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CORAL REEFS OF THE NEW HEBRIDES, MELANESIA, WITH PARTICULAR REFERENCE TO OPEN-SEA, NOT FRINGING, REEFS

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SUMMARY

The New Hebrides island arc is divided into two island chains and an inter-arc basin, preceded by a deep trench on the western side of the structure. This location of the trench means a reversed polarity of the system, the normal polarity including, in the western Pacific, a trench on the eastern side. The polarity was probably normal before the mid-Miocene, and reversed later on. The reversal was accompanied by a migration of the volcanic activity from the western island chain to the eastern chain, where it is now found. Tectonic disturbance continues to be active in the New Hebrides.

On the islands bearing the first generation of volcanoes, as Erromango, Efate, Malekula and Santo, raised terraces of Plio-Pleistocene reef limestones are beautifully exposed. In places, as at Efate, several sets of coral terraces are found; they may result either from a general uplift associated with alternations of transgressions and regressions, or from faulting. The terraces may have remained horizontal or have been tilted. The lowest terrace lying at 4 metres in Erromango Island around Cook Bay may be related to the last interglacial high sea-level. All these old reefs are fringing reefs, and grew either around volcanoes or around previously raised fringing reefs. Present-day fringing reefs, often accompanied by sand cays, exist around all these islands, one of the finest being at Aneityum.

Two reefs, however, belong to another type. They are very low structures in which the basement is concealed as in atolls, although they deserve to be called orientated coral banks rather than true atolls. The smaller one is Cook Reef, lying between Efate and Epi in the centre of the archipelago. It faces South-South-East, includes a shallow lagoon, and does not bear an island which is uncovered at high tide. It was observed only from aircraft at low altitude and was not investigated in the field.

The larger one is Reef Island, in the Banks Group at the northern end of the archipelago: it was studied in the field by the writer and F. Doumenge in July, 1971. Reef Island, which will be described here in some detail, faces East, that is towards the trade wind swell. As a whole, it is not a present-time reef, but consists of slightly emerged corals in the position of growth, up to high spring tides: these have been dated by radiocarbon at between 4150 and 6640 years (6 samples: CNRS Laboratory, Gif, France). A cemented rampart includes coral blocks of older age which were not found *in situ*. The reef is being now corroded by coastal weathering. The distribution of surficial features shows, from East to West, a windward row of islands made of emerged reef and rampart; a medium row of sandy islands with some beach-rock; a shallow lagoon coated with sand and turtle grass and a leeward sand cay with recurved sand spits and a pond in which some mangrove trees live. Reef Island was inhabited until 1939, and then abandoned after a hurricane which caused seas to wash over it.

I. GENERAL TECTONIC FRAMEWORK OF THE ARCHIPELAGO

The New Hebrides archipelago (Fig. 1), a Franco-British condominium, which structurally extends in the north to the Santa Cruz Islands belonging politically to the British Solomon Islands Protectorate, is one of the numerous seismic island arcs which girdle the western Pacific from the Aleutian Islands to the Kermadec Islands. But, whereas the structure of these seismic arcs is comparatively uniform in the north and in the south, with a deep trench on the oceanic side, a frontal arc bordering it, and a volcanic chain on the inner, continental side, the succession of features is, in several instances, complicated and modified in the central area, that is, in Indonesia and in Melanesia. So far as the New Hebrides are concerned, the major anomaly, from which the others derive, is that the position of the deep trench is reversed and lies on the western, inner side. The geophysical framework of these islands has been discussed recently in an excellent paper by Karig and Mammerickx (1972). This paper will be summarized here to allow a better understanding of the coral reefs, which overlie the volcanic rocks forming the basement of the islands.

The trench is divided into two parts, North and South, exceeding 5,000 metres in depth, between which a somewhat shallower area is found off Santo and Malekula Islands. The trench turns to a west and east direction at 23 deg. S and then follows the Matthew-Hunter Ridge which bears only Matthew Islet. The distribution of shallow, intermediate and deep foci earthquakes (down to at least 250 km) indicates that a Benioff zone dips

