-floored flats have been cut below present low water level, leaving residual edge rims now partly coated with pink algae. On the leeward side, large areas of slightly raised exfoliating reef rock remain. Radiometric dating has been used at Mururoa to argue for a post-glacial high stand of the sea reaching +4 meters (12 feet) at 3,000 years B.P., which could account for the high reef-flats at Rangiroa (Lalou and others 1966).

(3) Island formation has taken place, probably following the erosion of the elevated flats to present levels, though evidence here is sparse. Some sediments may have accumulated before the flats were raised, but there is certainly no sign of elevated reef rock surviving under the present islands, though as Newell has pointed out, it would be unwise to assume that reef flats are necessarily underlain by reef rock in the narrow sense. Detrital islands probably formed a nearly continuous chain around the windward rim of the atoll, except for the deep passes, and also along much of the southern rim. With the accumulation of sediments, there followed the formation of plates of conglomerate rock at island water tables.

(4) The phase of aggradation has been followed by one of erosion, resulting in the retreat of seaward beaches, exposing beachrock and leaving patches of relict beachrock on seaward reef flats, and in the cutting of numerous _hoa_ and the fragmentation of formerly continuous land. This is documented by the extent of island conglomerate between islands. It might be possible to argue that _hoa_ formation and closure is a continuing process, and that as one _hoa_ is being cut another is being filled. If this were so, stages (3) and (4) could be synchronous. However, eroding _hoa_ are so common, and infilling _hoa_ so rare (only one was seen at Mahereretiatae) that the inference of successive occurrence is thought to be justified. No detailed attempt can be made to link these observed changes with known Pleistocene events, though data from Mururoa is suggestive. It should be noted that the evidence for changes in level used here is not that used by Agassiz; and that the evidence which he used to demonstrate sea-level changes, _i.e._, the island conglomerate, is here used as evidence of recent stability.

There seems to be no simple and satisfactory explanation of the narrowness of reef flats and concentration of land on the windward side of the atoll, and the width of the flat and the relative absence of land on the leeward side. Newell's explanation of a similar situation at Raroia, that the strength of the southern swell sending a continuous sheet of water over the leeward flat prevented the accumulation of debris (Newell 1956, 330), clearly will not hold at Rangiroa, where such a mechanism is inhibited by the _feo_. Sediment production may be relatively greater on the windward side, where continuous erosion also limits the width of the flat.

NOTES ON LAND VEGETATION OF RANGIROA

On uncultivated islands the dominant vegetation is Guettarda forest extending from the backslope of the seaward ridge to the lagoon beach. On the seaward beach crest Suriana maritima is everywhere dominant in the most exposed situations, with Pemphis acidula much less common; Scaevola is absent in such situations. In some places (Mahereretiatae, Tepaetia) wind-trimmed clumps of Tournefortia and Hedyotis are found near the beach crest itself. The main vegetation hedge, situated on the backslope some distance landward of the seaward beach crest, consists of Guettarda and Tournefortia, with occasional Pandanus, and often much Cassytha. On the lagoon beach Suriana is again dominant, growing low on the beach; Pemphis is seen only rarely (e.g., Tivaru, Mahereretiatae). Immediately landward there is tall Tournefortia and Guettarda (Porahu, Tivaru), and sometimes low Scaevola (Tepaetia, Tivaru). In the Guettarda woodlands, Morinda citrifolia is not abundant, and trees normally associated with settlement are rare. The flora is a small one, and the number of important species very few. The importance of Suriana maritima is surprising compared with its role in the Caribbean and the Maldives; and so is the unimportance of Scaevola (an unusually small variety) compared with its importance in the Maldives and the Melanesian area.

On cultivated islands the basic pattern is much the same, but the Guettarda forest has been replaced by coconut plantations, there are many introduced weeds, and also numbers of cultivated and decorative plants in the villages. On the seaward ridges Suriana maritima is dominant, with some Pemphis; and between the beach and the plantation there is invariably a dense thicket of Tournefortia and Guettarda, with occasional Pandanus. In the coconut plantation both Guettarda speciosa and Morinda citrifolia are common (including many juveniles): there is a ground cover of Stachytarpheta, Cassytha, ferns and Lepturus, and occasional low bushes of Scaevola. The most striking undergrowth beneath the coconuts, however, is Euphorbia atoto, growing at least to heights of 3 feet, and on Avatoru to more than 6 feet. The lagoon beach again has Suriana and Tournefortia.

In the villages of Tiputa and Avatoru there are tall trees of Cordia subcordata, Hibiscus tiliaceus, Casuarina and Coccoloba along the shore, with Hibiscus rosa-sinensis, frangipani, Carica papaya and Artocarpus lining the streets. In the taro pits, root crops such as Colocasia, Xanthosoma and Cyrtosperma are no longer grown; breadfruit, bananas and melons are grown instead. Tacca was also formerly cultivated, but was not seen. Limes are grown but are not common.

Several habitats have distinctive vegetation, and may be briefly noted. On the feo, at Peari and Utoto, Pemphis acidula is dominant, with a little Suriana. On stripped island conglomerate surfaces, at Maeherehonae and in the Moao-Hararu gap, there is a sparse vegetation dominated by Pemphis, together with Suriana and Hedyotis: with very infrequently Tournefortia and even rare Morinda, Guettarda and Scaevola. In the hoa between islands, both Pemphis and Suriana line the edges of channels, often growing directly on the rock surface. Around the margins of pools near the lagoon shores of islands sedges are common: at

Avatoru and Tereiao there is a dense belt of *Cladium*. On the sand dunes of Maeherehonae vegetation is restricted to *Pandanus* and *Tournefortia*. Ottino (1965, 9) points out that old settlement sites may often be recognized by the concentration there of *Pandanus*, *Hibiscus tiliaceus*, *Casuarina*, *Calophyllum* and *Cordia*.

There is a marked absence at Rangiroa of a pioneer strand vegetation comparable to the *Sesuvium-Ipomoea* strand vegetation of the Caribbean; *Ipomoea* was not seen at all; and the pioneer seems to be a shrub, *Suriana maritima*.

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LIST OF VASCULAR FLORA OF RANGIROA

by Marie-Hélène Sachet

Botanists from various expeditions through the South Pacific have on occasion collected a few plants on Rangiroa, as for instance W. B. Jones of the Whitney Expedition which stopped for two days in August 1922, and E. H. Quayle in 1923. These plants are reported on by F. B. H. and E. D. W. Brown in the Flora of Southeastern Polynesia (Bishop Museum Bulletins 84: 1931, 89: 1931, 130: 1935). However, no intensive investigation of the flora has ever been made. In 1963 I was invited to spend a week at the coconut research station of the IRHO (Institut de Recherches pour les Huiles et Oléagineux) in order to make some botanical observations and a collection of plants for the use of the station. The director of the station, M. Pomier showed me various parts of the atoll. His help and hospitality made the visit very profitable and enjoyable and I am glad to express my appreciation to him and to the IRHO.

One set of the plants collected was left at Tiputa for ready reference, and one at the Department of Agriculture of Tahiti. Other sets are intended for the Muséum d'Histoire Naturelle in Paris, B. P. Bishop Museum in Honolulu and U. S. National Museum.

The 70 specimens collected, as well as some sight records, are listed below, with brief notes on occurrence. The determinations were verified by F. R. Fosberg. An asterisk * before a name indicates that the species is not indigenous in Rangiroa. Synonyms are given only when they have been widely used in the area.

PSILOTACEAE

PSILOTUM NUDUM (L.) Beauv.
Tepaetia islet, locally abundant at base of coconut palm and shrubs, Sachet 1356.

POLYPODIACEAE

ASPLENIUM NIDUS L.
Porahu islet, common locally in shady Guettarda forest, Sachet 1384.

NEPHROLEPIS BISERRATA (Schwartz) Schott
Porahu islet, common locally in tall Guettarda forest, in shade, Sachet 1382.

POLYPODIUM SCOLOPENDRIA Burm. f.
Tiputa village, very common everywhere on ground, Sachet 1344.

PANDANACEAE

PANDANUS TECTORIUS Park.
Common over much of atoll; spineless variety seen in Tiputa village.

GRAMINEAE

*CENCHRUS ECHINATUS L.
Tiputa village, common locally in weedy area back of village, Sachet 1375.

*CYNODON DACTYLON (L.) Pers.
Tiputa village, forming lawn; very common, Sachet 1350.

DIGITARIA STENOTAPHRODES (Nees) Stapf.
Avea islet, occasional on bare gravel in area cleared for planting of coconut palms, Sachet 1378.

*ELEUSINE INDICA (L.) Gaertn.
Tiputa village, common in weedy area back of village, Sachet 1371.

*ERAGROSTIS PILOSA Beauv.
Tiputa village, very abundant in weedy area back of village, Sachet 1370.

LEPTURUS REPENS var. REPENS (Forst. f.) R. Br.
Tepaetia islet, tufts at top of ocean beachridge, Sachet 1360.

PASPALUM DISTICHUM L.
P. vaginatum Sw.
Avatoru islet, Avatoru village, forming wide zone in weedy area around pond, Sachet 1385.

*SACCHARUM OFFICINARUM L.
Tiputa, a few plants seen in village.

*SPOROBOLUS AFRICANUS (Poir.) Rob. & Tourn.
Avatoru village, weed in village, common, Sachet 1389.

CYPERACEAE

CLADIUM JAMAICENSE Crantz
Avatoru village, forming dense patches at edge of marshy area around pond, Sachet 1386. This plant has yellowish achenes varying from ovoid to ellipsoid, and from 2 to 2.5 mm in length. It does not fit either var. chinense (Nees) Koy. or var. jamaicense, but exactly connects the two.

CYPERUS JAVANICUS Houtt.
Tiputa village, common locally in low area in weedy area back of village, Sachet 1374.

*CYPERUS KYLLINGIA Endl.
Tiputa village, common weed in village, Sachet 1395.

