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Geomorphology of the Marovo Elevated Barrier Reef, New Georgia

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1. Introduction

W. M. Davis considered that 'none of the elevated reefs of the Solomon Islands is more remarkable than the emerged barrier reef which skirts the north-eastern side of the long island of New Georgia' (Davis 1928, pp. 397–398), and this reef was one of the main objects of geomorphic work during the Royal Society Expedition to the British Solomon Islands. Davis did not visit the Solomons and based his discussion entirely on charts, and apart from the Admiralty *Pilot*, the *Pacific Islands Handbook*, and brief mention in the publications of the Geological Survey of the British Solomon Islands, the New Georgia reefs have remained entirely unstudied.

The Marine Party of the Expedition visited New Georgia three times: first, from 2 to 9 August 1965, concentrating on the northern Marovo Lagoon; secondly, from 26 August to 8 September, when the biologists returned to the same area, and geomorphic work was extended south to the southern end of Japuchajomo and north to Lumaliha; and thirdly, from 14 October to 18 November, when M.V. *Maroro* was engaged in echosounding and bottom sampling with the writer and Dr P. E. Gibbs in Marovo, Kolo, Togavai and Gerasi Lagoons. A brief visit was also paid by the whole marine party to Ulukoro and Batuona Islands, Wickham Anchorage, *en route* to Gizo, on 3 September. This paper reports on studies of reef geomorphology carried out during these visits, and includes studies made by diving at Matiu Island in collaboration with Dr S. A. Wainwright. The sedimentological and bottom fauna studies carried out during the coring, dredging and grab-sampling programmes on the lagoon floor will be reported separately.

2. Physical background

2·1. *Topography and structure*

The New Georgia Group consists of a series of large volcanic islands, partly surrounded by reef deposits, which extend for 220 km from Vella Lavella in the north-west to Gatukai in the south-east (figure 76). The volcanoes vary in form from the classical cones of Kolombangara (1768 m) and Gatukai (887 m) to the much more dissected topography of New Georgia and Rendova.

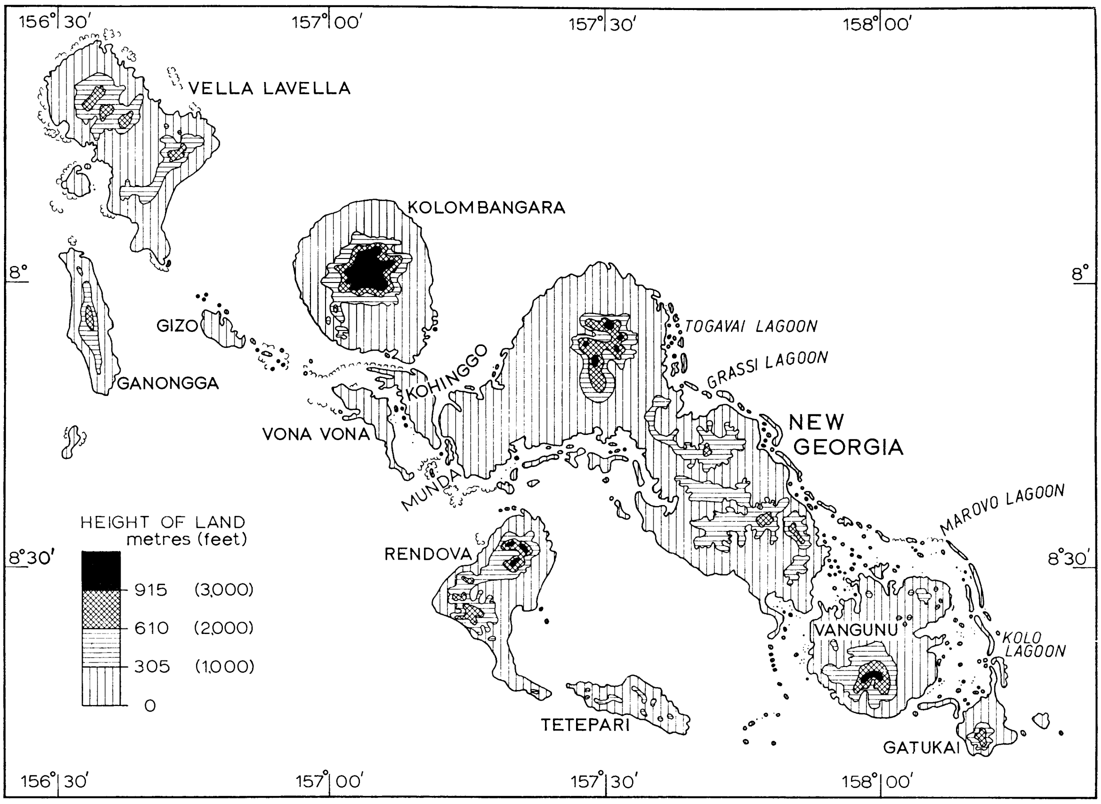

Figure 76. Topography of the New Georgia Group.

The geology is being studied by Stanton & Bell (1965), and has been summarized by Coleman (1965). Coleman identifies 20, and possibly 24, volcanic centres in the group, of which four show signs of activity: one of these is a submarine, intermittently active volcano 35 km south of Vangunu. The lavas are mainly andesitic, and also basaltic; they include flows, pillow lavas, dykes and sills, together with volcanic clastics. Coleman considers that most of the extrusion took place in the Pliocene, with activity continuing through the Pleistocene to the Recent. The Geological Survey (Coleman, Grover, Stanton & Thompson 1965) differentiates between Pliocene volcanics, on southern Vella Lavella, northern Rendova, New Georgia, and northern Vangunu, and Pleistocene volcanics on northern Vella Lavella, Ranongga, Kolombangara, south Rendova, Vangunu, and Gatukai (figure 77): the dating is based on geomorphic evidence of degree of dissection (Coleman 1965, p. 25).

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The volcanics are surrounded by reef limestones of differing ages. The Survey maps large areas of these, particularly on Vona Vona and Kohinggo Islands, with fringes on Vella Lavella and New Georgia, as Pleistocene, and older than some of the volcanics; others are mapped as Recent. The distinction is based on 'local observation of their degree of consolidation and relationship to sea level' (Coleman 1965, p. 25), though topographically some of the exposures seem to be continuous.

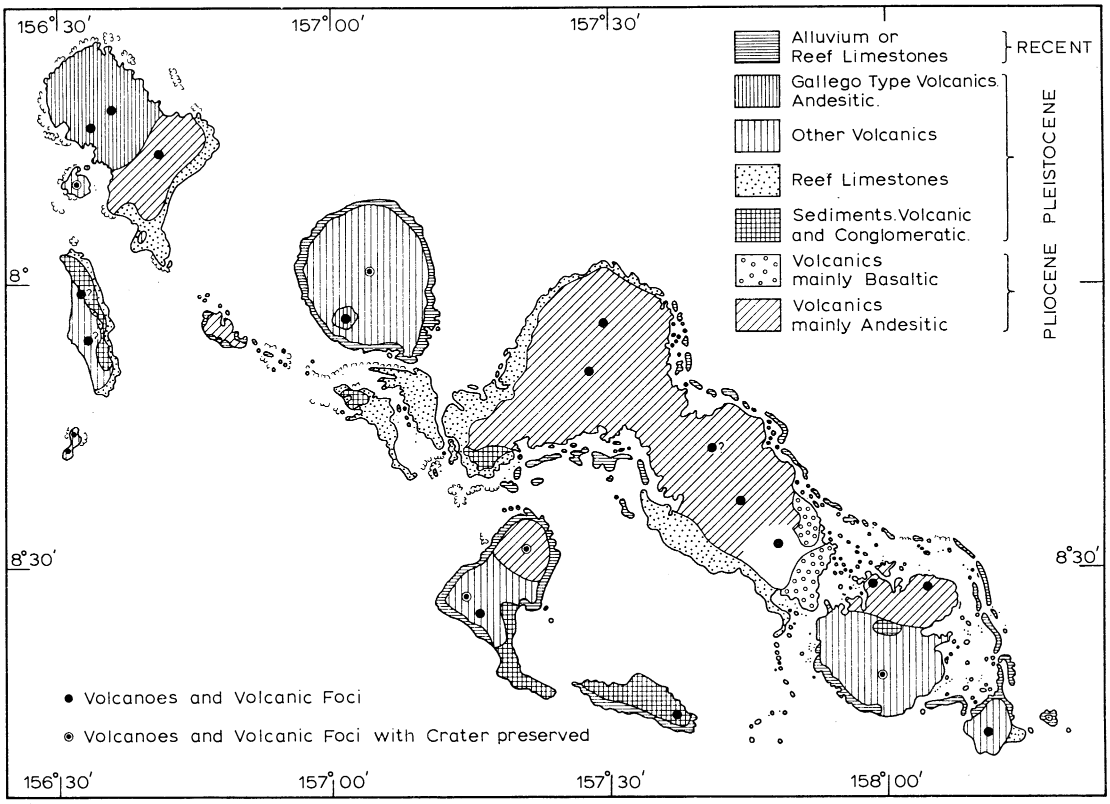

FIGURE 77. Geology of the New Georgia Group, after Coleman *et al.* (1965).

Structures have not yet been mapped in detail. Stanton & Bell (1965) describe large faults trending NNE–SSW, and Coleman (1965) mentions high-angle faulting in the Marovo Lagoon, perhaps controlling reef structures. The submarine volcano south of Gatukai erupted in 1952–3, 1958, and 1961–2, but the New Georgia area is markedly less seismic than either Bougainville to the west or Guadalcanal and San Cristobal to the east (Stoddart 1969, figure 62). A major earthquake on Vella Lavella in 1959, however, led to extensive changes of level and coastal changes (Grover 1965).