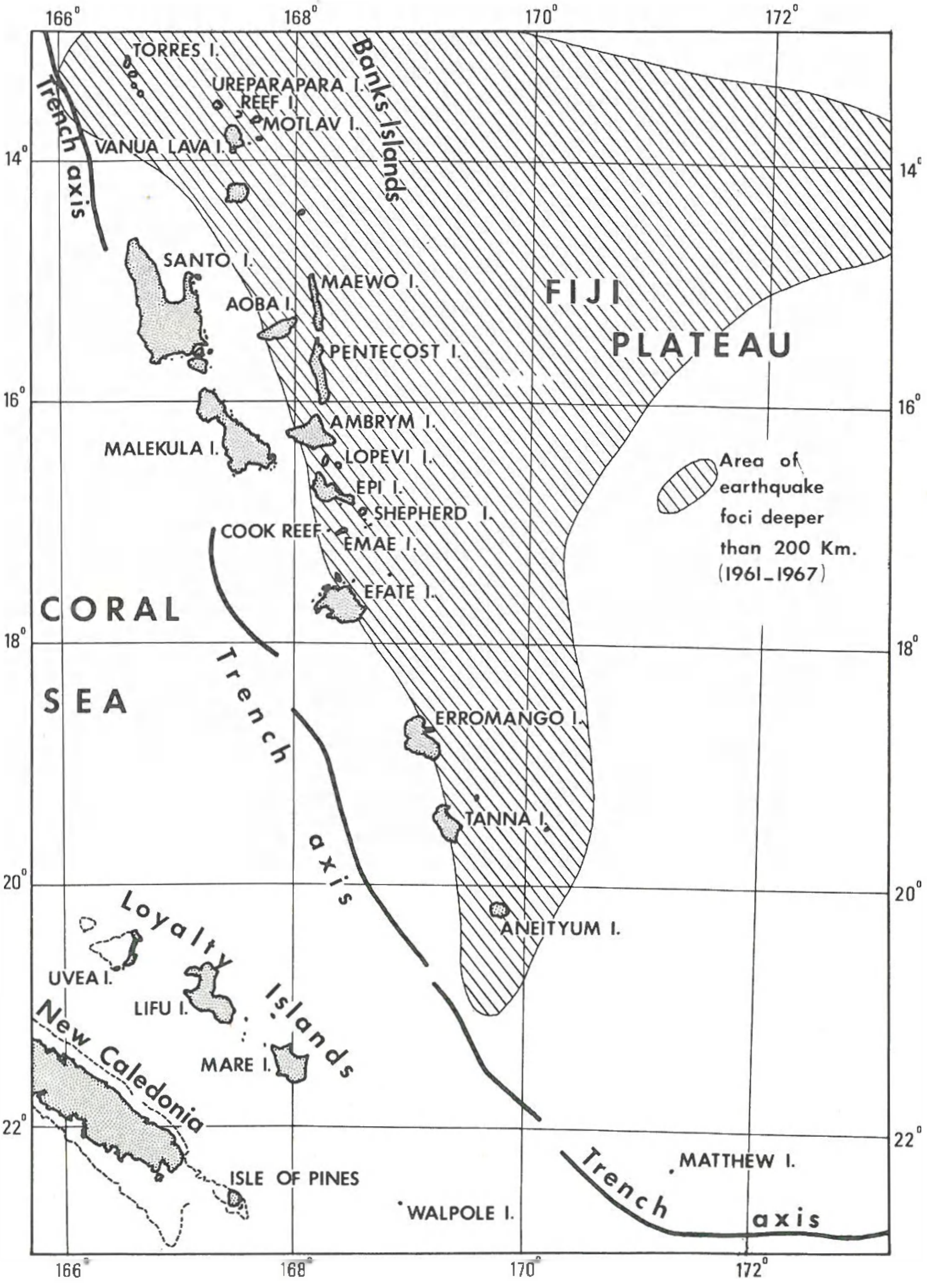

Figure 1: General map of the New Hebrides Island Arc. Deep earthquake foci from Karig and Mammerickx (1972).

to the east, so that the deep foci are located below the Fiji Plateau (whereas, if the sloping direction was normal, they would be below the Coral Sea: see Fig. 1). There is no decrease in seismic activity or focal distribution in the central section, in spite of the interruption of the trench, so that the whole structure bears evidence for subduction or underthrusting of the western sea-floor beneath the island arc. The existing volcanic chain lies in a reversed position in relation to the trench and the Benioff shearing plane, and is consequently located in the eastern row of islands, or in the basin between the western and the eastern island chains, but not in the western chain; the volcanoes are subaerial as in Ambrym, Lopevi and Matthew Islands, or submarine as off Epi and Erromango Islands (Doumenge, 1966). Extensive submarine troughs have developed in the median basin or in the eastern part of the arc. The larger islands are found in the western chain and are made up of extinct volcanoes covered with fossil or modern coral reefs, the best known being Efate, Malekula and Santo Islands.

From this distribution of structural features, it seems that the New Hebrides island arc developed in a first stage before mid-Miocene with a normal polarity. This was the time of volcanic activity on the western side of the arc, mostly at Efate, Malekula and Santo Islands. When the polarity was reversed, the volcanism shifted generally to its present position, and the former volcanic islands were uplifted, tilted or warped. This sequence of events seems to have occurred also in the Solomon arc system, along the western side of which the Planet Trench (9,140 m) lies at present. The two archipelagoes were originally parts of a continuous series of arcs from the Lau, Fiji, to the Bismarck archipelago. The Matthew-Hunter Trench acted first as a transform fault, and the opening of the Fiji Plateau was associated with it. Later on, in the Quaternary it was incorporated in the western trench system, and the inter-arc trough opened by extension between the two rows of New Hebridean islands. An extension parallel to the system also occurred, with lateral displacements.