*CYPERUS POLYSTACHYOS Rottb.
Tiputa village, occasional along road in weedy area back of village, Sachet 1373.

*CYPERUS ROTUNDUS L.
Tiputa village, occasional weed in lawns, Sachet 1402.

FIMBRISTYLIS CYMOSA R. Br.
Avatoru village, occasional on dry ground at edge of marshy area, Sachet 1387. This collection has compact, button-like heads, styles with either 2 or 3 branches, predominantly 3, achenes mostly trigonous, smooth.

PALMAE

*COCOS NUCIFERA L.
Planted over most of atoll.

*Unidentified palm, possibly *Caryota* sp.
Planted.

COMMELINACEAE

*COMMELINA sp.
Tiputa, seen in village.

*RHOEO SPATHACEA (SW.) Stearn
Avatoru, cultivated in village.

LILIACEAE

*CORDYLINE FRUTICOSA (L.) Goepp.
Porahu, persisting in former inhabited site.

AMARYLLIDACEAE

*CRINUM sp.
Tiputa, seen in village.

*ZEPHYRANTHES ROSEA (Spreng.) Lindl.
Tiputa, planted in village.

DIOSCOREACEAE

*DIOSCOREA BULBIFERA L.
Porahu islet, occasional in shady forest, Sachet 1383, probably remaining from cultivation.

TACCACEAE

TACCA LEONTOPETALOIDES (L.) O. Ktze.
Tiputa village, occasional in abandoned yards and in plantation, Sachet 1341.

MUSACEAE

*MUSA sp.
Tiputa, planted in village.

CANNACEAE

*CANNA sp.
Tiputa, planted in village.

CASUARINACEAE

*CASUARINA EQUISETIFOLIA L.
Tiputa, planted in village.

MORACEAE

*ARTOCARPUS ALTILIS (Park.) Fosb.
Tiputa, Avatoru, planted in villages.

URTICACEAE

LAPORTEA RUDERALIS (Forst.) Chew
Fleurya ruderalis (Forst.) Gaud. ex Wedd.
Vahituri islet, common in open areas in coconut plantation, Sachet 1397.

PIPTURUS ARGENTEUS (Forst.) Wedd.
Tiputa village, occasional in scrub forest between village and ocean, Sachet 1367.

POLYGONACEAE

*ANTIGONON LEPTOPUS W. & A.
Tiputa, cultivated in village.

*COCCOLOBA UVIFERA L.
Tiputa village, planted in village, Sachet 1334.

NYCTAGINACEAE

BOERHAVIA TETRANDRA Forst.
Tepaetia islet, occasional in coconut plantation, Sachet 1358; Vahituri islet, common in open areas in coconut plantation, Sachet 1398; Paitia islet, occasional in open coconut plantation, Sachet 1401.

*MIRABILIS JALAPA L.
Tiputa, planted in village and escaped.

PISONIA GRANDIS R. Br.
Paitia islet, a few trees left in scrub forest, Sachet 1400; Kaorafara islet, small grove in center of islet, Sachet 1399.

AMARANTHACEAE

ACHYRANTHES CANESCENS R. Br.
Moore 204 (US)

PORTULACACEAE

PORTULACA JOHNII v. Poelln.
Peari islet, common on sandy ground in open coconut plantation, Sachet 1381. Known previously from the Tuamotus, Austral Is., and Christmas Island. This species, in habit resembling *P. oleracea* L. but with the flowers, "open around 10 a.m. till 2 or 3 p.m."; stamens "30-40"; seeds more or less glossy, with interdigitating star-shaped, slightly raised tesselae.

LAURACEAE

CASSYTHA FILIFORMIS L.
Tiputa village, abundant locally climbing over shrub in scrub forest between village and ocean, Sachet 1366.

CRUCIFERAE

LEPIDIUM BIDENTATUM Montin
Tiputa village, common locally in weedy area back of village, Sachet 1372.

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CRASSULACEAE

*KALANCHOE PINNATA (Lam.) Pers.
Tiputa, seen in village.

LEGUMINOSAE

*CASSIA OCCIDENTALIS L.
Avatoru, seen in village.

*DESMODIUM TRIFLORUM (L.) DC.
Utoto, seen in cleared coconut plantation.

*INOCARPUS EDULIS (Park.) Fosb.
Kaorofara, one seen persisting.

*LEUCAENA LEUCOCEPHALA (Lam.) deWit
L. glauca of authors, non (L.) Benth.
Tepaetia islet, one shrub seen in scrub, Sachet 1355.

*MIMOSA PUDICA L.
Utoto, Tuhere Pari, small patches seen in holes filled with soil from Tahiti.

SESBANIA SPECIOSA var. TUAMOTENSIS F. Brown
Avea islet, one clump seen (occasional on other islets) in area cleared for planting of coconut palms, Sachet 1380.

*VIGNA MARINA (Burm.) Merr.
Tuhere Pari, a few chlorotic vines seen in hole filled with soil from Tahiti.

RUTACEAE

*CITRUS AURANTIFOLIA (Christm.) Swingle
Tiputa, in village; Porahu islet, persisting, several flourishing trees.

*CITRUS sp.
Tiputa, one tree of "pamplemousse" seen in village.

SURIANACEAE

SURIANA MARITIMA L.
Tiputa village, abundant, forming strip at edge of scrub forest at top of ocean beach ridge, Sachet 1376.

EUPHORBIACEAE

*ACALYPHA spp.

Tiputa, several forms (red-leaved, green-and-white-leaved and frilled) cultivated in village.

EUPHORBIA ATOTO Forst.
Tiputa village, Sachet 1333; very abundant everywhere.

*EUPHORBIA HIRTA L.
Avatoru village, very common weed in village, Sachet 1390.

*EUPHORBIA PROSTRATA Ait.
Avatoru village, common locally as weed in village, Sachet 1391.

*EUPHORBIA sp.
Tiputa, succulent Euphorbia seen in village.

*PEDILANTHUS TITHYMALOIDES (L.) Poit.
Tiputa, planted in village.

*PHYLLANTHUS AMARUS Schum. & Thonn.
Tiputa village, common weed in yards, Sachet 1346, and in plantation.

*RICINUS COMMUNIS L.
Tiputa, planted in village.

ANACARDIACEAE

*MANGIFERA INDICA L.
Tiputa, 2 small trees planted at east end of village.

SAPINDACEAE

*POMETIA PINNATA Forst.
Tiputa, planted in village.

VITACEAE

*VITIS sp.
Tiputa, planted in village.

TILIACEAE

*MUNTINGIA CALABURA L.
Tiputa, planted as street tree, very abundant.

TRIUMFETTA PROCUMBENS Forst.
Tiputa village, abundant in ground-cover in scrub forest between village and ocean, Sachet 1365.

MALVACEAE

ABUTILON ASIATICUM var. ALBESCENS (Miq.) Fosb.
Tiputa village, weed in abandoned area, Sachet 1337.

*GOSSYPIUM sp.
Avatoru, seen in village.

HIBISCUS TILIACEUS L.
Tiputa village, common locally in scrub forest between village and ocean, Sachet 1369.

*HIBISCUS, ornamental hybrids
Tiputa, Avatoru, planted in villages.

*MALVASTRUM COROMANDELIANUM (L.) Garcke
Tiputa village, common locally in abandoned yards, Sachet 1352.

*MALVAVISCUS sp.
Tiputa, planted in village.

*SIDA RHOMBIFOLIA L.
Avatoru village, weed in village, common, Sachet 1388.

THESPESIA POPULNEA (L.) Sol. ex Correa
Tiputa, Kaorofara, planted or persisting.

BOMBACACEAE

*CEIBA PENTANDRA (L.) Gaertn.
Avatoru, seen in village.

STERCULIACEAE

*WALTHERIA INDICA L.
Tiputa village, occasional weed in plantation and yards, Sachet 1339.

GUTTIFERAE

CALOPHYLLUM INOPHYLLUM L.
Tiputa village, only a few trees seen, perhaps planted, in scrub forest between village and ocean, Sachet 1368.

CARICACEAE

*CARICA PAPAYA L.
Tiputa, planted in village, often in foundations of ruined houses.

PASSIFLORACEAE

*PASSIFLORA FOETIDA L. var. FOETIDA

Tiputa village, common weed in abandoned garden, Sachet 1335, also in plantation. The typical variety of *P. foetida*, widespread in the Caribbean and South America has previously not been reported from the Pacific Islands. The varieties known from there are var. *hispida* and var. *gossypifolia*. The present material, because of its long, yellow scarcely glandular stem pubescene, seems closer to var. *foetida* than to var. *gossypifolia*. Its non-interlaced, non-matted involucral bracts distinguish it from var. *hispida*.

LYTHRACEAE

PEMPHIS ACIDULA Forst.

Tiputa village, occasional (common elsewhere) in scrub forest at top of ocean beach ridge, Sachet 1377.

COMBRETACEAE

*TERMINALIA sp.

Tiputa, planted in village.

MYRTACEAE

*EUGENIA CUMINI L.

Tiputa, large tree planted in village.

*PSIDIUM sp.

Tiputa, Avatoru, seen in village; Porahu islet, persisting.

CACTACEAE

*OPUNTIA sp.

Tiputa, seen in village.

ARALIACEAE

*BRASSAIA ACTINOPHYLLA Endl.

Tiputa, planted in village.

*POLYSCIAS spp.

Tiputa, several species planted in village.

APOCYNACEAE

*ALLAMANDA sp.

Tiputa, planted in village.

*CATHARANTHUS ROSEUS (L.) G. Don
Tiputa village, Sachet 1340, common escaped from cultivation.

*NERIUM sp.
Tiputa, planted in village.

*PLUMERIA RUBRA L.
Tiputa, planted in village.

ASCLEPIADACEAE

*ASCLEPIAS CURASSAVICA L.
Avatoru, seen in village.

CONVOLVULACEAE

*IPOMOEA BATATAS (L.) Lam.
Tiputa, planted in village, in foundations of ruined houses.