2·2. *Tides*

Table 22 lists Admiralty tide data for stations on the north-west coast of New Georgia; grid references are given to the New Georgia 1:50000 series maps. These give an average range of 0·46 m in the south increasing to 0·49 m in the north, and a range at spring tides near the solstices of 0·91 m in the south increasing to 0·98 m in the north. A Foxboro–Yoxall automatic tide-gauge was installed at Cheke village jetty, Mbariki Peninsula,

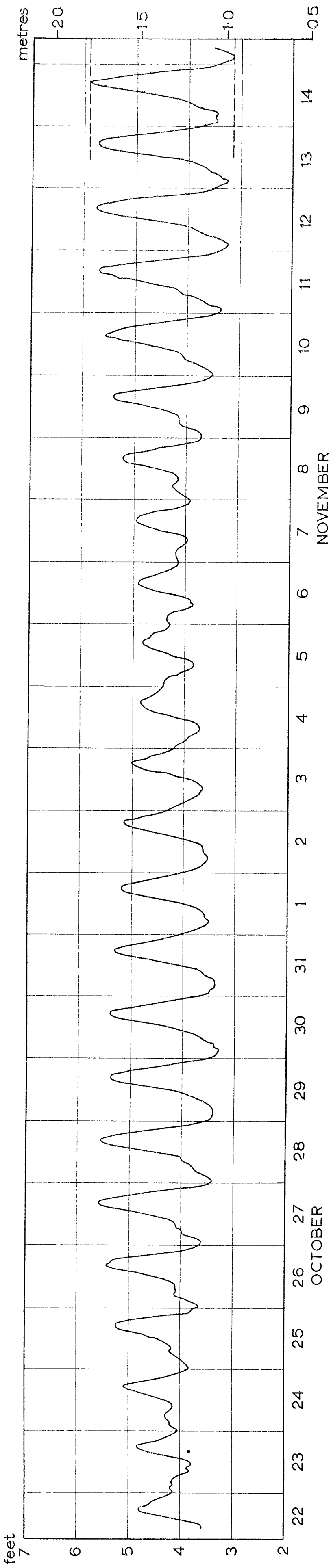

FIGURE 78. Tide record at Cheke Village, Marovo Lagoon, 22 October to 15 November 1965.

Marovo Lagoon, and operated from 22 October to 15 November 1965. The record is given in figure 78; tides were diurnal, with a tendency to be semidiurnal at neaps. The extreme tidal range recorded was 0·84 m at springs, and the smallest range 0·25 m at neaps.

Table 22

station	coordinates	average heights (m)		heights at springs near the solstices (m)	
		mean higher high water	mean lower low water	mean higher high water	mean lower low water
Marovo Lagoon	—	0·61	0·15	0·85	−0·06
Mongo Entrance	UL 740 765	0·64	0·18	0·88	−0·03
Lolomo Entrance	UM 530 955	0·79	0·30	1·04	+0·06
Blackett Strait	—	0·67	0·18	0·95	−0·03

3. The elevated reefs

This paper concerns the reefs of New Georgia, Vangunu and Gatukai Islands; the reefs of Gizo have been discussed in the preceding paper (Stoddart 1969). New Georgia Island is a volcanic complex 2000 km² in area, with a maximum altitude of 1008 m and several peaks over 600 m. Vangunu to the south-east has an area of 470 km² and rises to 1125 m; and Gatukai, the best preserved and presumably most recent volcano, an area of 50 km² and an elevation of 887 m.

The coastline of the volcanic complex is crenulate, with numerous inlets and offshore volcanic islands; geomorphically it is typically drowned. Only Gatukai, the youngest volcano, has a smooth shoreline. Barrier reefs enclose lagoons along the whole north-east-facing coast, forming a shelf with an area of 700 km². This is locally known (from north to south) as Togavae, Gerasi, Marovo, Kolo and Kalikolo Lagoons; collectively it is conveniently known as Marovo Lagoon. On the south side of New Georgia, a similar smaller lagoon is enclosed by a barrier reef: this is known as the Roviana Lagoon, with an area of 200 km². South of Vangunu there is a further partial barrier reef, open to the south, enclosing the lagoon of Panga Bay.

3·1. *Reef morphology*

The reefs enclosing the lagoons are elevated barrier reefs: that enclosing Roviana Lagoon is stated to be 40 to 60 m high, and that enclosing Marovo Lagoon 43 to 55 m high (*Pacific Islands Pilot*, Vol. 1, 1956). The elevated reef islands in the Marovo Lagoon, according to charts, are 27 m high. No study could be made of the Roviana Lagoon, and work was concentrated on the elevated reefs of Marovo Lagoon.

In the northern sector, north of 8° 26′ S, the Marovo barrier reef is a single feature formed by short, irregular islands 0·3 to 1·5 km wide. Farther south, off Vangunu, the islands are longer and narrower, of more regular outline, and generally less than 0·5 km wide. This southern barrier is a double feature, with a line of outer islands separated by water up to 180 m deep from an inner line of islands. West of Gatukai the barrier enclosing Wickham Anchorage is again a single feature.

Profiles were surveyed across outer barrier islands at four stations (figure 79); datum in

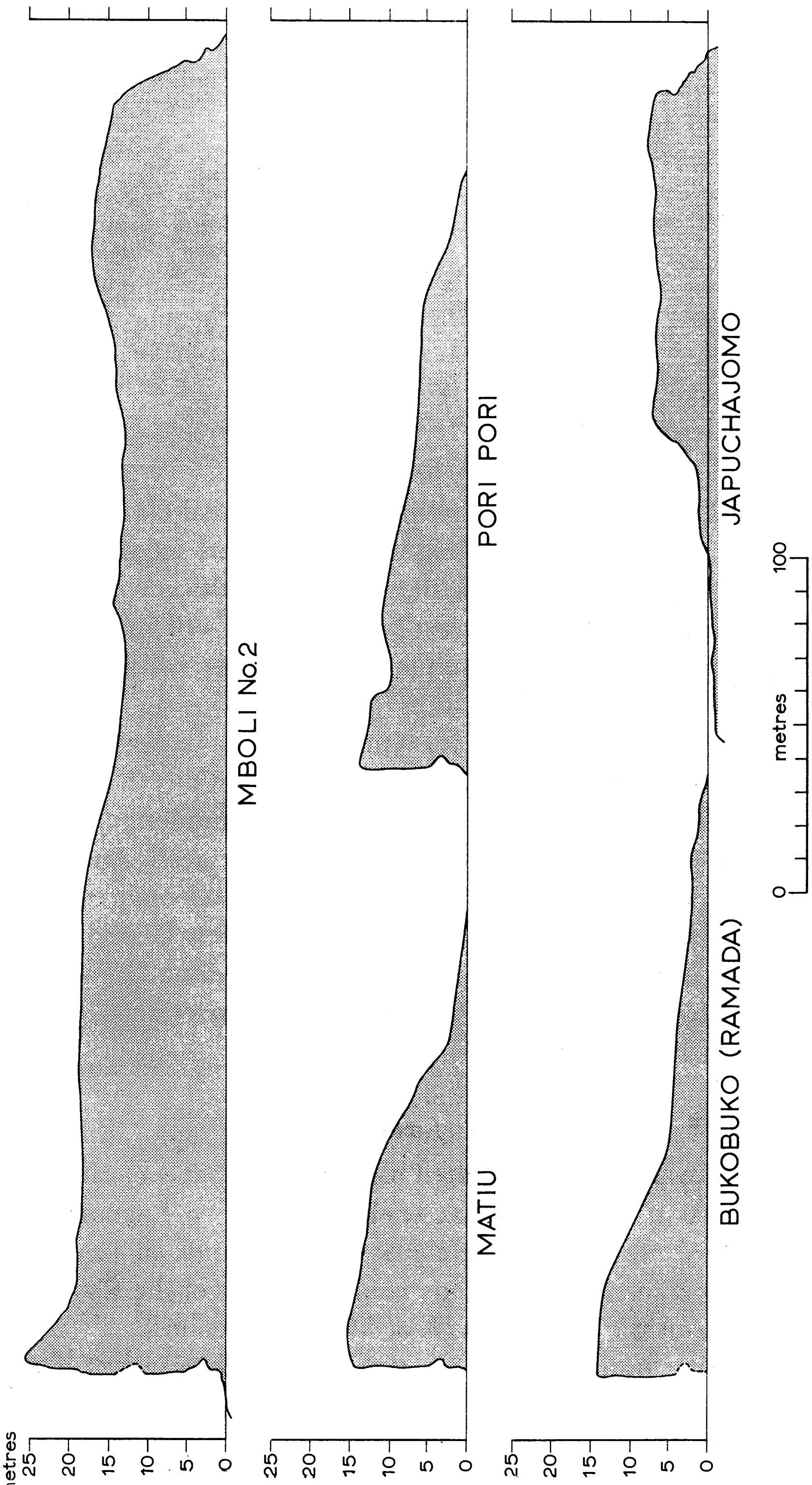

FIGURE 79. Profiles across the elevated barrier reef, Marovo Lagoon.

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each case is approximately mean sea level, obtained from biological indications of low water level and tidal-amplitude records, though the local ground relief of 0·5 to 1·0+ m is greater than the probable variation in datum. Maximum elevation at Bukobuko, Ramata Island, in the north, is 14 m; at the northern end of Matiu Island 15·25 m; at the centre of Porepore Island 13·75 m; and at the north end of Mboli Island, in the south, 25·4 m. This suggests a fairly constant elevation of 14 to 15 m for the outer barrier, except close to Gatukai, where the barrier becomes higher and wider. These elevations are much lower than those previously reported (charts show 75 m on Mboli, for example), and it is likely that earlier elevations referred to tree-tops rather than to ground level. The inner barrier is much lower than the outer: a profile surveyed across Japuchajomo Island gave a maximum elevation of 7·5 m, and parts of Samihulimu Island are at sea level. Islets of elevated reef within the lagoon are probably all less than 10 m high: a profile on Burongo Island, near Lingutu Passage, gave an elevation of 8·5 m.