II. GENERAL CLIMATIC CONDITIONS

The climate of the New Hebrides is everywhere perhumid and hot. The rainfall and, to some extent, the temperature, increase from south to north, the former exceeding 1,500 mm in the south and 3,000 mm in the north, where the tropical belt of maximum rainfall in the South Pacific is reached in the Banks Islands and in the Santa Cruz Islands (Doumenge, 1966, p. 16). These figures are even considerably higher in the mountains, although no precise measurements are made in these areas devoid of population. On the other hand, the New Hebrides are rather frequently swept by tropical cyclones in all parts during the summer. These hurricanes are extremely severe and periodically they drive seas over the reefs. We shall return to this point when speaking of Reef Island in the Banks Group.

III. LIVING AND FOSSIL FRINGING REEFS IN THE NEW HEBRIDES

It follows from the tectonic framework explained above that the reefs are expected to be found principally in the western islands, which are, as a whole, older, and where the corals had more time and more favourable conditions to grow since the end of the main eruptions. I do not intend to describe here the reefs of all the islands, but to review the main features of the most typical ones, from the south to north.

A. THE SOUTHERN ISLANDS

1. Aneityum Island, the southernmost island (except for Matthew Islet), is presently surrounded by fringing reefs, especially well developed in the north and in the southwest. The southwestern reef, or Intao Reef, extends as an apron into the sea for 2.7 km , and bears on its sheltered side a sand cay, Inyeug Island. Such an apron-reef with a leeward sand cay is a very common structure in the New Hebrides.

2. Tanna Island, which bears an active volcano, has living fringing reefs that are poorly developed, but elevated fringing reefs may occur in the west and in the north. More information is needed on this island.

3. Erromango Island has extensive elevated coral terraces. On the southern side the highest terrace rises to more than 300 m; lower ones stretch along the coast. Other coral terraces are found in the northeast and in the southeast. The writer has visited Cook Bay, in the southeast, where a high coral terrace exists at approximately 100 m, above a lower terrace at 4 m. The latter consists of colonies in the position of growth; it is extremely jagged owing to coastal corrosion as far as 60 m inland. A narrow platform has been cut into it. The 4 m terrace is dissected by several narrow, steep-sided estuaries, as Pouta (*alias* Ipota) estuary which small freighters can penetrate. These estuaries, which resemble more or less the shurum (sing.: sherm) in slightly elevated coral reefs on the western and eastern coasts of the Red Sea (Guilcher, 1957, p. 156), are obviously drowned valleys. It seems that these features are best explained in terms of eustatism: the lower terrace would be a

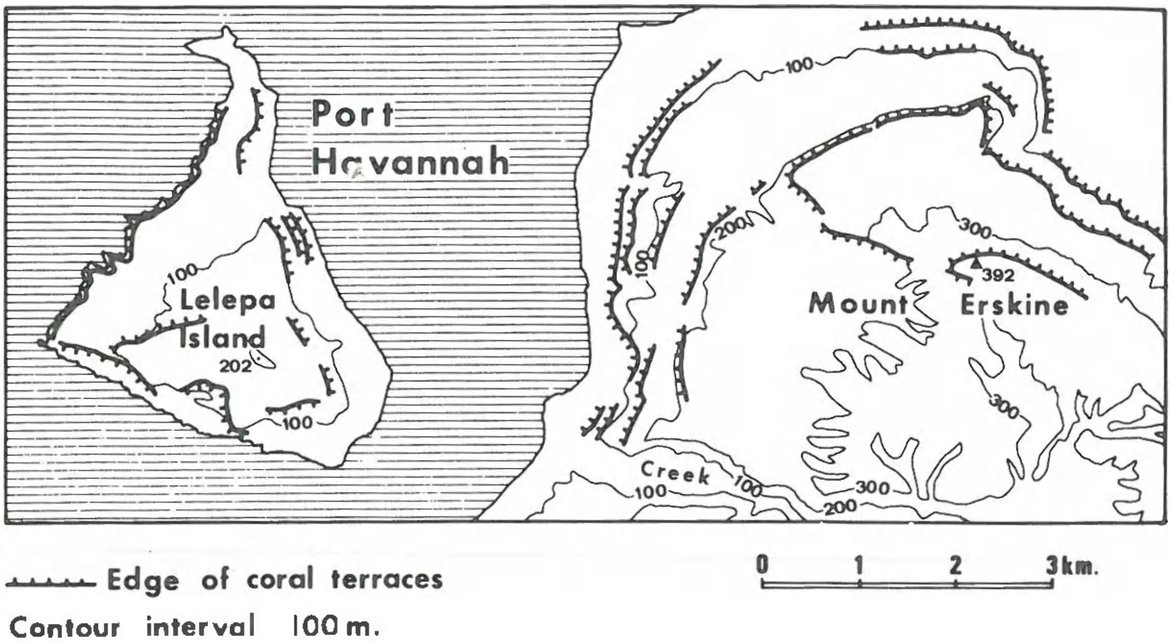

Figure 2: Raised reef terraces around Mount Erskine, Efate Island, and at Lelepa Island, after Obellianne and 1: 50,000 map.