*IPOMOEA OBSCURA (L.) Ker.
Tiputa village, weed in yard, Sachet 1353.

IPOMOEA TUBA (Schlecht.) Don
Porahu, in mixed scrub on lagoon side.

BORAGINACEAE

CORDIA SUBCORDATA Lam.
Tiputa village, planted in village, Sachet 1396.

HELIOTROPIUM ANOMALUM H. & A. var. ANOMALUM
Avea islet, occasional on bare sand, forming wide patch in area cleared for planting of coconut palms, Sachet 1379.

TOURNEFORTIA ARGENTEA L.f.
Tiputa village, common in scrub forest between village and ocean, Sachet 1363.

VERBENACEAE

*LANTANA CAMARA var. ACULEATA (L.) Moldenke
Tepaetia islet, a few plants seen in scrub, Sachet 1359.

NESOGENES EUPHRASIOIDES (H. & A.) A. DC.
Tepaetia islet, locally abundant in scrub, Sachet 1361.

*STACHYTARPHETA URTICIFOLIA Sims
Tiputa village, occasional weed in abandoned yards, Sachet 1347.

LABIATAE

*OCIMUM BASILICUM L.
Avatoru village, occasional in village, probably escaped from cultivation, Sachet 1392.

*OCIMUM sp.
Tiputa, some dried-up plants seen in village.

SOLANACEAE

*CESTRUM DIURNUM L.
Tiputa village, planted in garden, Sachet 1336.

*DATURA METEL L.
Tiputa village, a few plants escaped from cultivation, Sachet 1342.

SCROPHULARIACEAE

*RUSSELIA EQUISETIFORMIS L.
Avatoru, cultivated in village.

ACANTHACEAE

*PSEUDERANTHEMUM CARRUTHERSII var. ATROPURPUREUM (Bull) Fosb.
Tiputa village, planted in village, Sachet 1393.

RUBIACEAE

*GARDENIA TAITENSIS DC.
Tiputa, cultivated in village.

GUETTARDA SPECIOSA L.
Tiputa village, abundant in scrub forest between village and ocean, Sachet 1364.

HEDYOTIS ROMANZOFFIENSIS (C. & S.) Fosb.
Tepaetia islet, only a few plants seen in scrub, Sachet 1357.

*IXORA spp.
Tiputa, several species planted in village.

MORINDA CITRIFOLIA L.
Tiputa village -- Sachet 1338, common in scrub around village.

*PENTAS LANCEOLATA (Forsk.) Schum.
Tiputa village -- Sachet 1362, planted.

TIMONIUS POLYGAMA Forst.
Tiputa village, very common in scrub around village and in plantation, Sachet 1343 (staminate), 1348 (pistillate).

GOODENIACEAE

SCAEVOLA TACCADA var. TUAMOTUENSIS St. John
S. sericea Vahl, commonly misidentified as S. frutescens (Mill.) Krause.
Tiputa village, very common in scrub and in plantations, Sachet 1345.

COMPOSITAE

*BIDENS PILOSA L.
Tiputa village, occasional in yards and on roadside, Sachet 1349.

*ELEPHANTOPUS SPICATUS HBK.
Tiputa, seen in village.

*EMILIA JAVANICA (Burm.f.) C. B. Rob.
Tiputa village, occasional weed in roadside, Sachet 1354.

*SYNEDRELLA NODIFLORA (L.) Gaertn.
Tiputa village, weed in village, Sachet 1394.

*VERNONIA CINEREA var. PARVIFLORA (Bl.) DC.
Tiputa village, occasional weed, Sachet 1351.