West of Gatukai, the barrier islands of Raparapa, Salu and Ulukoro are charted as 'about 100 ft.' (30·5 m) high: this certainly refers to tree-tops. A profile between Salu and Raparapa did not reach a greater height than 0·74 m, and no reef limestone was seen higher than 2 m except adjacent to Gatukai itself. The barrier enclosing Wickham Anchorage continues westwards as a submerged reef 7 to 9 m deep, again emerging in the Hele Islands enclosing Panga Bay.

3·2. *Reef structure*

No studies have been made of the thickness of reef limestones or of relationships with the volcanoes. Davis (1928, pp. 398–399) argued on geomorphic grounds for upgrowth of the reefs during subsidence, adding that 'the coral seas afford no finer exemplification of Darwin's theory of barrier-reef formation than is here shown'. The shelf enclosed by the barriers is generally less than 50 m deep, and is up to 10 km wide; outside the barriers the sea floor falls steeply to great depths. Charts record many soundings of more than 350 m within 2 km of the reefs; several echotraces were made through gaps in the barrier, and in all cases the floor plunged steeply until the trace was lost at 180 to 200 m.

It is possible to suggest the thickness of reef growth on geometric grounds, by assuming the present volcanic land surfaces to be continued beneath the sea, and beneath reef deposits. Vangunu is a relatively undissected volcano of simple form, which has been photogrammetrically contoured (New Georgia 1:50000 series, sheets 8/157/12 and 8/158/9). Radial profiles from the crater to sea level were plotted at 15° intervals on semilog paper, and the cone surface gave the expected excellent fit to a straight line. These profiles were then extended beneath the sea, and used to predict the topography of the cone to a depth of 900 m. Gatukai is much less adequately known topographically, but the same technique was used at 30° intervals, and predicted bottom contours plotted. Allowance was made in these predictions for areas of Recent alluvium and of limestones above sea level, and the assumption was necessarily made that both Vangunu and Gatukai are simple cones. Figure 80 shows contours on the land surface of the two volcanoes, and projected contours beneath the sea: Robertson & Kibblewhite (1966) have found a good empirical fit between submarine slopes of isolated volcanic islands in the South Pacific and negative exponential functions of the type used here. The elevated barriers roughly parallel the projected

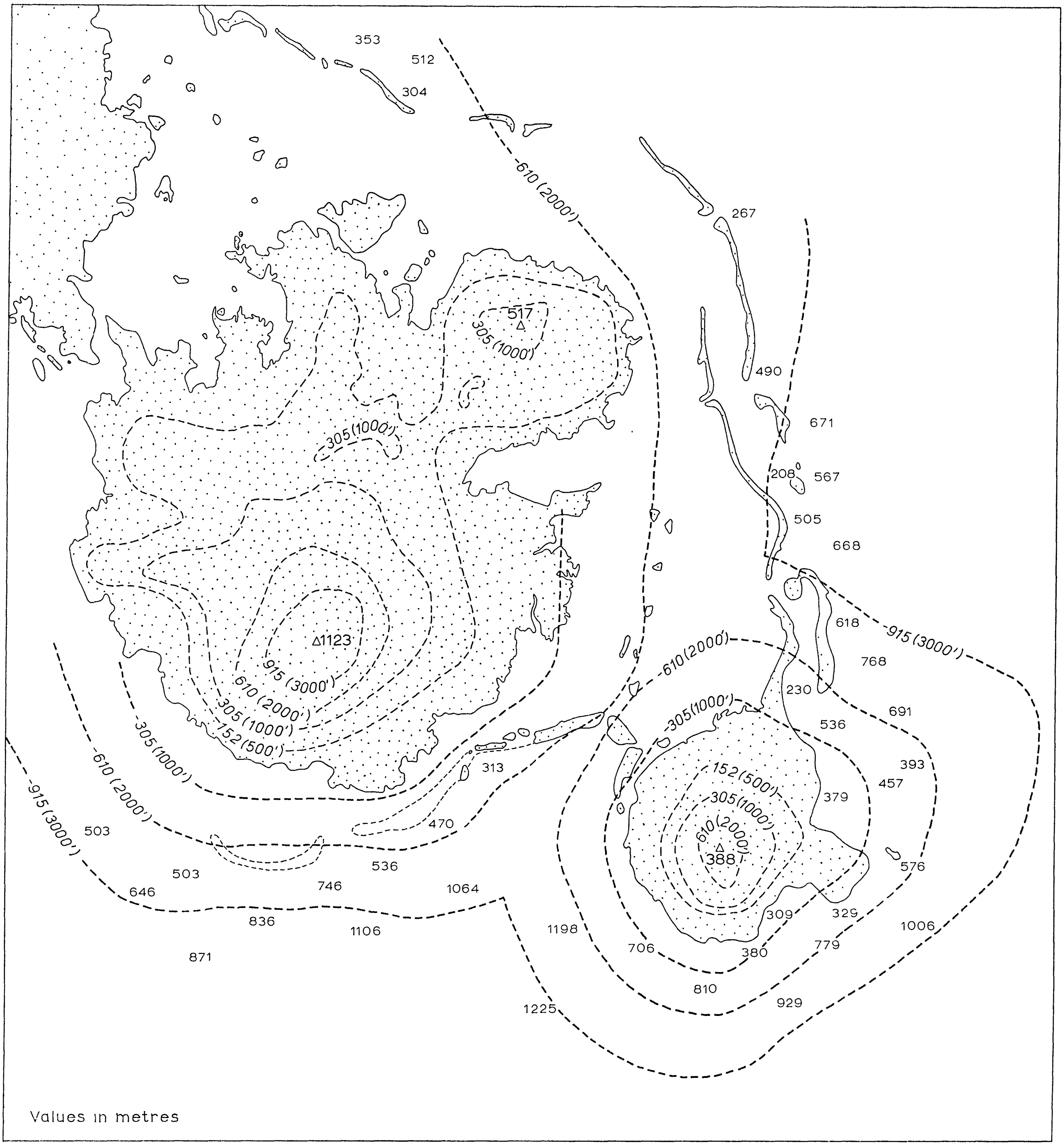

FIGURE 80. Topography and projected underwater and sub-reef contours on Vangunu and Gatukai Volcanoes.

contours, overlying the −2500 ft. (−760 m) contour north of Gatukai, and between the −1500 ft. (−460 m) and −2300 ft. (−700 m) contours west of Gatukai. Figure 80 also plots available Admiralty soundings outside the reefs: in the southern area the root mean square deviation between actual soundings and predicted contours is 690 ft. (210 m). Considering the inaccuracies inherent in the method, the lack of surveyed topographic

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data, and the inadequate location of soundings drawn from small-scale charts, this is remarkably small.

This analysis suggests that the Marovo reef prism is not less than 300 m and possibly more than 600 m thick at its outer edge. This is an order of magnitude of reef growth comparable to that on some open-Pacific atolls. At Eniwetok Atoll, for example, 1400 m of reef deposits have accumulated during subsidence since the Eocene, at a net rate of 2×10^{-5} m y^{-1} (Ladd, Ingerson, Townsend, Russell & Stephenson 1953). At such rates a reef 500 m thick would be built in 25×10^6 y, a time equivalent to that since the Miocene. If, however, the elevated reefs stand on faulted foundations the analysis will not be valid. There is at present no reason to dissent from Davis's conclusion, that the reefs have grown by subsidence, and this is supported by the gross outline of the reefs and their relationship to the drowned mainland coasts.

Provisionally we conclude that reef growth began soon after the New Georgia complex was built in the late Tertiary. Upgrowth continued over several million years to form the barrier reef, which grew on subsiding foundations in the Darwinian manner. Comparatively recent warping raised the barrier above the sea along the whole Marovo shelf, reaching a maximum in the south near Gatukai. West of Gatukai warping carried the barrier down to a few metres above sea level near the volcano and below sea level farther west. Continuing round New Georgia, warping also brought the Roviana barrier and much of its lagoon floor above sea level. The present detailed form of the barrier islands is partially determined by high-angle faulting. This is best seen in the north, where the gaps between islands are often alined along NW–SE faults. It is impossible to determine the role of faulting in the genesis of the southern double barrier and the deep trenches between such islands as Mboli and Tamba without drilling or geophysical work.

4. The lagoon

Apart from Admiralty charts at 1:250000 and a more detailed chart at 1:75000 of the lagoon between Tongoro and Lumaliha Entrances, no bathymetric data existed on the Marovo Lagoon floor before the Expedition. Topographic control was provided in the field by print lay-downs of aerial photographs at *ca.* 1:63000 prepared by the Directorate of Overseas Surveys. Echo-sounding traverses were made using a Simrad EC4 echo-sounder manufactured by Simonsen Radio A.S., Oslo, and lent by B.S.I.P. Marine Department, and a Marconi Offshore 500 echo-sounder. Two areas were studied: (1) the Marovo Lagoon proper, from Marovo Island south to Wickham Anchorage, 30 km from north to south and 6 to 13 km wide, and (2) Togavae and Gerasi Lagoons in the north, 50 km from north to south but only 1·5 to 5 km wide. Twenty-five profiles totalling 150 km were recorded in the former area, and twenty-one profiles totalling 66 km in the latter. Profiles are located in figures 81*a* and 82*a*; in the Marovo area, profiles were concentrated in the southern sector because of the existence of a more detailed harbour survey (Admiralty Chart 2927) in the north.