remnant of the last interglacial high sea level, and the cut by rivers would have occurred during the last glaciation. But this hypothesis needs to be checked by absolute datings of the corals; and tectonic movements are likely to have played a very large part in the position of the higher terraces. Anyway, all the terraces were originally fringing reefs around the volcanic core of Erromango Island. Living fringing reefs also occur; they are, however, narrow, except for a few places along the east coast.

B. THE MAIN ISLANDS OF THE ARCHIPELAGO

These islands, which lie in the western chain, include the best examples of multiple raised coral terraces. These terraces may be considered as developments of what is found in Erromango Island. Those of Efate, Malekula and Santo Islands will be described and their origin will be subsequently discussed.

1. Efate Island. Here these features are exposed mainly in the southwestern, western and northern coastal areas, and may easily be recognized on the air photos and the 1: 50,000 and 1: 100,000 French contour maps. See also Obellianne (1958, Figs. 3 to 12). Four examples are given here.

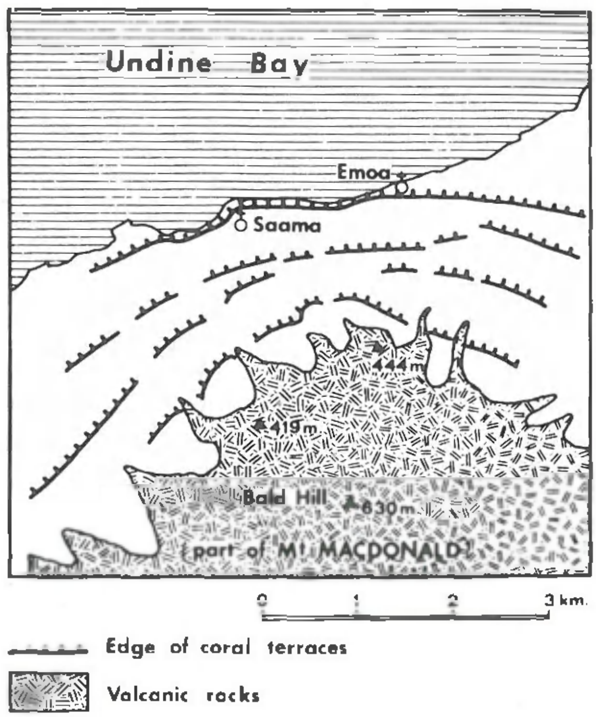

Figure 3: Raised reef terraces along Undine Bay, Efate Island, after Obellianne and 1: 50,000 map.

a. *The west coast of Mele Bay* near Port Vila consists of a slightly emerged reef flat, washed by waves and dissected in shallow pools and outer erosional spurs and grooves. This reef abuts at its inner side against a steep cliff, also in coral limestone, with overhangs and other usual corrosion features. Behind this cliff a sloping terrace 10-20m high is found, ending in turn against a massive and steep limestone escarpment (Boukoura cliff) rising to between 80 and 160 m in different places. The foot of this escarpment is cut by fossil visors and the terrace bears mushroom stacks. The top of the escarpment is an undulating plateau covered by a very dense rainforest.

b. *Mount Erskine* near Port Havannah (north coast) consists of coral limestones resting upon volcanic tuffs, and divided in at least five semicircular terraces between sea-level and 392 m (Fig. 2). On the west side of Port Havannah, Lelepa Island also displays three or four coral terraces, which give a typical stepped profile. The top of Lelepa Island reaches 202 m.

c. *Malafao Plateau*. Port Havannah, 225 m high, is made of white coral limestones divided into four steps. The limestones rest upon pumice tuffs which can be seen in creek sections.

d. *Undine Bay*, a few km more to the east on the north coast (Fig. 3), is bordered by another set of fossil fringing reefs lying upon breccia and basalts which form Mount Macdonald, the highest summit in Efate (647 m). The same stepped profile is again visible, four coral terraces rising up to at least 320 m.

Fringing reefs are still growing around Efate, and some of them, projecting beyond the general coastline, bear a sand cay on their leeward side, as at Mele Point near Port Vila. This type of reef is, however, more common around Malekula Island.