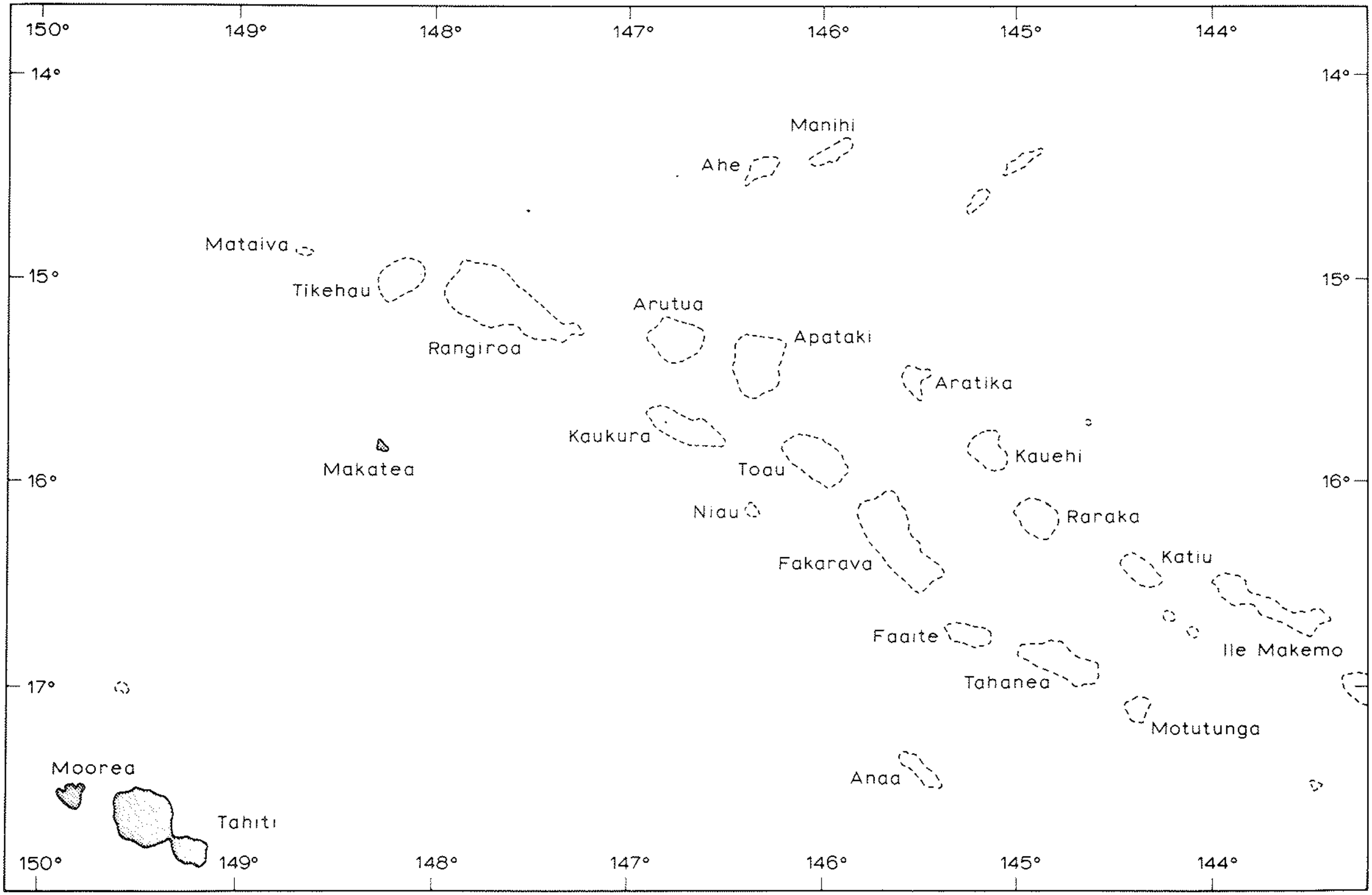


Fig. 1 Location of Rangiroa Atoll

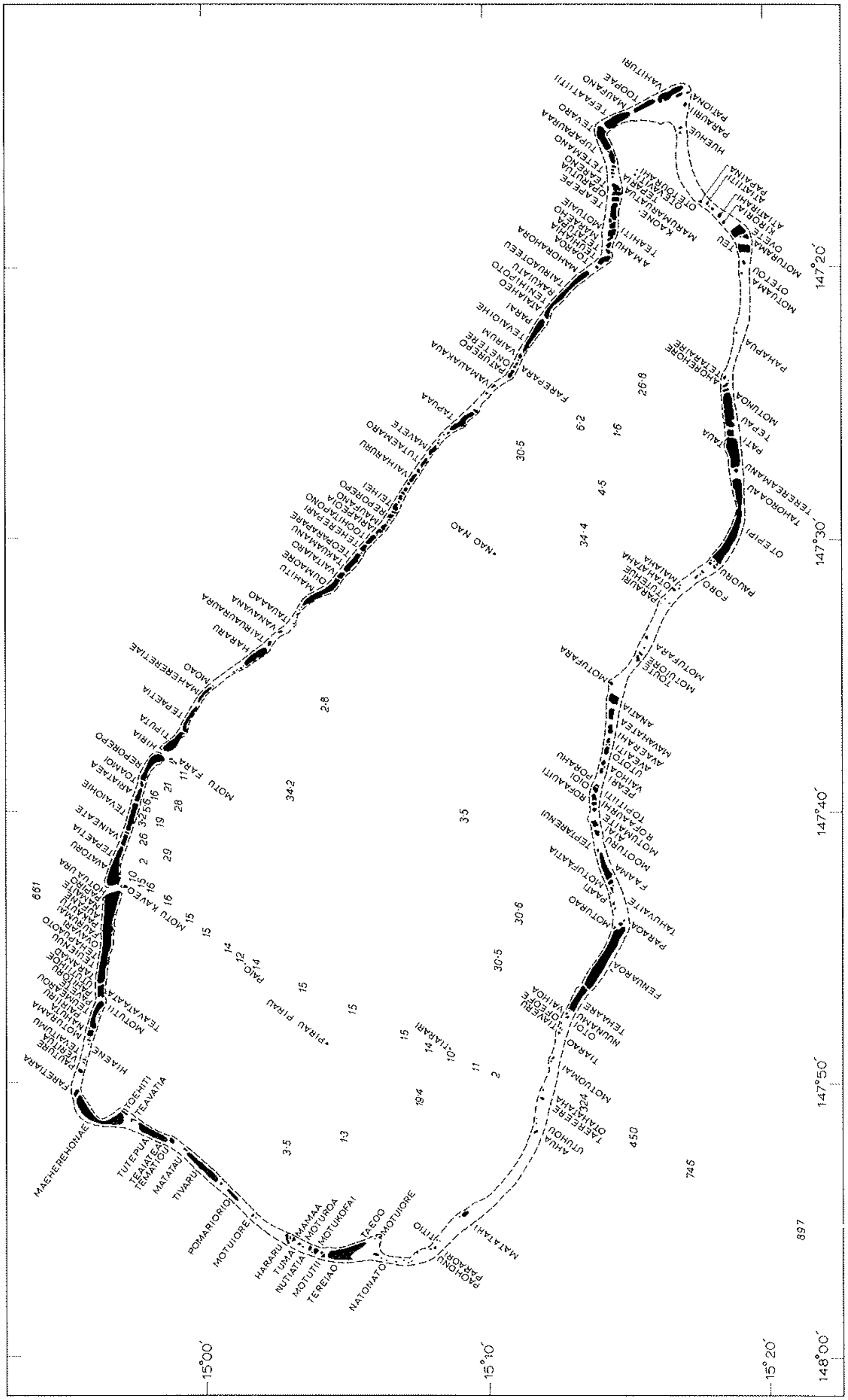


Fig. 2 Rangiroa Atoll

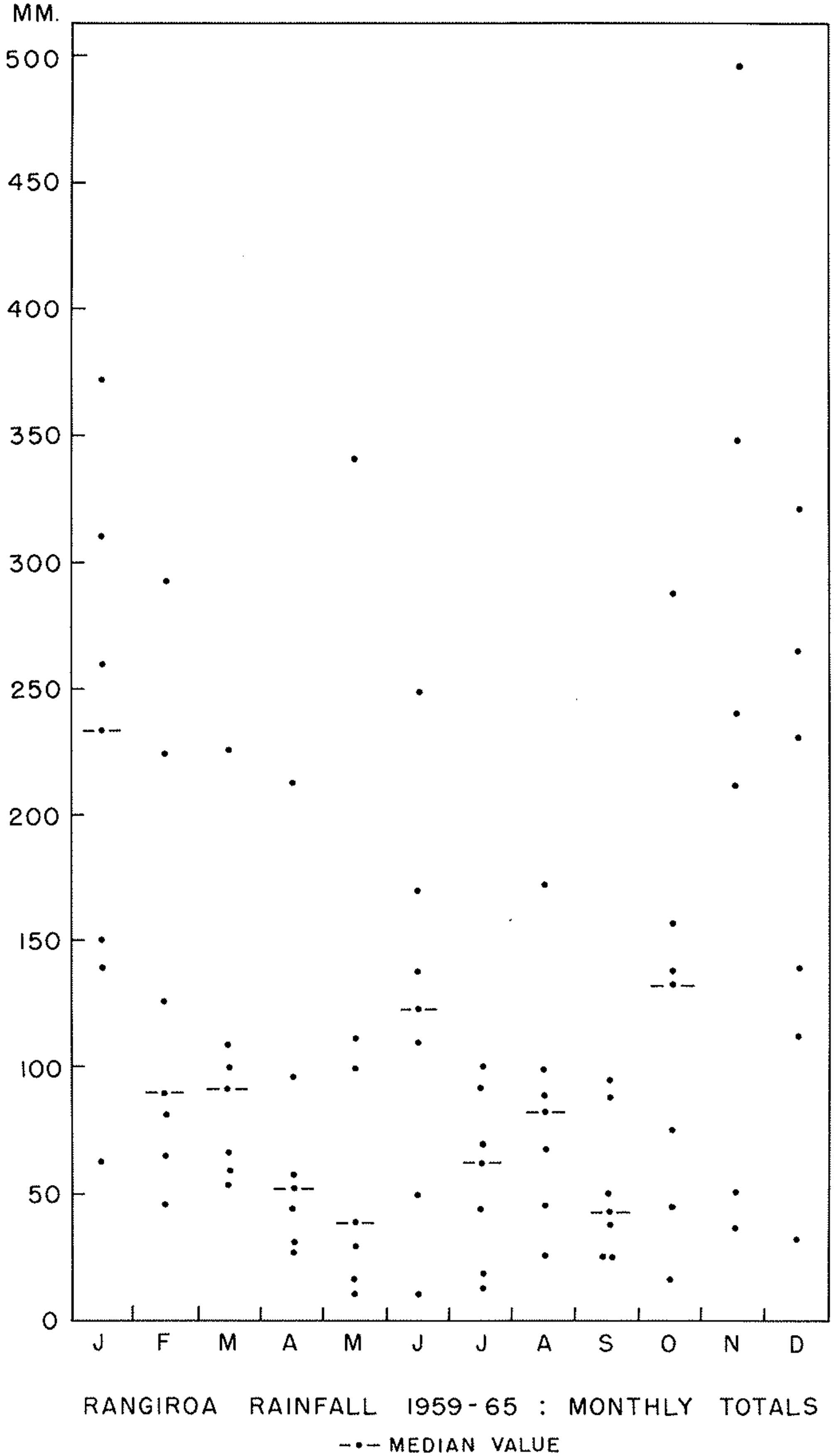


Fig. 3 Rangiroa rainfall 1959-65: monthly totals

RANGIROA RAINFALL 1960-65 : SINGLE DAY MAXIMUM FALLS IN EACH MONTH OF EACH YEAR OVER PERIOD OF RECORD.