Profiles in the Marovo sector showed great topographic irregularity: the lagoon is here widest and deepest, but is interrupted by many linear and patch-like shoals rising steeply from the floor to form platforms at −2 to −5 m, or emerging as elevated reefs. The floor

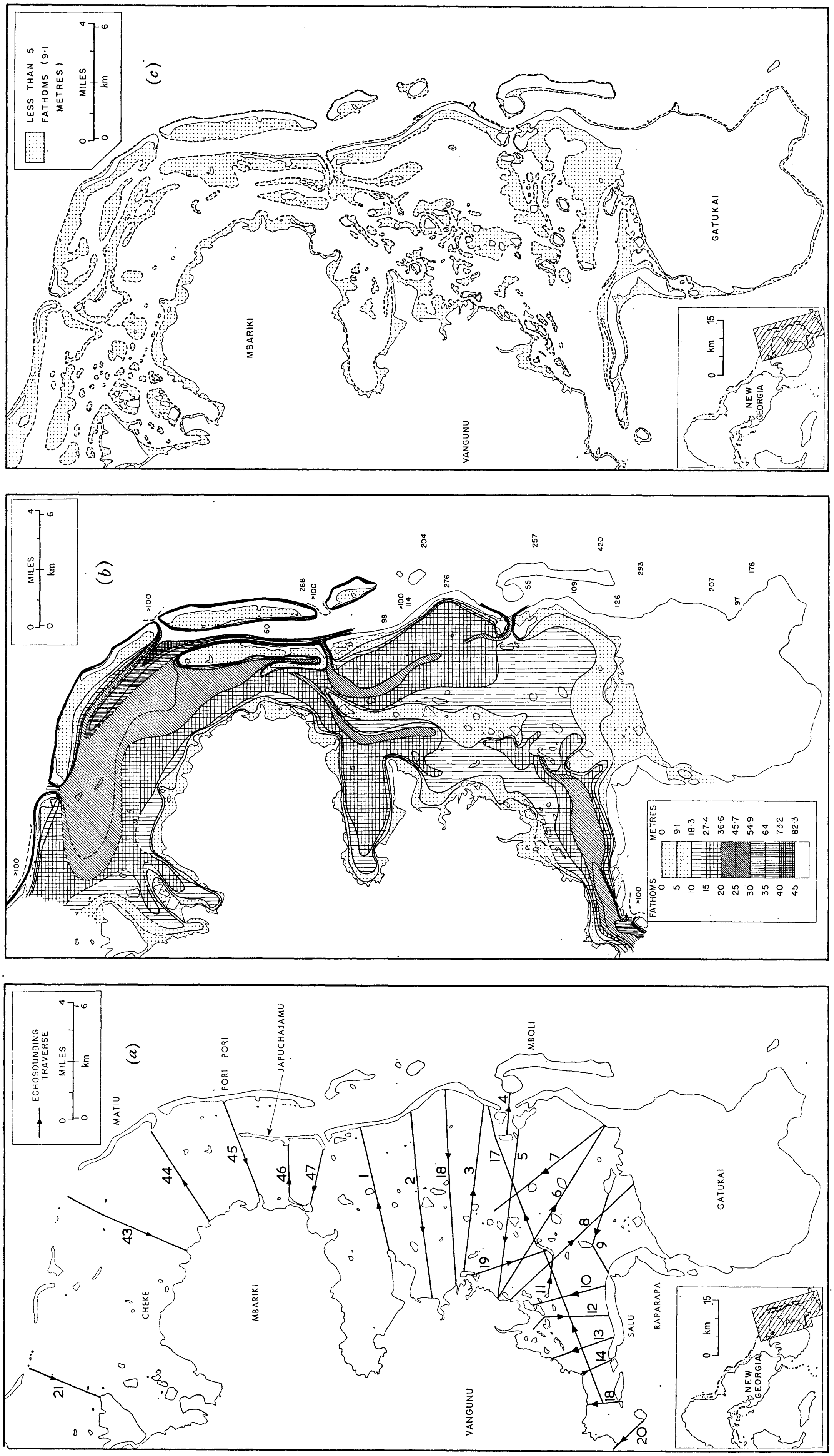

FIGURE 81. Bathymetry of Marovo Lagoon: (a) location of echosounding profiles; (b) generalized contours on the lagoon floor; (c) areas less than 5 fm (9·1 m) deep.

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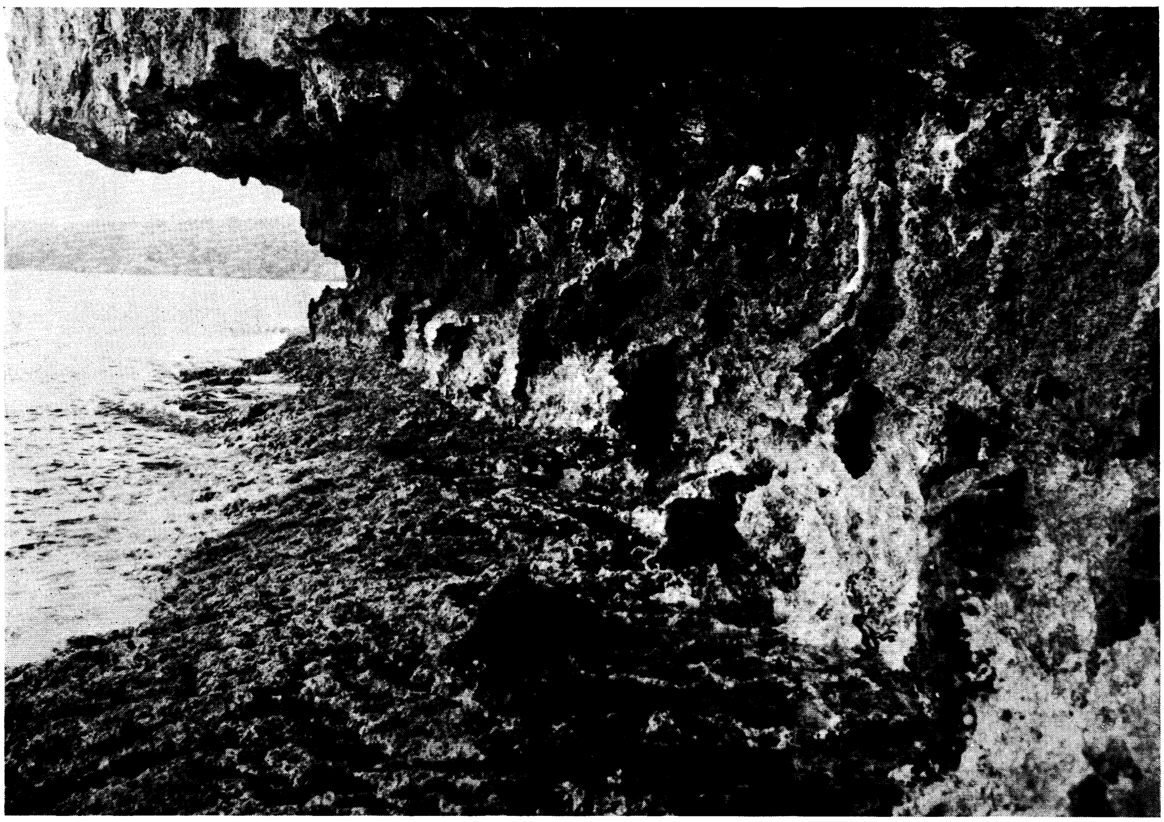

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FIGURE 86. The 4 m notch at Matiu Island, showing the faceted visor and dripstone columns.

FIGURE 87. The 4 m and lower notches at Matiu Island, showing the exposure of brown pipe-limestone columns by erosion of reefrock.

(*Facing p.* 392)

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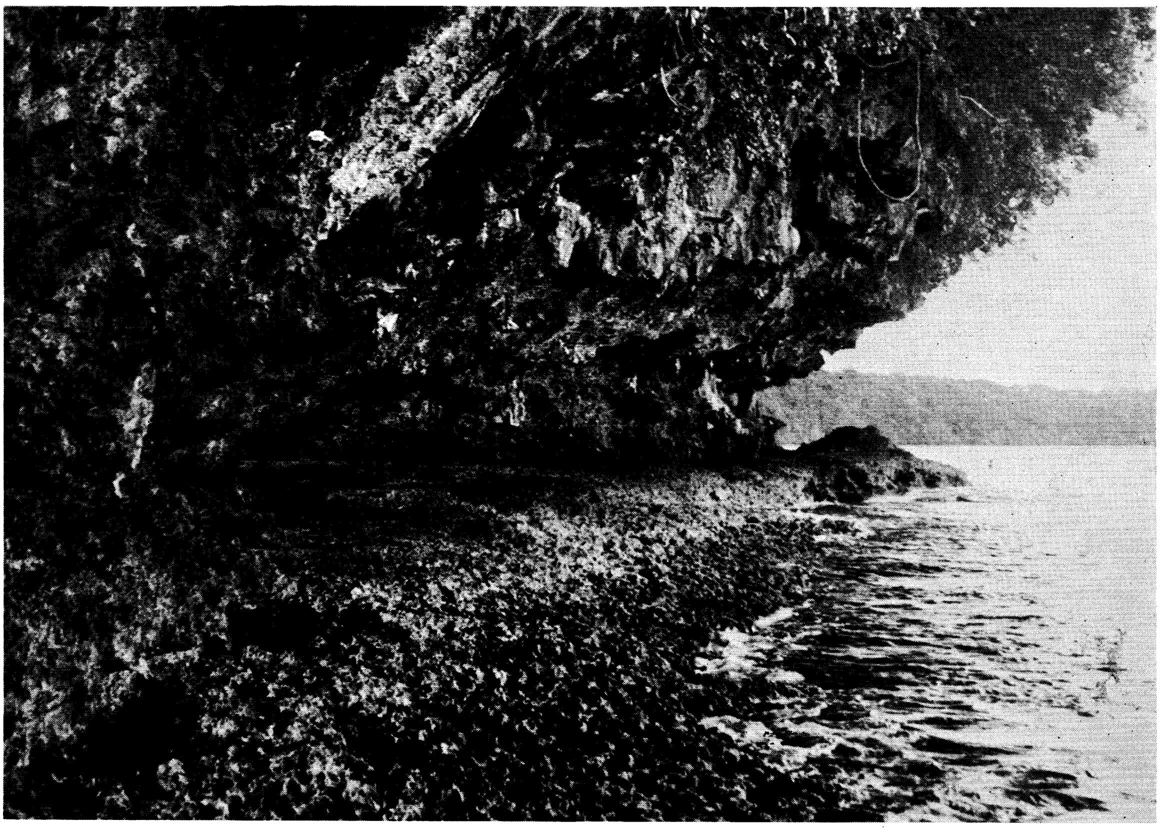

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FIGURE 88. The 4 m notch at Matiu Island, floored by a layer of algal limestone which now forms a conspicuous ledge between the 4 m level and the lower contemporary notch.