2. Malekula Island. The raised coral terraces of the northwestern part of this island have been studied by Mitchell (1968). Reference should also be made to the 1:50,000 French map, île Malékoula N. O. Following the deposition of lower Miocene pyroclastic rocks, Pliocene marine sediments were laid down, their minimum thickness amounting to 120 m. Subsequently, six reef-capped terraces were cut into these Pliocene strata, detrital limestones and constructional coralgal reefs being involved in the terraces. The terraces are clearly superposed, as at Efate Island; and, as at Efate, they represent former fringing reefs (Fig. 4). They did not, however, remain horizontal, but have been tilted to the northeast, and decrease in height in that direction. Thus, the elevation of the third terrace decreases from 250 m south of Tenmaru to less than 18 m near Port Wowo. A part of the tilting occurred during the formation of the terraces, and it is still going on during earthquakes. As at Efate the terraces are cut by creek gorges.

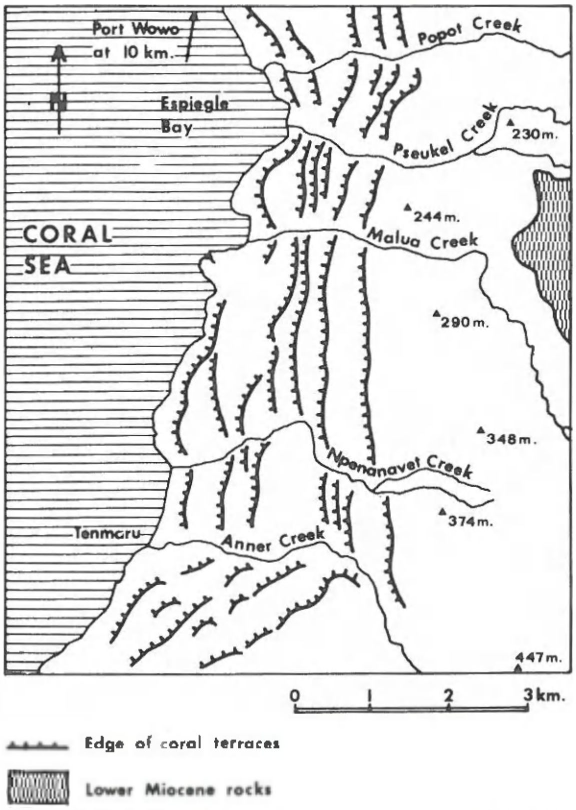

Figure 4: Raised reef terraces in Northwestern Malekula Island, after Mitchell and 1: 50,000 map.

Malekula Island is bordered on its eastern coast by living fringing reefs, sometimes of considerable width. Just off the coastline a number of isolated reefs with wooded cays may be seen. They are often raised as in the Maskelyne Islands.

3. Santo Island. This island also displays excellent examples of raised coral terraces, especially on its eastern side around Queiros Peninsula and adjacent islets around Port Olry. They have been described by Obellianne (1958). The common type consists of circular escarpments surrounding hills and islets like staircases. The number of steps may be as many as seven. Most of them are nearly horizontal, but in some cases, as at Boutnas Plateau, tilting has occurred. The highest terraces exceed 350 m.

Origin of terraces in Efate, Malekula and Santo Islands.

A first approach to the problem was made by H. T. Stearns (1945) and A. C. Tester (1950), who observed parts of the terraces in the New Hebrides, especially those on the east coast of Santo, during the Second World War, and attempted a correlation with other observations made by them during the American occupation of the South Pacific Islands. Their interpretation is purely eustatic, although they consider that the glacio-eustatism is insufficient and must be completed by a subsidence of the oceanic basins. Stearns thinks that the undulations observed in the main terrace at Santo (between 155 and 165 m) are explained by gullying and weathering. But further investigations have clearly shown that the New Hebridean terraces are much more frequently tilted or warped than these geologists thought at first sight. Furthermore, the present views on eustatism do not fit with their conceptions and lead one to presume that the history of the terraces is more complicated than was thought in the forties.

According to Obellianne (1958), all the escarpments bordering the coral terraces around Efate are fault scarps. As a matter of fact, there is not evidence of faulting for every scarp, but in several instances faults are proved by the occurrence of friction breccia. Moreover, faults are evident in fossil corals around Port Vila, where they have created the outline of the coast. There is also evidence of tilting of a part of the Efate terraces, as at Etoumao on the south side of Port Vila Bay: Etoumao is a coral block 141 m high, sloping to the south and divided into several steps on its western and eastern sides. Other terraces have remained horizontal, as around Malafao Plateau.

Concerning Santo Island, however, Obellianne's opinion is generally different. He states that at least a part of the staircase profiles in this island are not associated with faulting, but with uplift interrupted by halts, and sometimes with a subsidence during the growth of the coral (?): thus, for instance, at Zingora Plateau (p. 187 and 190 of his volume).