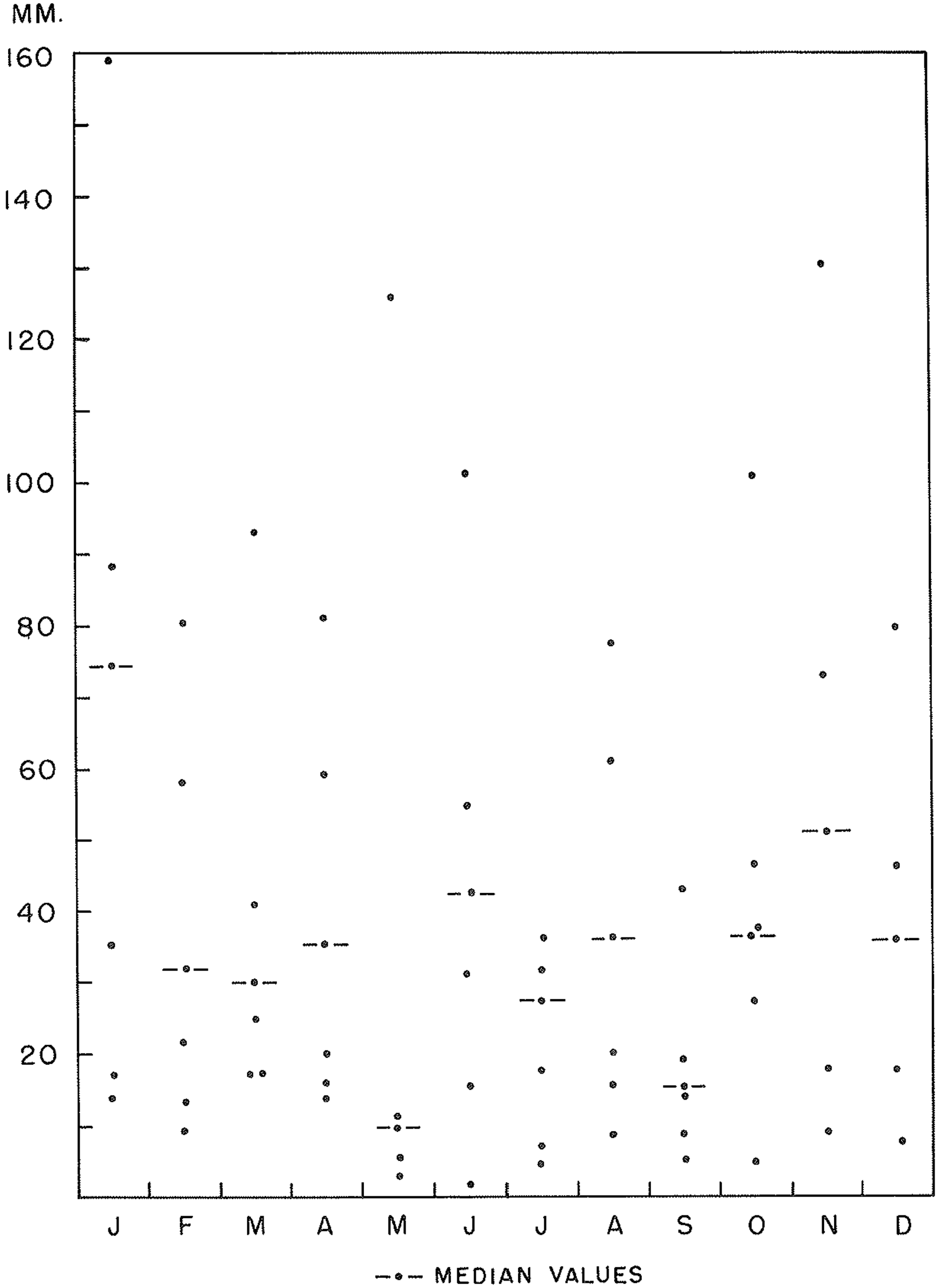


Fig. 4 Rangiroa rainfall 1960-65: single-day maxima

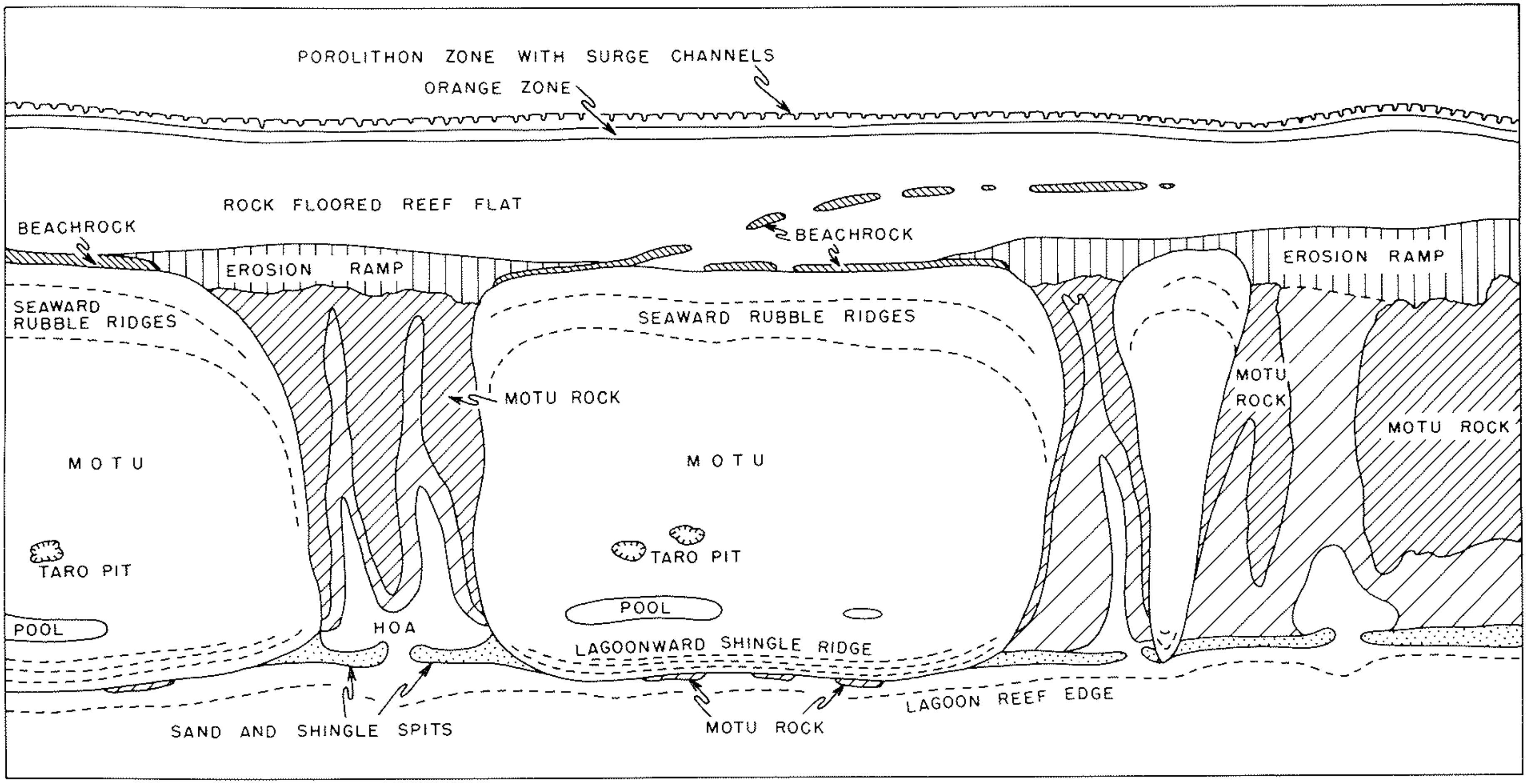


Fig. 5 Schematic diagram of northern rim with islands

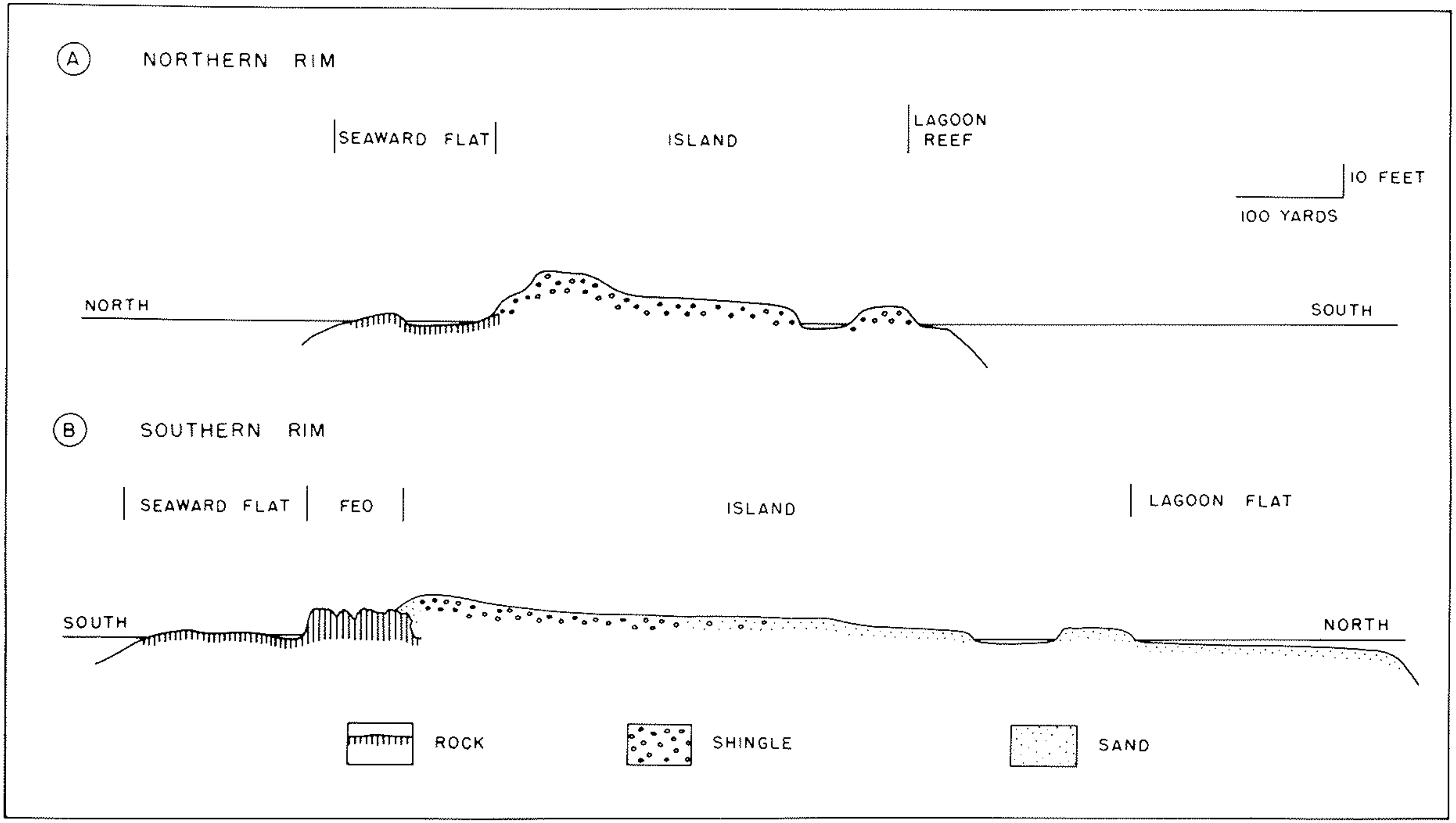


Fig. 6 Schematic sections of islands on north and south rims

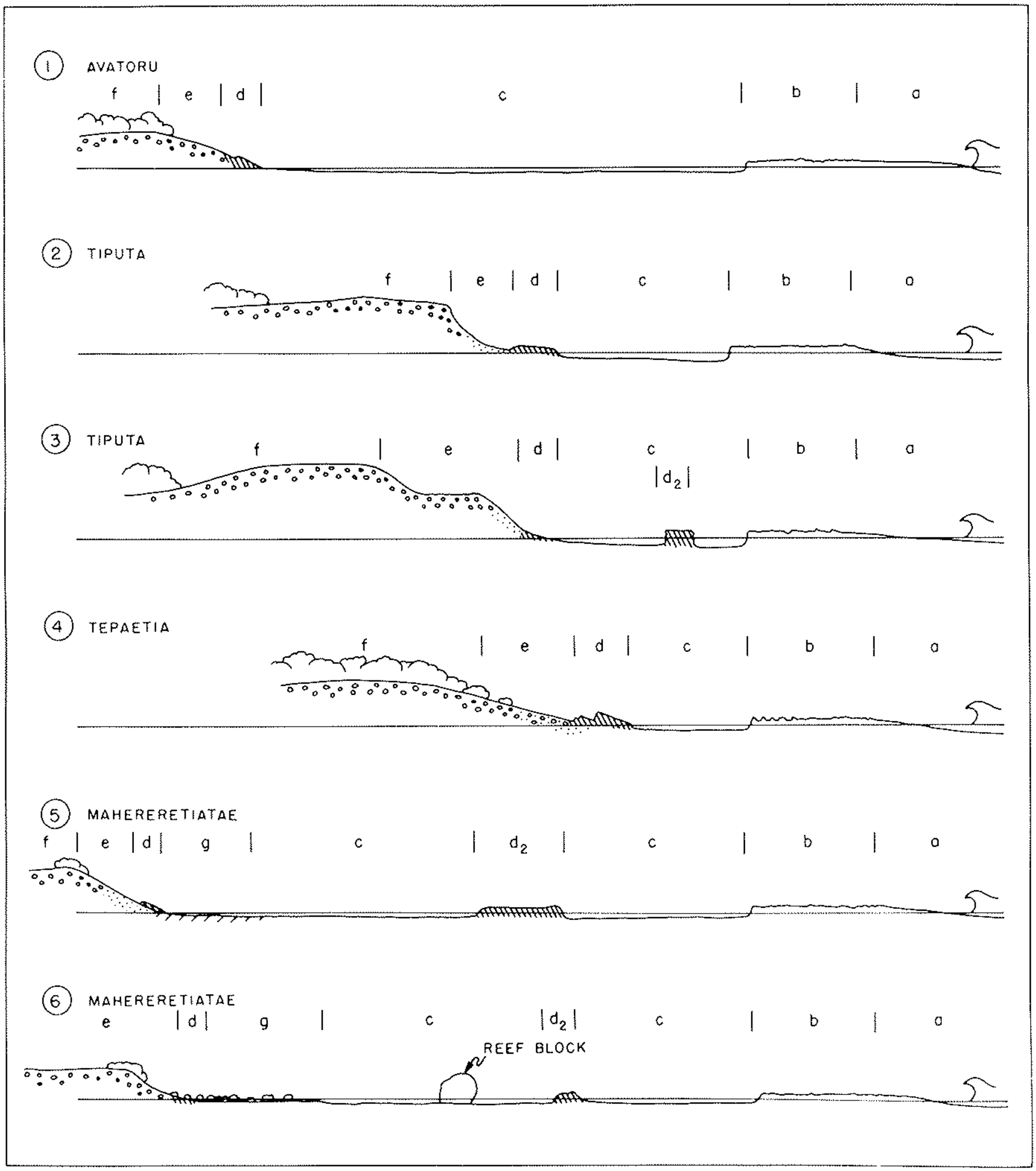


Fig. 7 Profiles 1-6, northern rim

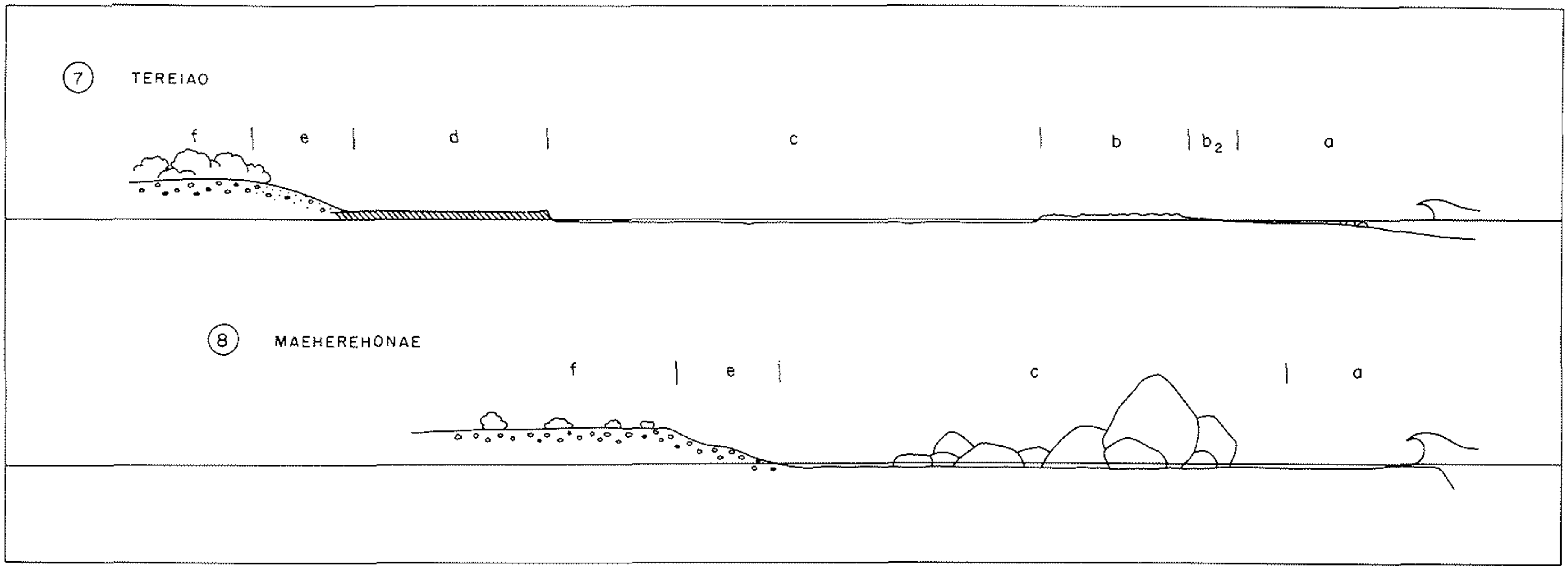


Fig. 8 Profiles 7-8, western rim

33-682 O-69-10

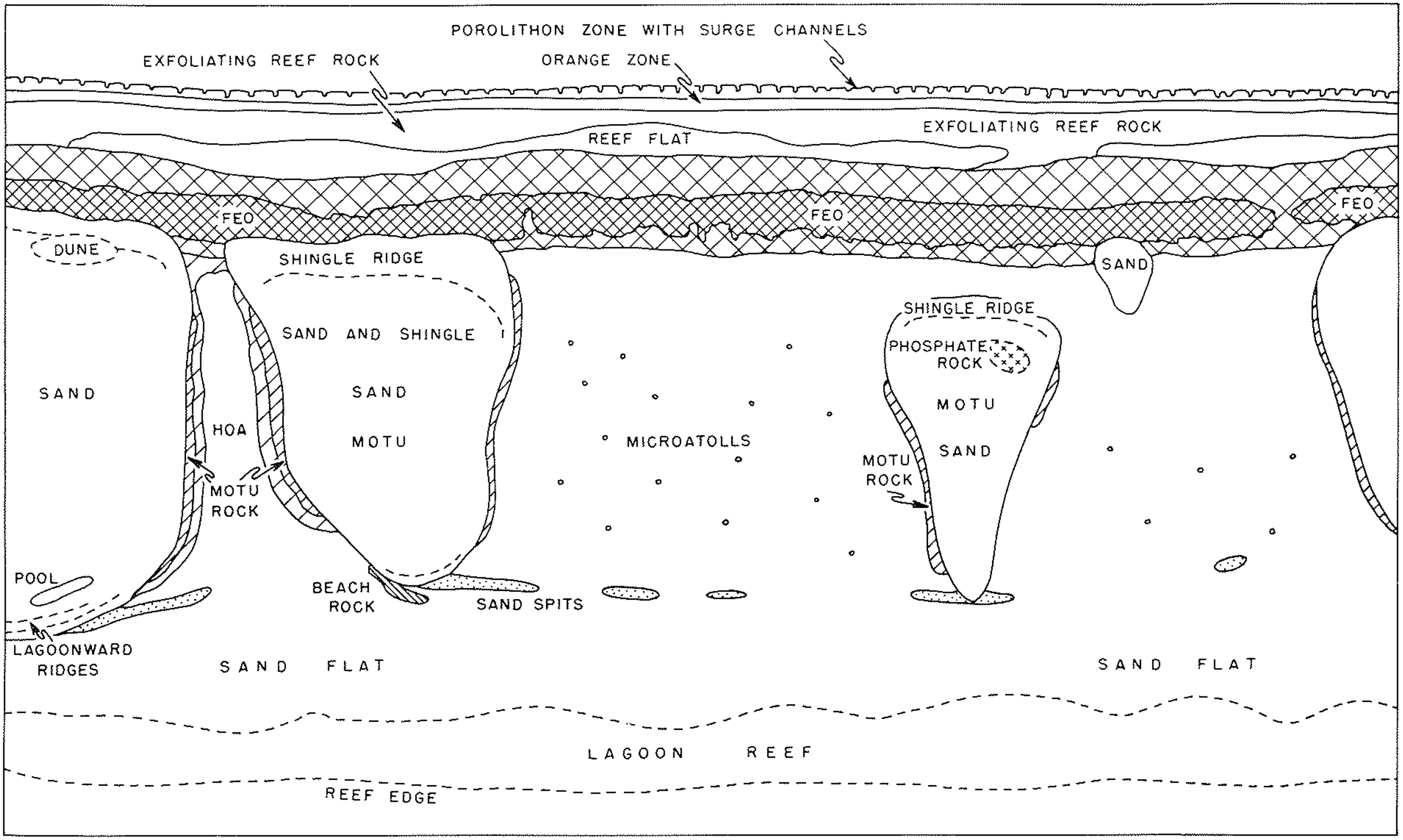


Fig. 9 Schematic diagram of southern rim with islands

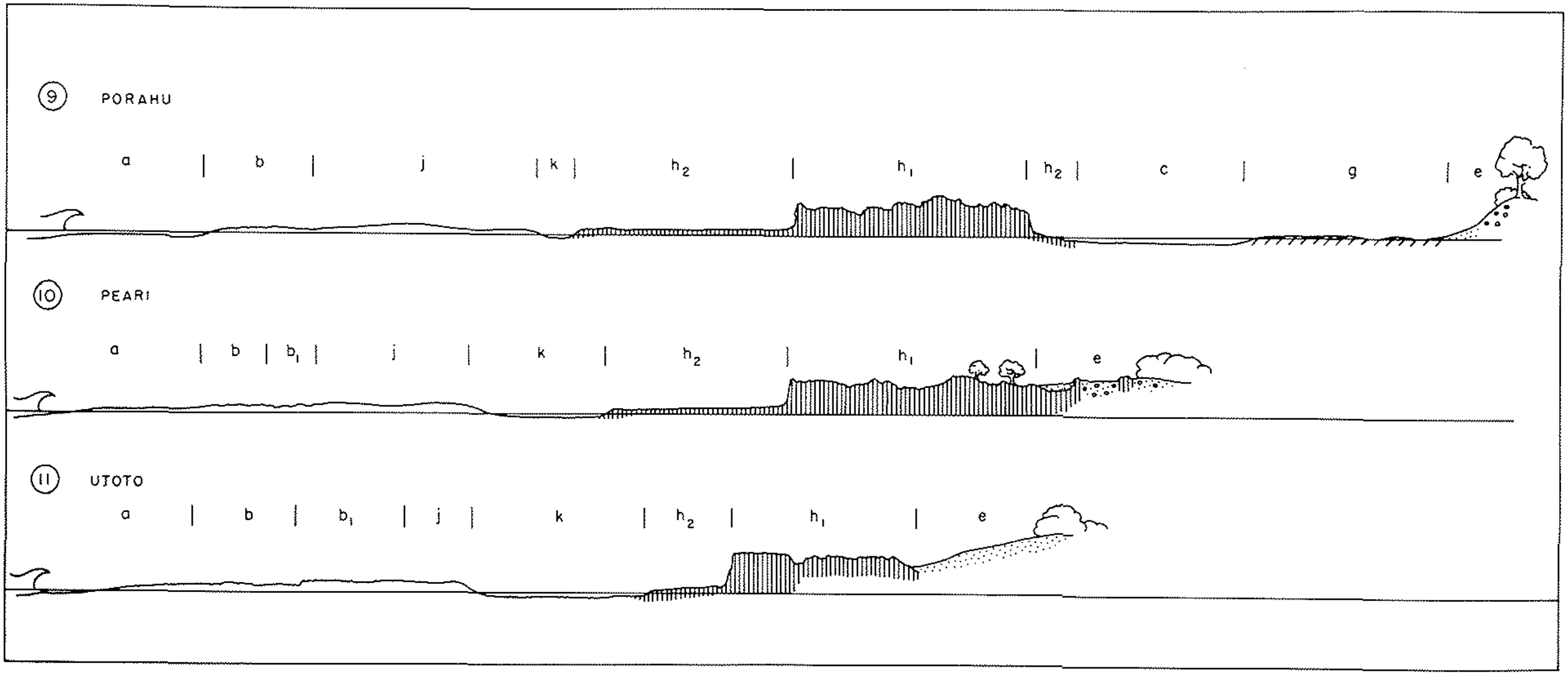


Fig. 10 Profiles 9-11, southern rim

1 Tiputa, north shore: seaward shingle ridge, smooth erosion ramp, and beachrock and rubble. Relict beachrock on reef flat in background.

2 Tiputa, north shore, west end, looking towards Reporepo: steep shingle beach, erosion ramp, and conglomerate beachrock.