FIGURE 89. Massive overhang formed by deep erosion of the 4 m and contemporary notches at the south end of Matiu Island.

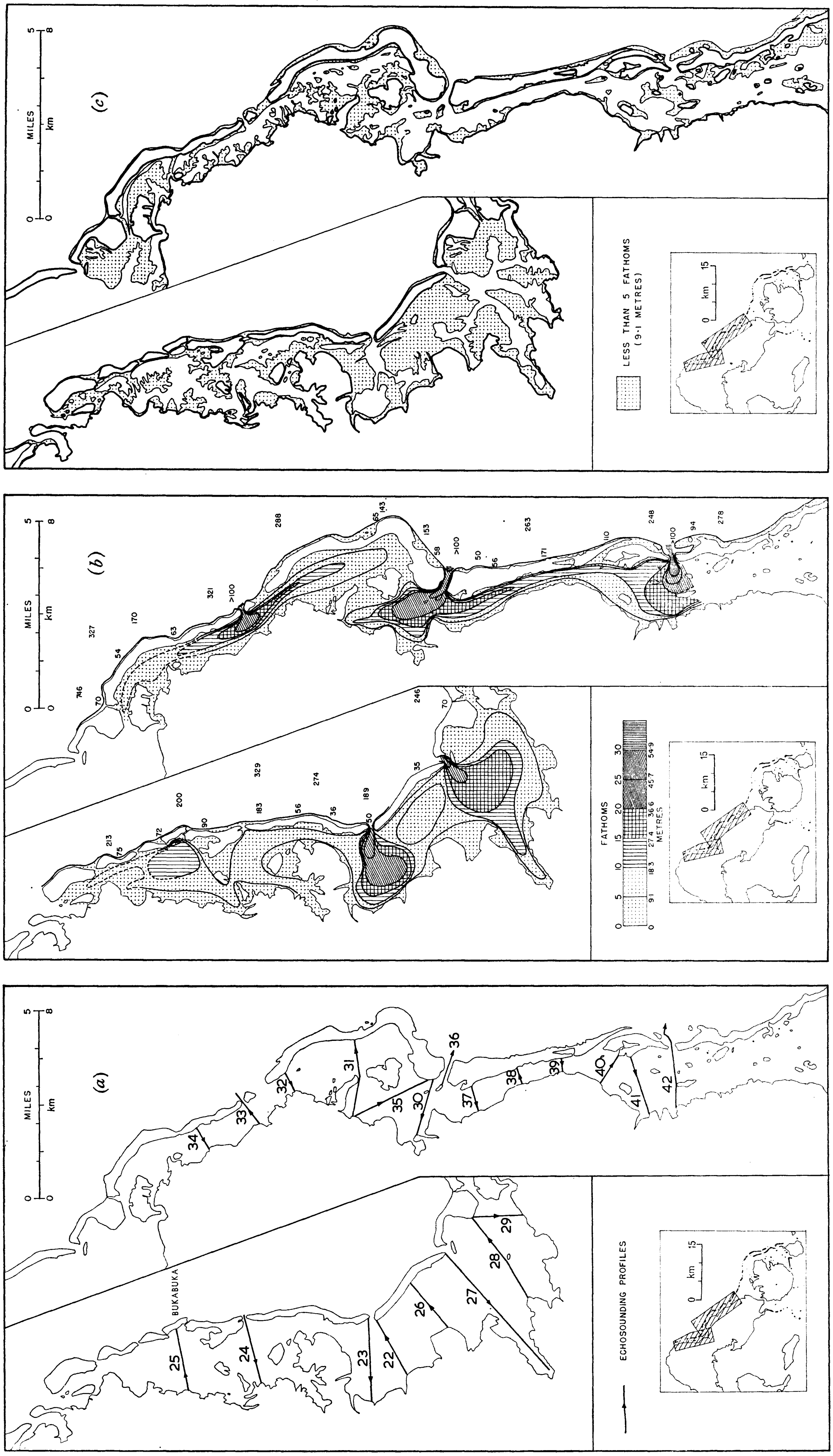

Figure 82. Bathymetry of Togavae and Gerasi Lagoons: (*a*) location of echo sounding profiles; (*b*) Generalized contours on the lagoon floor; (*c*) areas less than 5 fm (9·1 m) deep.

between these ridges is generally smooth. Because of the complexity of relief and the wide spacing of profiles, detailed contouring is not possible. Figure 81 *b*, therefore, plots generalized bathymetric contours on the lagoon floor, i.e. ignoring the steep-sided shoals. Notice the existence of a broad sill between Gatukai and Vangunu, not deeper than 15 fm (27·4 m), with deeper basins to the south in Wickham Anchorage, with depths increasing to more than 30 fm (55 m), and to the north, where the deeper areas are generally 20 to 30 fm (36 to 55 m). The area between the inner and outer barrier reefs was too deep for profiling with the available equipment, except between Porepore and Japuchajomo (profile 45), but depths of more than 100 fm (180 m) are charted. Note too the tongue of shallow water (less than 10 fm (18 m)) extending north–south in the centre of the lagoon, surmounted by islands, and forming at the southern end of Japuchajomo virtually a third barrier. Using the air photographs and the echotraces it is possible to draw a third map (figure 8*c*) showing areas less than 5 fm (9·14 m) deep. Because the shoals are steep-sided most of these areas are also less than 2 m deep: 5 fm was chosen as a critical depth for mapping to include the rather deeper ridge summits in the area between Lumaliha and Tongoro Entrances. Here the air photographs show elliptical ridges with central hollows and rims at 4 to 5 fm (7·3 to 9·14 m).

The northern study area, Togavae and Gerasi Lagoons, is very different. The lagoon is narrower and also shallower. Profiles were treated in the same way as for Marovo Lagoon. The generalized bottom contours (figure 82*b*), show deep water only at five major gaps in the elevated reef barrier: each gap opens lagoonward into a basin with depths of more than 20 fm (36·6 m). Between the basins, behind uninterrupted barrier reef, the lagoon floor is shallow, mostly less than 10 fm (18·3 m), and over large areas, especially in the north, almost intertidal. The map of areas less than 5 fm (9·1 m) deep (figure 82*c*) shows a more intricate pattern: again the shoal areas are steep-sided and fall rapidly to the deeper floor.

This irregular bottom topography is interpreted as a karst erosion landscape developed during low sea levels on reef limestones and lagoon deposits and later submerged. The recency of the latest submergence is indicated by the unimportance of fluvial deposition at the present coastline, in spite of high relief and rainfall. The long inlets north and south of the Mbariki Peninsula, though floored by muddy sediments, are still steep-sided and deep (10 to 15 fm, 18 to 27 m), and the only extensive area of fluvial deposition is the delta of the Gevala River, draining south-west from Vangunu into Kolo Lagoon. During the sediment programme 181 bottom samples were taken in the southern study area and 69 in the northern; preliminary study of these indicates that terrigenous sediment is only important near the mainland shores, and that most of the lagoon is the site of carbonate mud deposition in partly enclosed basins. The drowned tops of ridges at depths of up to 5 fm (9·1 m) must result from the submergence of erosional bevels: coral growth on these submerged ridge flats is rare, and sediment cover is sparse. The New Georgia lagoon profiles contrast with those from the elevated lagoon on Rennell, south of the Solomons, where the profiles are marked by smooth flat floors (Christiansen 1964). The elliptical ridge structures with central hollows, on one of which stands Matiu Island, are similar in form and dimensions to those found in the central British Honduras barrier reef lagoon, in the Caribbean (Stoddart 1963, figure 36), which have been interpreted as being formed by slight folding.

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5. Changing land and sea levels and barrier morphology

The elevated reefs of the outer barrier are of variable form (figure 79). At Bukobuko (Ramata), Matiu and Porepore, the elevated barrier is asymmetric with a steep face to seaward and a gentler incline lagoonward. There is some evidence of a notch on the lagoon side between 1·4 and 2·5 m, and again at 4·6 m (Ramata) and 6·1 m (Porepore). Mboli shows a central depression below a clear bevel at 18 m, and the lagoon shore is steep and quite conspicuously notched at 1·5 and 3·7 m.

5·1. *Elevated notches*

The seaward side of outer barrier islands is generally vertical or overhanging, and deeply notched by elevated intertidal solution notches. These were measured at Matiu and Mboli Islands (figure 83). The largest and most extensive is at +4 m; it has a maximum depth of 15 m (though usually 5 to 10 m), and a vertical amplitude at its mouth of 5 to 7 m. It is usually flat-floored, except near the mouth, where contemporary salt-spray erosion leads to deep pitting and degradation of the lower rim. The visor or upper rim is rarely a simple feature: it usually has, in profile, two concave sections, and sometimes suggestions of several more (figures 86, plate 60 and 89, plate 61). The back wall of the notch is etched into a reticulate pattern of horizontal grooves and ridges, similar to those described from elevated limestones in Sarawak (Wall & Wilford 1966). Dripstone deposits form stalactites, stalagmites, and sometimes columns from floor to roof up to 1 m in diameter. Stalagmites often have concave tops containing pools of potable fresh water. The floor of the notch is in places formed by algal limestones presumably of the same age as the notch itself (figure 88, plate 61). Corals identified in the raised limestones in which the notch is cut include *Favia*, *Goniastrea*, *Leptoria*, *Symphyllia* and lobate *Acropora*. The +4 m level is not well developed on the lagoon sides of islands, and it disappears in channels and gaps in the barrier. Nor is it well-developed on lagoon islands, though a notch at this level is found on the west side of Japuchajomo, and very weakly on its east (seaward) side (figure 79). On Matiu Island the 4 m notch has been used by local people, at least in the past, for exhibiting the skulls of their dead, though this practice is not mentioned by Russell (1948).