Mitchell's interpretation (1968) of Malekula terraces is also based on uplift (although Obellianne's work was apparently unknown to him); but he associates the uplift with Pleistocene shifts in sea level, whereas Obellianne apparently did not take this essential factor into account. Mitchell assumes that the six terraces at Malekula result from six transgressions followed by regressions, occurring during a general uplift of the island and a tilting to the northeast. There is no special difficulty, in the writer's opinion, in accepting these views, which seem to explain satisfactorily the facts observed in northwestern Malekula, and also, probably, on the east coast of Santo. It has been established now that more than four major changes in temperature, and no doubt consequently in sea level, occurred during the Pleistocene (Emiliani, 1966 a and b; Hopkins, 1967). What could be criticized in Mitchell's paper is that he tends to limit to six the number of cold periods in the last 400,000 years, while Emiliani's curve (op. cit.) shows eight: this is, however, a minor point.

Summarizing this discussion, we may presume that a large part of the coral terraces in the main islands of the New Hebrides arc are best explained by Mitchell's theory; but that other terraces, especially those in Efate Island, result mostly from faulting, sometimes associated with tilting, since faults are actually observed in several places in the vicinity of the scarps; that this local faulting must have combined in some way with the general succession of Quaternery transgressions and regressions; that more accurate work remains to be done to determine the precise combinations in each particular case; and that this succession of events took place after the reversal of the polarity in the New Hebrides Island Arc, when the volcanism had shifted from its former position in the main islands to its new location in the eastern set of islands and the inter-arc trough.

C. FRINGING REEFS AROUND HIGH ISLANDS OF THE EASTERN VOLCANIC CHAIN.

Only brief discussion of the reefs around some islands will be given.

1. **Pentecost and Maewo Islands** are two long, narrow islands situated in the same latitude as Santo Island. Both are described in Obellianne's book. Both include extensive elevated limestones which seem to belong in all cases to the fringing reef type. Raised benches are found, not so remarkable, however, as those in Efate, Malekula and Santo Islands. Much faulting has certainly occurred in the two islands, and tilted blocks, both of limestone and of volcanic rocks, are common. Pentecost and Maewo Islands are close to Ambrym and Lopevi active volcanoes.

2.**The Banks Group.** *Vanua Lava* is the largest island and is essentially volcanic; nevertheless, it bears present fringing reefs, particularly on its east coast. Just offshore in this area, two apron reefs with large, mature sand cays (Ravea, Pakea, Nowela) were visited by the writer in 1971: they may be quoted as good examples of this type. The western promontory of *Motlav Island* in the same group is girdled by a wide fringing reef, again with a cay, probably raised. *Ureparapara Island*, again in the Banks Islands, shows a fine example of a caldera invaded by the sea. Fringing reefs are very narrow, except for some places in the drowned caldera.

To sum up, the fringing reefs, present or raised, are represented in the eastern volcanic chain, but as a whole they are not so extensive as in the western chain, probably because the history of these islands has been shorter. In any case, the tendency to uplift is common.

IV. OPEN-SEA, NOT FRINGING, REEFS.

There are only two reefs which cannot be classified as fringing reefs in the New Hebrides: Cook Reef, lying 5 km west of Mai (or Emae) Island, and 25 km south of Epi Island; and Reef Island, in the northern part of the Banks Group between Motlav and Ureparapara Islands. Both are situated in the open sea and are quite distinct from the surrounding volcanic islands; the volcanic basement, which certainly exists at depth, is everywhere concealed under the corals and associated sediments.

A. COOK REEF (17 deg 04' S, 168 deg 17' E).

This reef has not been investigated in the field, but was only seen from aircraft at low altitude and examined on vertical air photographs of Institut Geographique National (Fig. 5). It occurs, as several high islands, in the inter-arc basin. It bears no emerged low island. It consists of a roughly triangular rim upon which the swell breaks, enclosing a lagoon in which the depth is generally less than 10 m and even apparently less than 5 m. The coral growth has created in the lagoon, cells, although much less regular and conspicuous, resemble somewhat those existing at Mataiva Atoll in the Tuamotus (Doumenge, 1966, p.107), and at Raiatea and Maupiti Islands in the Society Islands. Cook Reef faces south-south-east, although the trade winds, which generate the swell, blow from the east or the east-south-east, doubtless because Cook Reef is protected in that direction by Emae Island. A curious peculiarity is that the reef is interrupted by a passage on the exposed side, though it is well known that passages in atoll rims are mostly found on the leeward side. This passage leads to a small lagoon deeper (20 m at least) and narrower than the main one. A number of subcircular coral knolls thrive on the leeward side.