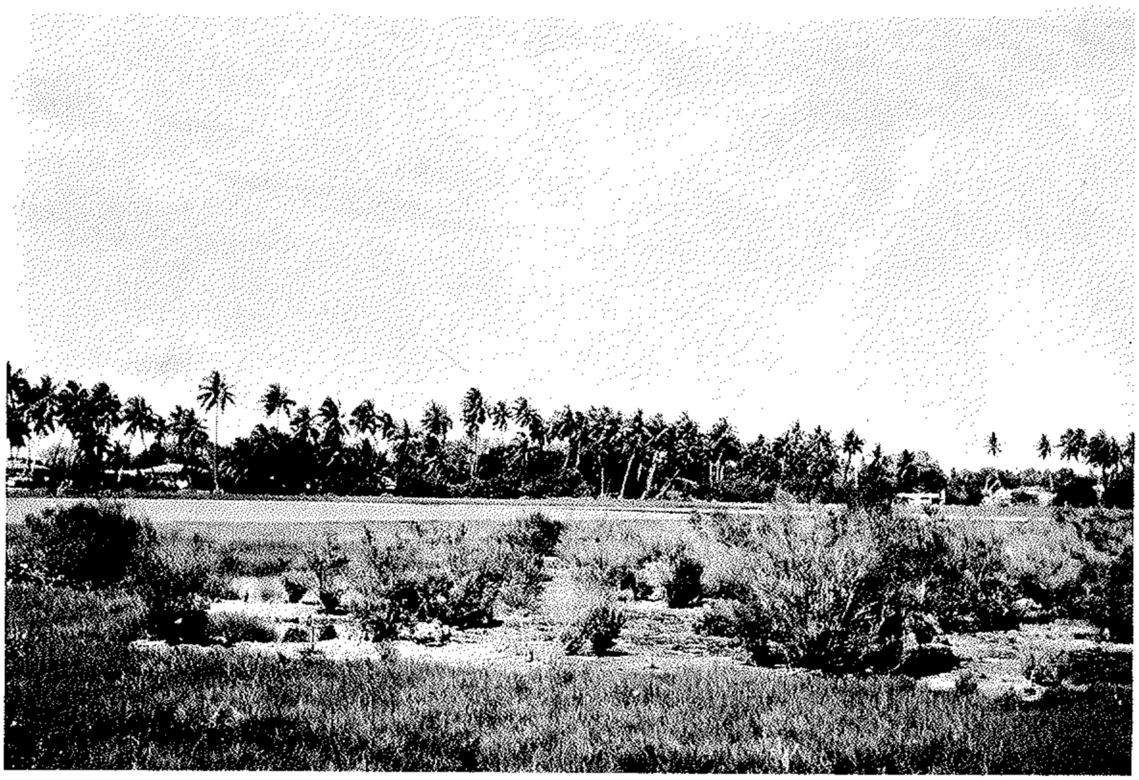
3 Tiputa, north shore: shingle beach with massive beach-foot conglomeratic beachrock. Note the narrowness of the reef flat.

4 Tiputa-Tepaetia hoa: view from the lagoonward end, on Tiputa, towards the seaward reef.

5 Tiputa, north shore: beach-crest vegetation hedge of *Tournefortia* and *Hedyotis*, showing defoliation, with coconut palms.

6 Tiputa, south shore, east end, looking westwards: low sandy lagoon beach with coconut plantation.

7 Tepaetia, south shore, west end, near entrance to <u>hoa</u>: outcrop of island conglomerate on a sandy beach. Note the absence of a lagoon reef.



8 Avatoru: marécage at west end of the island, looking north.

9 Tepaetia, north shore, east end, view east: edge of seaward reef flat at low water: pink algal zone on the left (covered with water), dissected orange zone in the center; drying reef flat to the right.