Below the 4 m notch a second small notch is sometimes developed, as in Matiu profile no. 3 (figure 83). Partly this results from the erosion of a notch at present sea level, and partly from the outcropping of the more resistant algal limestone on the 4 m notch floor. The modern notch lies above the level of encrusting *Porolithon*, which often forms a slight shelf at the foot of the cliffs. The surface of this notch is highly irregular, with a population of chitons and *Nerita*. The notch is deepest at 1 to 2 m above low water (tops of living coral); it is well developed round many of the lagoon islands, and on the seaward side of more protected barrier islands such as those between Lumalihe and Karikana Islands. Corals exposed by erosion of this lower notch at Matiu include *Favia*, *Leptoria*, *Symphyllia*, *Hydnophora*, *Platygyra* and (?) *Mycedium*.

Above the 4 m notch at Matiu and Porepore the cliff face is vertical or markedly overhanging, often with possible traces of shallow notches, especially when seen in profile. The cliff top is bevelled at +15 m. At Mboli, however, there is another deep and prominent notch, separated from the 4 m notch by an estimated 5 m of cliff face. This upper notch

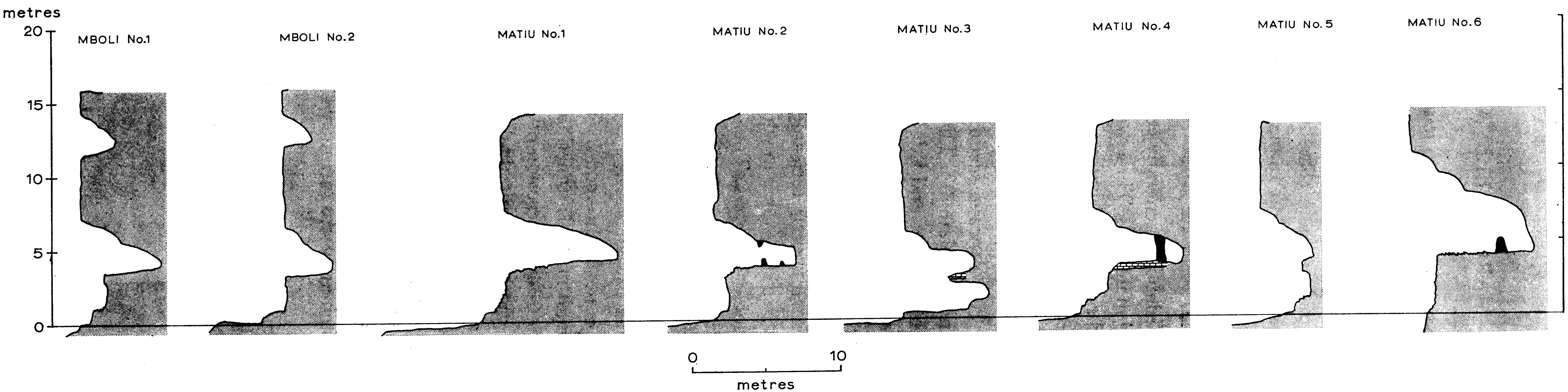

FIGURE 83. +4 m notch at Matiu and Mboli Islands, Marovo Lagoon.

has an amplitude of 4 to 5 m, and is provisionally referred to as the 12 m notch. It was impossible to gain access, or even see this notch with ease, from below, and quite impossible, on an overhanging 25 m cliff face, from above; from the sea the notch is largely obscured by vegetation hanging down from the crest, and was only seen from a distance. The height is therefore approximate, and it is possible that the high notch stands at 18 m and correlates with the pronounced bevel on the backslope of Mboli.

The 4 m notch where measured correlates closely with the notch at a similar elevation and comparable size at Lingatu Point, Banika Island, 120 km to the east (Stoddart 1969). It is tempting to correlate the two, especially as dripstone deposits of the same size are found in each. The 4 m level is not well developed on other Solomon Island shores, however, and it is certainly variable within the Marovo area. On Matiu Island, for example, the 4 m notch may be followed laterally southwards, where it falls, 2 km from the south end of the island, to +1 m. I am also not convinced that the 4 m level is found throughout the Togavae and Gerasi barriers, though a notch at this elevation is certainly present in places, as on the south side of Mongo Passage. The emergence of the 4 m notch must thus be ascribed to tectonic rather than eustatic causes. As previously argued (Stoddart 1969), the depth of the notch suggests a stillstand of the order of 3 to 15 thousand years; similarly, the small notch at present sea level suggests a stillstand of not more than 1000 years.

5·2. *Submerged levels*

Apart from the evidence of drowned ridge crests in the Marovo Lagoon mentioned in §4, a search was made at Matiu Island with Dr S. A. Wainwright for drowned features on the seaward face. Three profiles were studied by SCUBA diving.

The first site was immediately north of Matiu (figure 84, profile 1): a leadline profile was measured to −15·5 m, and direct observation carried to −30 m. Apart from small ledges there are no conspicuous bevels, but there are numerous overhangs up to 2 m deep and 2 to 3 m high. The face is vertically grooved: Wainwright measured vertical ridges 3 and 6 m apart at a depth of 6 m, with grooves between them 2 to 2·5 m deep; at 12 m depth the ridges were 12 m apart and the groove 4·5 m deep. Alcyonaceans and algae abound on the rock surface; the dominant coral is a lobate *Porites*, with a *Pachyseris*, *Echinophyllia*, occasional encrusting *Acropora*, *Lobophyllia* and other corals.

The second site was south of the northern end of Matiu (figure 83, profile 2), with observation to −45 m. Here there is a narrow intertidal platform at the base of the cliff, edged with *Porolithon onkodes* and *Neogoniolithon myriocarpon*, and then a steep fall to a ledge 15 to 20 m wide at a depth of −10 to −15 m. This ledge is covered with living *Halimeda* (*H. opuntia*, *H. discoidea*, *H. taenicola*) and *Halimeda* sand, with scattered living and dead corals. These include large colonies of *Echinophyllia*, tabular *Acropora*, dead staghorn *Acropora*, and delicate *Montipora* and *Pachyseris*. There are few alcyonaceans. Wainwright collected the hydrocorals *Distichopora* and *Stylaster* in deeply shaded crevices from the surface to −40 m. The wall above the −10 to −15 m ledge is not dentate, as in the first profile, but is irregular with small overhangs. Encrusting algae are common, with some small live corals, sponges, alcyonaceans, hydroids and ascidians. The wall is undercut by 2 to 3 m immediately below the intertidal terrace. At the end of the −10 to −15 m terrace, the wall plunges almost vertically to a second, narrower, more steeply inclined terrace at −45 m. Irregularities in the wall are less than 1 m deep; the surface is covered with encrusting algae, with *Halimeda* sand in pockets but no living *Halimeda*. Corals are not common on the wall, and are rare below 27·5 m. Gorgonians grow on the −45 m terrace. Below the −45 terrace the wall descends vertically as far as can be seen, down to at least −60 m.

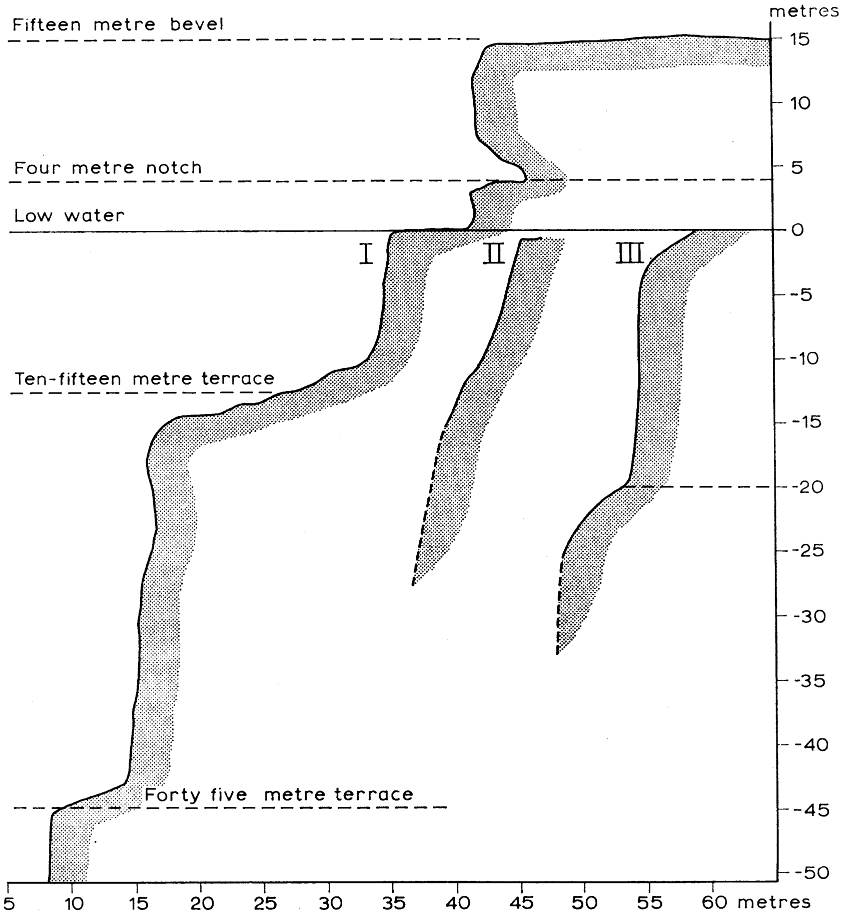

FIGURE 84. Submarine profiles, seaward face of Matiu Island, Marovo Lagoon.