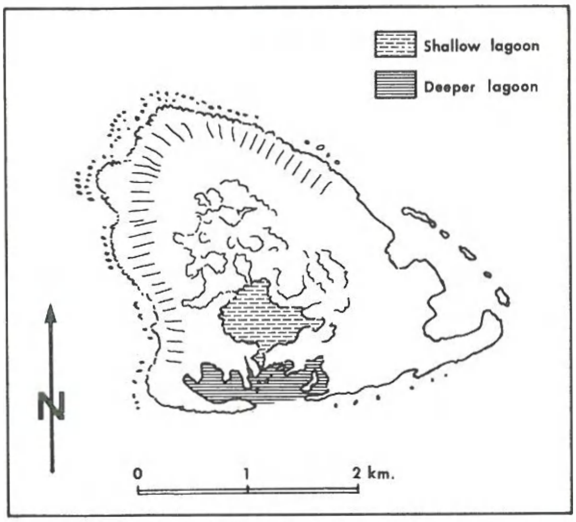

Figure 5: Cook Reef. Drawing from air photograph.

It would be, of course, interesting to investigate Cook Reef, but in a first approximation it seems much simpler and less interesting than Reef Island; this is why I selected Reef Island for a morphological survey in 1971; much more detail will be given here about the latter.

B. REEF ISLAND (13 deg. 37' S, 167 deg. 32' E).

Research at Reef Island was carried on in the second part of July, 1971, by F. Doumenge and A. Guilcher. They used M.S. *Astrolabe*, a small ship 16 m long, belonging to the French Residence in the New Hebrides, and kindly lent by the Resident, Mr. R. Langlois. The sediments collected on the reefs and in the lagoon were studied at Brest by Anne Marec under Guilcher's direction. The samples from old reefs were sent for radiocarbon dating to Gif Laboratory, France, where they were analysed by Dr. G. Delibrias.

Reef Island, 8.5 km long and 5.2 km wide in its widest part, is an arcuate reef, its convexity facing east-south-east whereas it is concave on the western side (Fig. 6). It may thus be called an orientated coral bank. The general shape is obviously related to the trade wind swell. During the research, M.S. *Astrolabe* was anchored in the western bay where the sea was quite smooth, while the other side was constantly beaten by a heavy surf.

However, Reef Island as a whole does not consist of living reefs, but of older ones, now dead; these are widely exposed on the eastern, northern and northwestern sides of the rim, and in some places in the median part. They form a reef flat up to high spring tide level (the tidal range reaches 1.80 m at spring tides). The highest parts of the old reef are jagged as the result of coastal corrosion, as is usual. The whole of the old ledge in the intertidal zone consists of corals in position of growth, often perfectly preserved, and in several instances very large tridacnae were found with their two valves *in situ*. Above high spring tide level the old reef has, on the contrary, the character of a reef conglomerate, i.e. the corals occur in blocks which are not in position of growth. This conglomerate reaches 1.50 m above high spring tides in the northwest, and up to 6.00 m in the northeast at Rowa Island, the highest place in Reef Is-