10 Tereiao, west shore, view south: edge of seaward reef flat at low water: dissected pink algal zone.

11 Tereiao: massive conglomerate at the foot of the seaward beach.

12 Tereiao: fresh coral shingle on the crest of the seaward beach.

13 Tereiao: lagoon-side marécage with Cladium.

14 Macherehonae: large lagoon-side marécage with sandy lagoonward sand strip in the foreground.

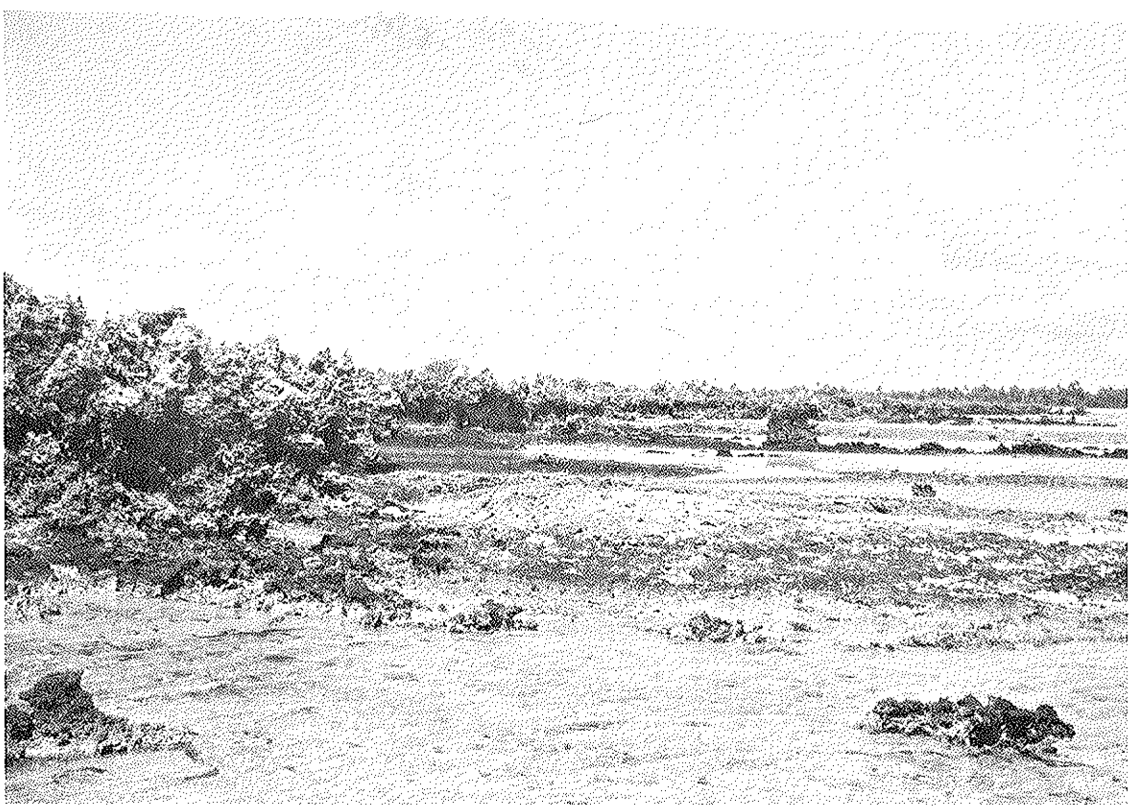
15 Maeherehonae: view towards the lagoon from the summit of the dunes, across the marécage. Pemphis, Pandanus and coconuts in the foreground.

16 Maeherehonae: a recently-excavated marae on top of the lagoon-side dunes.

17 Maeherehonae: conglomerate platform, with Pemphis acidula, at water-level between the dunes.

18 Maeherehonae, west shore, northern end: storm blocks on the seaward reef flat, photographed from the seaward beach. Note the human figure on the largest block.