The third site is farther south on the Matiu seaward side, where the intertidal terrace is exceptionally wide (figure 84, profile 3). The edge of the intertidal terrace has considerable coral growth, with *Porites*, *Montipora* and *Acropora*. The slope below is steep, with a small terrace at −9 m, and a notch 2 m deep at −15 m. Large gorgonians, and colonies of *Acropora*, *Millepora*, *Merulina*, *Leptoria* and *Pachyseris* are found on the wall, the corals being sparser and more delicate at −15 to −23 m. At −30 m the wall is again dentate, with ridges 6 m apart and grooves 2 m deep. Tapping with a hammer started slumping of reef material which began a debris slide of sand-size material down one of these grooves, and this slide continued during the rest of the dive. Below −30 m the wall becomes almost vertical, and though live corals are not common they are more abundant than on the other profiles at this depth.

These three profiles show marked terracing in some places but not in others. The −10

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to −15 m terrace was seen in other dives, but not the −45 m terrace. As with the +4 m notch, the −10 to −15 m terrace is of variable depth, and appears to have been affected by post-terrace warping or faulting: at one place on Matiu it rises to sea level and is terminated by a high-angle fault in the cliff face. Elsewhere the −10 to −15 m terrace is absent, and the intertidal platform is deeply undercut and fissured. Undercuts of 3 to 6 m were seen at depths of 6 to 8 m, and collapse of the intertidal platform is certainly frequent.

It would be premature to correlate the submerged Matiu terraces with the 8 to 10 fm (15 to 18 m) terrace described in recent years on the seaward slopes of atolls, particularly as in New Georgia its level is certainly controlled by at least local tectonics. On atolls, furthermore, it is not certain that the 15 to 18 m terrace on atolls is an erosion feature; it could equally be a growth feature resulting from depth-differences in coral growth.

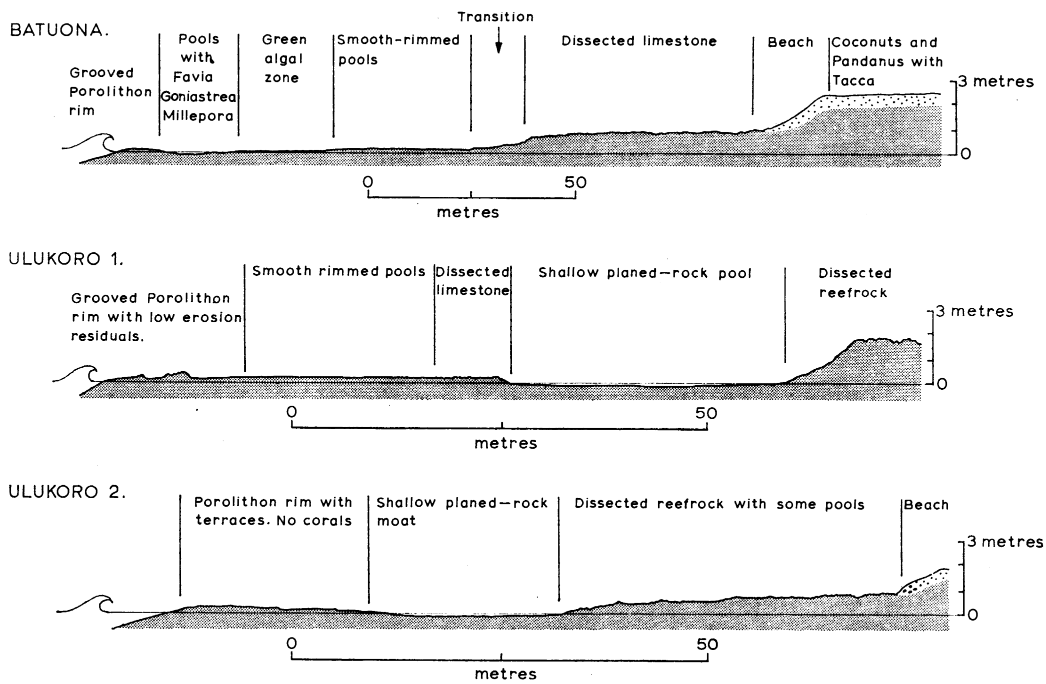

FIGURE 85. Reef-flat profiles at Batuona and Ulukoro Islands, Wickham Anchorage.

5·3. *Sea-level reef flats*

Immediately west of Gatukai the reefrock forming the south side of Wickham Anchorage rises in low headlands notched at the +4 m level, as at Gauve Island and the east end of Raparapa. The level of the elevated reef falls rapidly westwards, and most of Raparapa, Salu and Ulukoro are less than 2 m above mean sea level. Clastic sediments become increasingly important in the land surface westwards, and Batuona Island is entirely detrital, perched on an intertidal eroding reef flat. The broadleaf forest of the elevated Marovo barrier is replaced on these detrital islands by a woodland of tall *Casuarina*, coconuts and *Pandanus*, with *Tacca*, and *Pemphis acidula* on reefrock residuals on the shore. Figure 10 shows profiles of the seaward flat on this southern low barrier.

Batuona is a detrital island standing on a platform of partly eroded reefrock at up to 1 m above low water. The outer flat, 90 m wide, is close to low water level. It is a smooth-eroded surface with algae and no corals, rising at its outer edge in a low terrace of *Porolithon*-rimmed pools over which waves spill at low water. Some small corals survive at the lower levels. The inner, higher reef limestone is pitted and creviced.

At Ulukoro the reef flat is up to 100 m wide. Eroded reefrock rises up to 2 m at its inner end, and is partly covered by beach deposits; residuals of eroded reefrock outcrop in places across the flat as far as the edge, which is encrusted with *Porolithon onkodes* and *Neogoniolithon myriocarpon*. The rock surface stands at about mean sea level, except for pools or moats, which, with undercut walls, are up to 0·5 m deep. These have flat planed floors, and are subject to considerable heating at low water; they contain no corals.

These profiles resemble the flats at Banika Island, Russell Group, more closely than the rest of Marovo (Stoddart 1969). The flats are clearly eroding from a higher level, but are not yet low enough for coral growth. On the lagoon side of Ulukoro there is generally a lower shelf up to 30 m wide, with growing corals. Tidal and subtidal flats were examined at many other places on the north-east side of New Georgia, particularly on the outer barrier where emergent reef has been eroded away. These flats are usually planed rock surfaces, with a thin cover of sand and rubble, their most striking characteristic being the field of dead corals found on them. These corals are still in the position of growth, growing at levels where they are emersed at lowest low water.

5·4. *Stratigraphy and structure*

The elevated reef limestones forming the barrier islands are extremely recrystallized, and it is often difficult to identify organisms in hand specimens. In general character the rock is comparable to the Older Limestone of Aldabra Atoll in the Indian Ocean, but it is less eroded than the elevated *feo* of the Tuamotus or the raised reefs of Mahé, both of which have been radiometrically dated as last interglacial (Veeh 1966). After elevation, the limestone was subject to karst erosion, with the formation of numerous solution holes: these holes were filled with sediment which has lithified to form a brown pipe-limestone considerably more resistant to solution-weathering than the reef-limestone matrix. Similar pipe-limestone was also seen in elevated reefs at Lingatu, Banika Island, and has since been found on Aldabra Atoll, Indian Ocean (Stoddart & Wright 1967). Beach cobbles of a similar rock have been found on a Caribbean atoll where pipe-limestone does not now outcrop (Stoddart 1962, p. 106). This recrystallization and formation of pipe-limestone took place when sea level was lower than at present, as the pipes descend below present sea level.

With the rise of sea level the high notches were cut, probably first that at +12 m (though this may have been locally upwarped), then that at +4 m, which is also demonstrably warped. Apart from the fact that there was a relative rise in sea level, it is not possible to distinguish tectonic and eustatic influences on present evidence. Solution-erosion at these levels cut deep notches, exposing pillars of brown pipe-limestone as pseudo-stalactites and pseudo-stalagmites in the roof and on the floor of the +4 m notch (figure 87, plate 60). These pillars are being exposed on the shore at present, both on cliffed shores, as at Matiu, and on low shores as at Salu and Raparapa west of Gatukai. On these lower shores the brown limestone often forms horizontal sheets filling joint planes and fissures as well as solution holes. At the time of formation of the +4 m notch, algal limestones were laid down on its floor, in places overlying bevelled pipe-limestone; and subsequently various dripstone deposits have formed on the roof and walls of the notch.

The influence of faulting in determining island outline has already been mentioned (§3·2); smaller-scale fracturing has also been important in controlling detailed shore morphology. High-angle fractures in the cliff face in places displace the summit level of the elevated reef. Some are older than the +4 m notch, and some have also displaced the −10 to −15 m terrace. Most of the fracturing is, however, more recent. Deep undercutting of the +4 m notch leads ultimately to collapse of the overhanging cliff, in sections 50 to 100 m long and 10 to 20 m deep, in places blocking the use of the notch as a route along the cliff-face. Collapse of the modern intertidal platform, which is also deeply undercut, is frequent: this platform varies considerably in width, from zero to 100 m, and is frequently interrupted by wide gaps where sections have collapsed. The reasons for the great variation in width of the flat where collapse has not occurred are not known; in one place on Matiu the flat is so wide that trees are able to grow in front of the +4 m notch and cliff face.

6. Conclusions

1. New Georgia is a volcanic complex surrounded by reef deposits. These reef deposits are partly elevated to form raised barrier reefs enclosing Marovo and Roviana Lagoons, and partly drowned to form a submerged barrier south of Vangunu.

2. Reef growth clearly postdates the formation of Vangunu and is partly contemporary with that of Gatukai. The reefs, unless faulted, may be at least 300 m thick, which would imply growth since the late Tertiary.

3. The Marovo elevated barrier reef has a constant altitude of +15 m, except in the south where it rises to +25 m. West of Gatukai it falls to sea level, and becomes submerged. The inner barrier reef and lagoon islands are lower than the outer barrier.

4. The lagoon floors are irregular, with depths of 20 to 30 fm (37 to 55 m) between steep-sided ridges in the southern Marovo lagoon. The northern lagoons are narrower and shallower.

5. The outer barrier is notched with elevated tidal terraces at +1, +4 and (?) +12 m, and there are submerged terraces at −10 to −15 and −45 m. Variations in level and known instability suggests that these result from crustal movement rather than eustatic sea-level changes.

6. Modern coral growth is limited by vertical submarine topography and the lack of suitable substrates beneath the sea. Corals on the intertidal flat are often dead, but those at deeper levels, though not luxuriant, are alive.

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Koete, of Nggela. This work was carried out during the Royal Society Expedition to the British Solomon Islands Protectorate 1965, in the programme of the Marine Party (leader Professor J. E. Morton): I thank the Royal Society for the opportunity to take part in the expedition, the Ministry of Overseas Development for financing my participation, and the University of Cambridge for leave of absence. I am grateful to Dr H. B. S. Womersley, Dr A. Bailey and Dr P. E. Gibbs for their comments on this paper.

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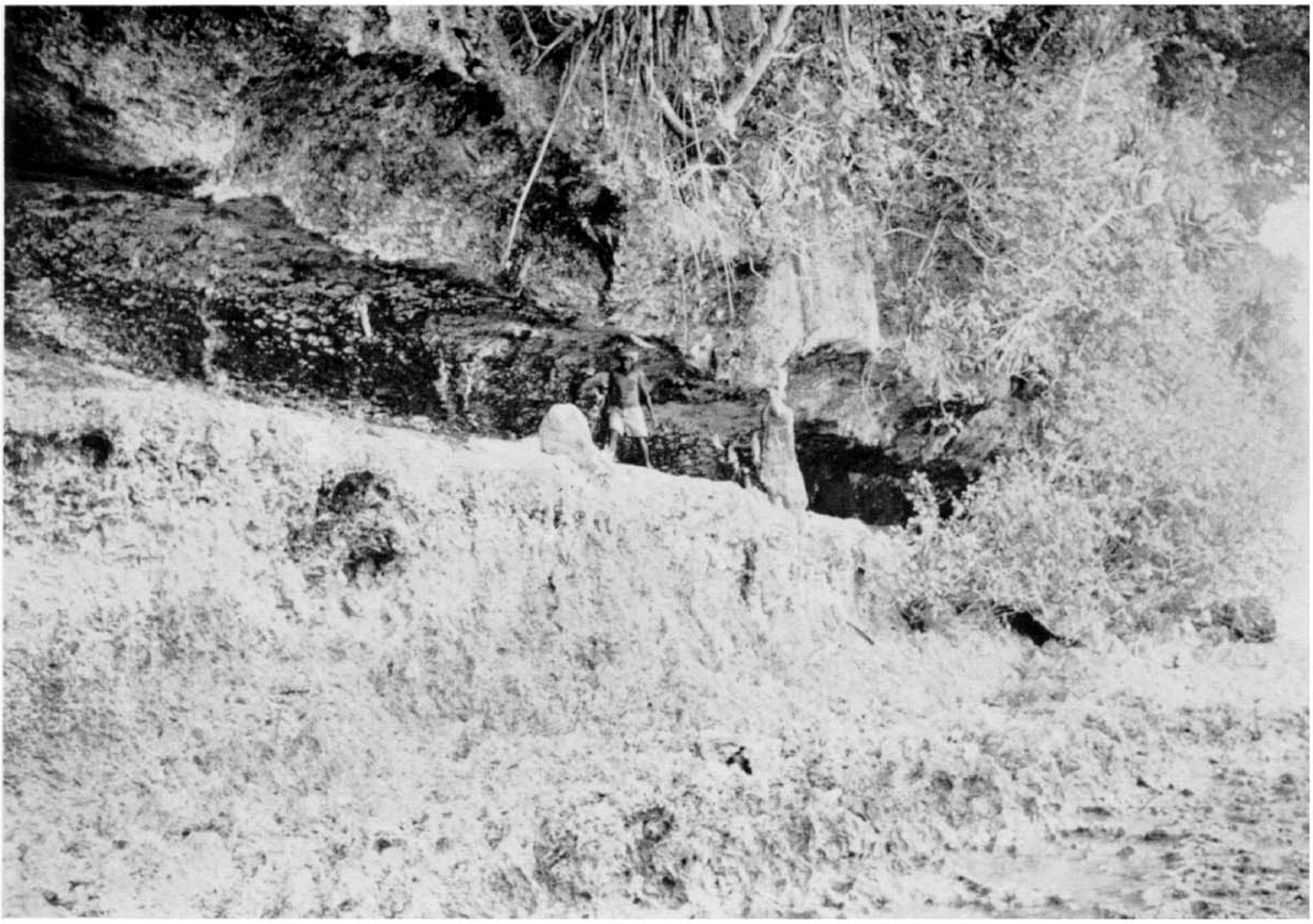

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FIGURE 86. The 4 m notch at Matiu Island, showing the faceted visor and dripstone columns.

FIGURE 87. The 4 m and lower notches at Matiu Island, showing the exposure of brown pipe-limestone columns by erosion of reefrock.

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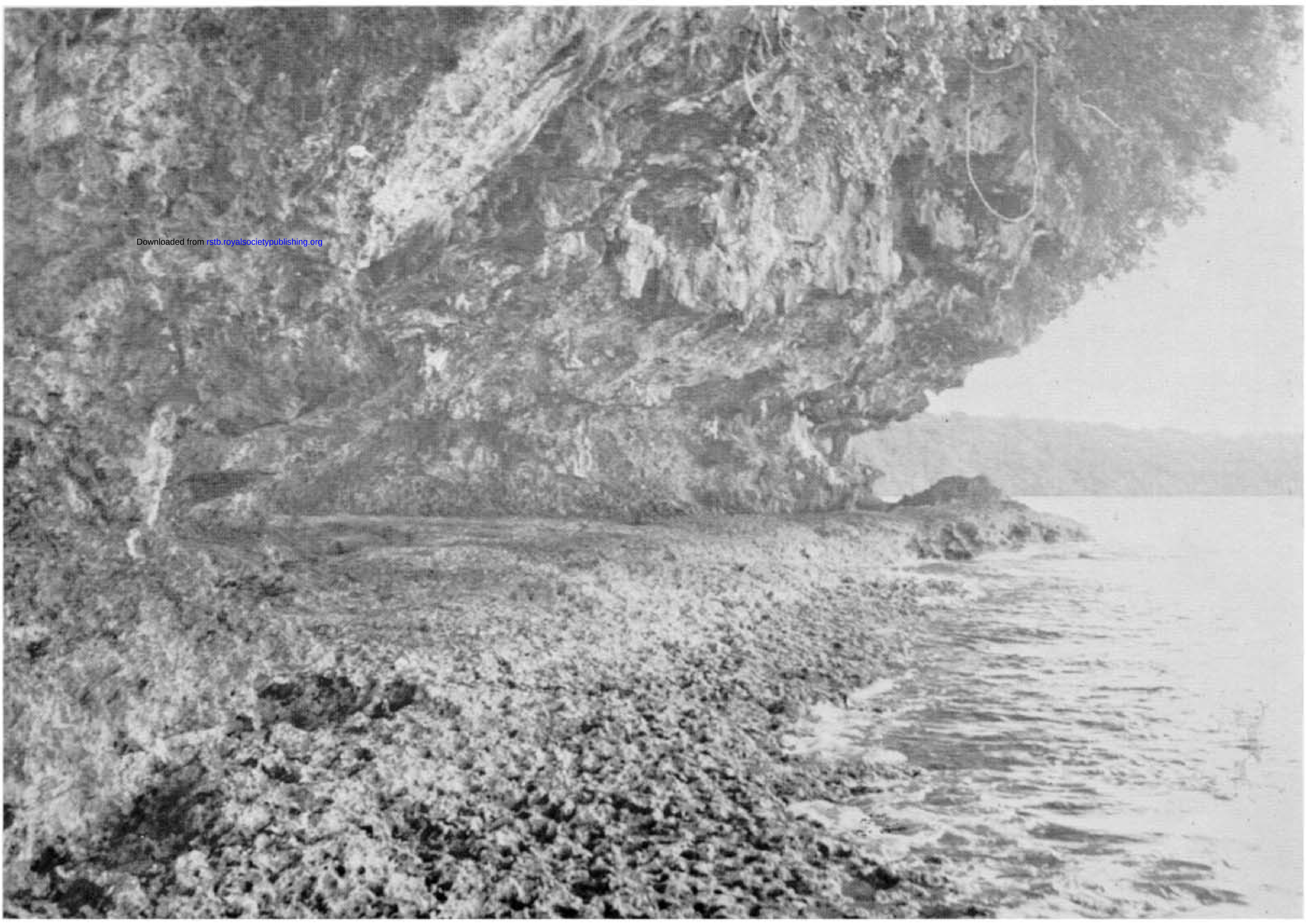

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FIGURE 88. The 4 m notch at Matiu Island, floored by a layer of algal limestone which now forms a conspicuous ledge between the 4 m level and the lower contemporary notch.

FIGURE 89. Massive overhang formed by deep erosion of the 4 m and contemporary notches at the south end of Matiu Island.