19 Porahu, seaward shore: feo separated by a narrow moat from the seaward shore of the island.



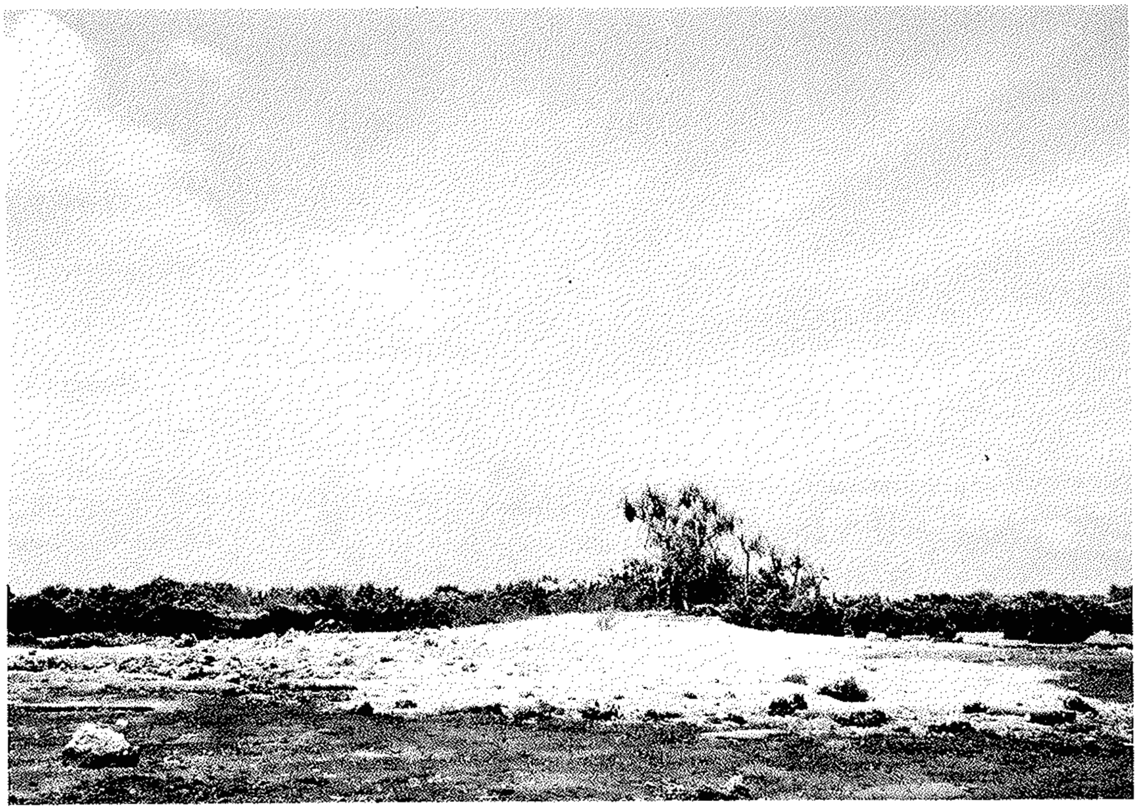
20 Porahu: islandward margin of the feo shown in Plate 19. Note the narrow basal erosion platform.

21 Porahu, west shore: island conglomerate unconformably overlying truncated reef corals. Seaward feo in the background.

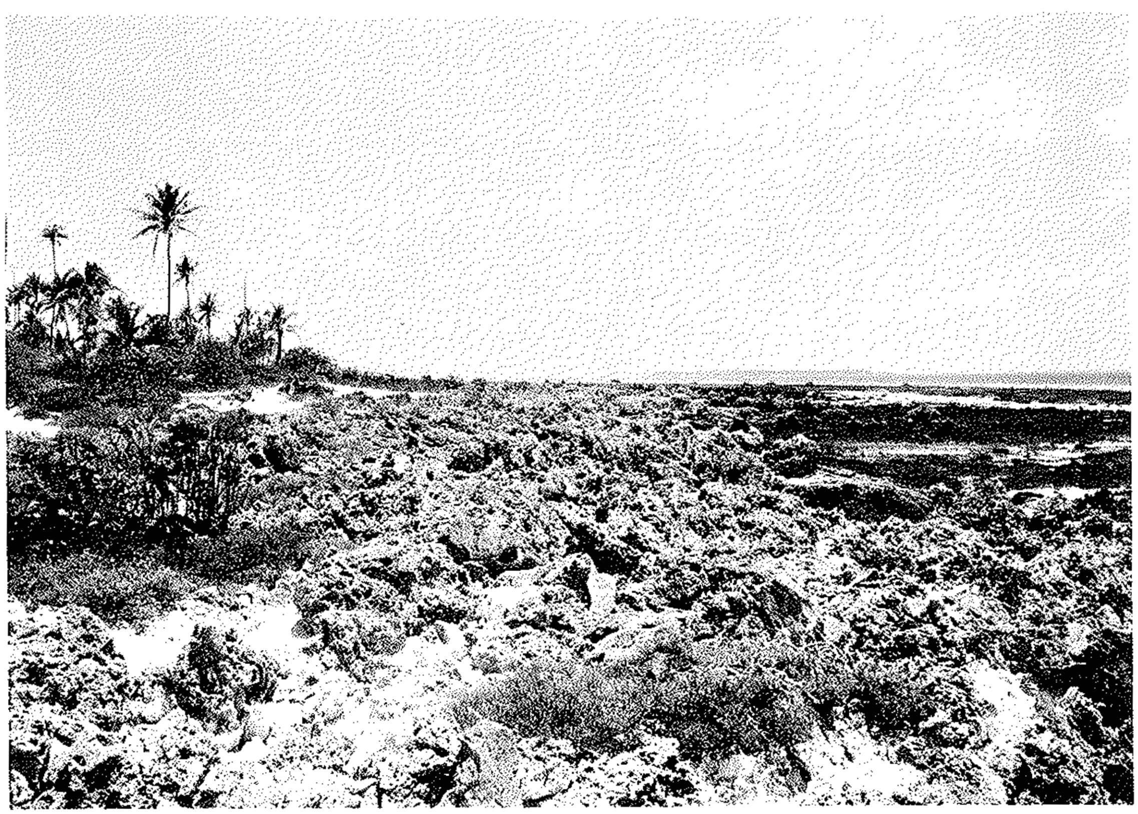
22 Peari: seaward reef edge with exfoliating reef rock on the reef flat.

23 Peari: exfoliating reef rock on the seaward reef flat.

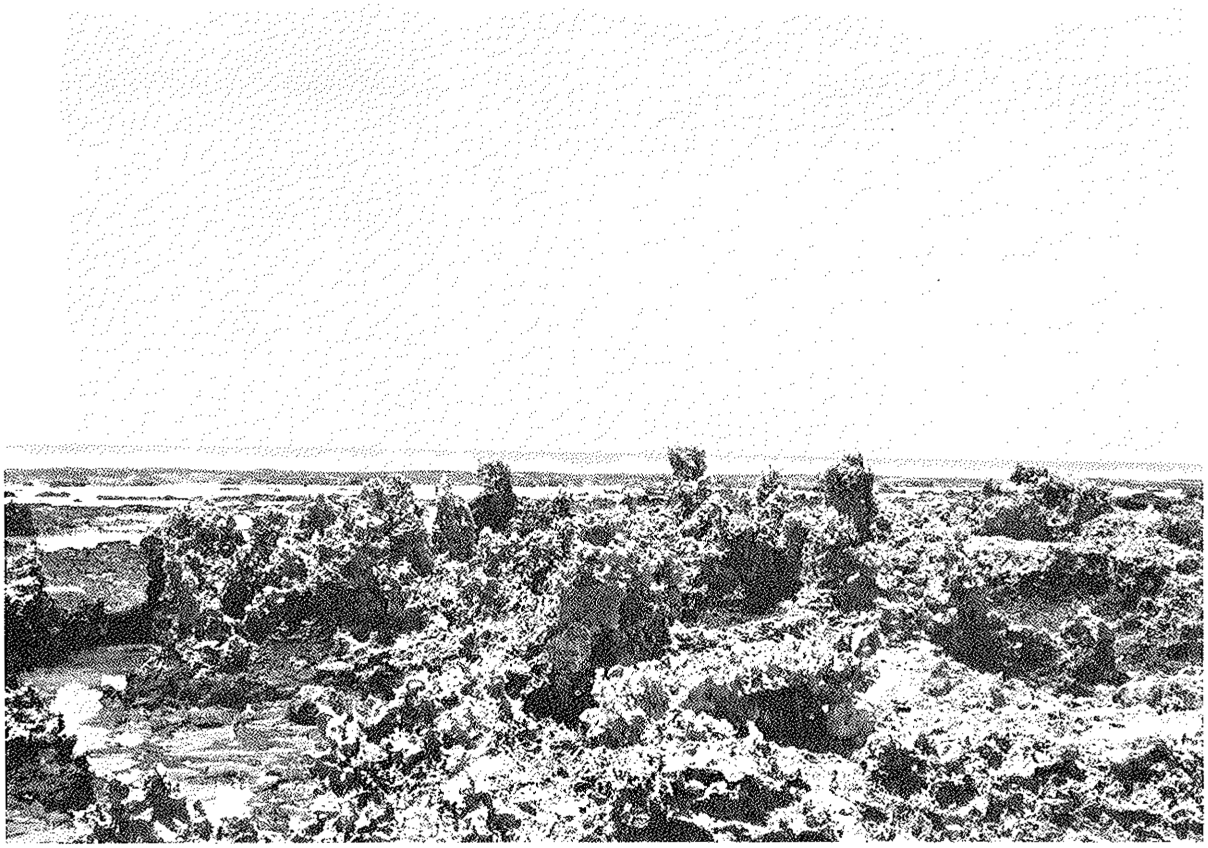
24 Peari-Baihoa hoa: island conglomerate outcropping in the hoa walls with seaward feo in the background.



25 Vaihoa-Tuoto *hoa*: small sand cay with *Pandanus* perched against the seaward *feo*.



26 Utoto: *feo* with *Pemphis* and perched beach, looking eastwards.



27 Utoto: dissected seaward margin of the feo.