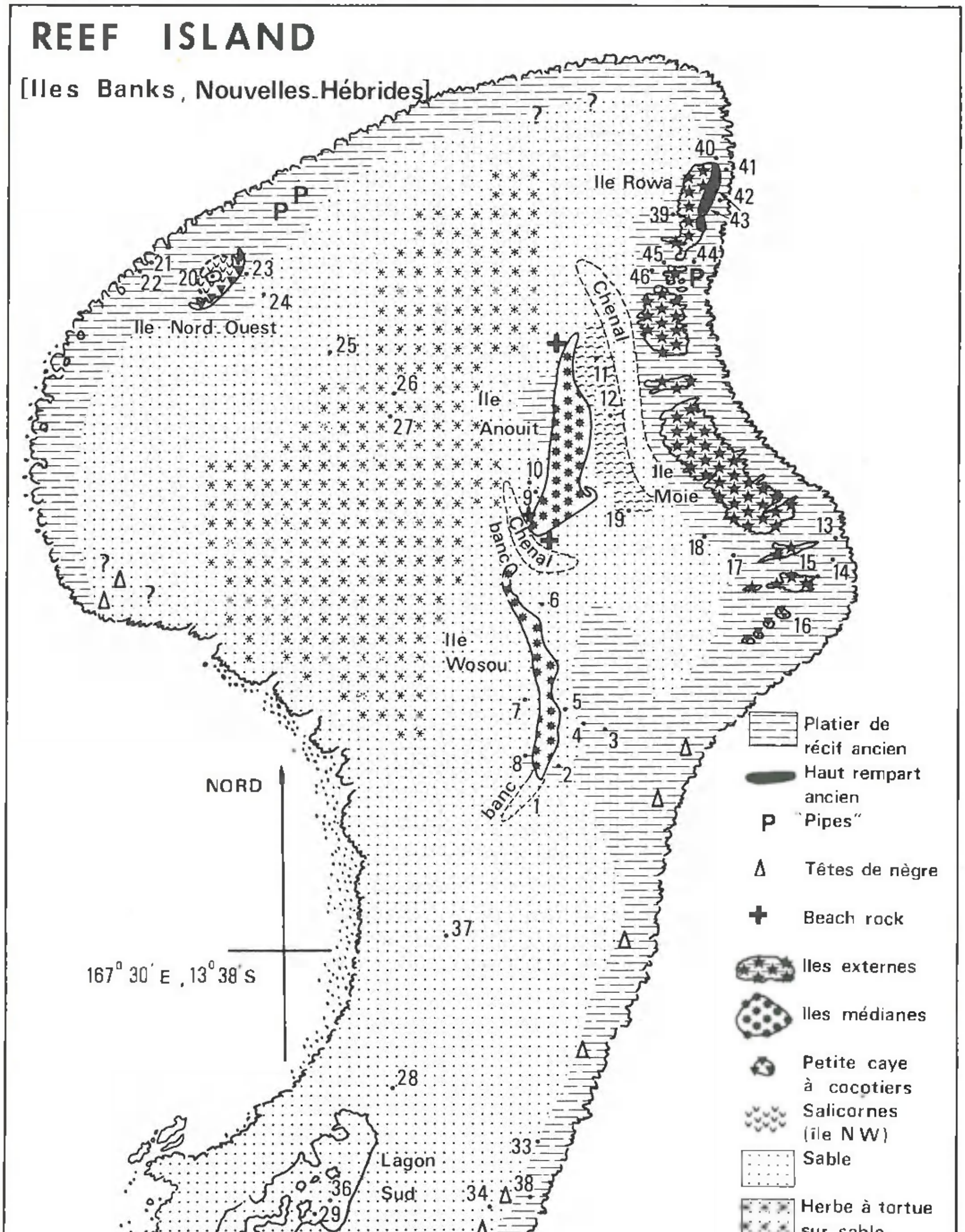

Figure 6: Geomorphological map of Reef Island, New Hebrides.

land, which was certainly built as a rampart and is at present being deeply corroded and made jagged. The northeastern corner is still now the most severely beaten place in Reef Island (see below). In places indicated as P on Fig. 6, the old ledge includes vertical pipes filled with a hardened calcareous yellow loam. These pipes stand above the present general level of the ledge because they were not so rapidly eroded as the intervening parts. They resemble pipes (which also contain a soil filling) in an uplifted reef near Port Vila, Efate Island.

Six samples of corals or tridacnae in position of growth submitted to Gif Laboratory for radiocarbon dating have given the following ages B P (location of samples on Fig. 6).

sample 2 (GIF 2535) 4320 ± 80 years half tide level
sample 3 (GIF 2536) 5980 ±90 years half tide level
sample 8 (GIF 2531) 4570 ±80 years just above half tide level
sample 17 (GIF 2532) 4150 ± 80 years half tide level
sample 18 (GIF 2534) 4970 ± 80 years half tide level
sample 45 (GIF 2533) 6640 ± 100 years ordinary high tide level

One sample has also been taken in the filling of a pipe immediately to the South of Rowa Island. The age is:

sample 44 (GIF 2624) 3270 ±100 years B P

Another sample was taken in the rampart of Rowa Island. The date obtained is:

sample 43 (GIF 2625) 20600 ± 320 years B P

After discussion with Dr. Delibrias, the best interpretation seem to be the following.

Samples 2, 3, 8, 17, 18 and 45 show that the old reef was formed during the Holocene, when it stood at least 0.50 to 1.50 m lower than now, relative to sea level. It is not possible, however, to prove that the difference from the present level is due only to a variation in sea level, since the seismicity of the archipelago is high, and, as seen previously in this paper, there is a general tendency to uplift. It is more probable that two factors are involved: the end of the post-glacial transgression, which, according to various data, could have been at -6 or -7 m in 6000 B P; and a tectonic rise of Reef Island. It is significant that the highest sample (45) is also the oldest. Owing to the possibility of tectonic disturbances, Reef Island cannot provide data on the much-debated problem of the highest post-glacial sea level, which is thought by one of the authors to have exceeded the present level (Guilcher, 1969, p. 89-91).

Sample 44 indicates that at 3270 years B P this site was sufficiently emerged to bear soil, which fell down into a pipe, already carved by erosion into the reef. This is again evidence for a tectonic uplift of the reef during the Holocene.

Sample 43 is much older than the other ones. Since the corals included in it are not in position of growth, mixing may have occurred and the age is not imprecise. What seems to be proved by this analysis, however, is that sample 43 includes Pleistocene corals which have not been found *in situ*, probably because, in the places visited, they are concealed beneath the Holocene formations. Therefore, it is probable that Reef Island has a Pleistocene basement at a shallow depth. Evidence favouring this hypothesis will be presented later in this paper.

The reef flat bears in several places small volcanic pebbles, none of which are coated by calcareous algae nor are any incorporated in the reef flat. It is improbable that they were derived from

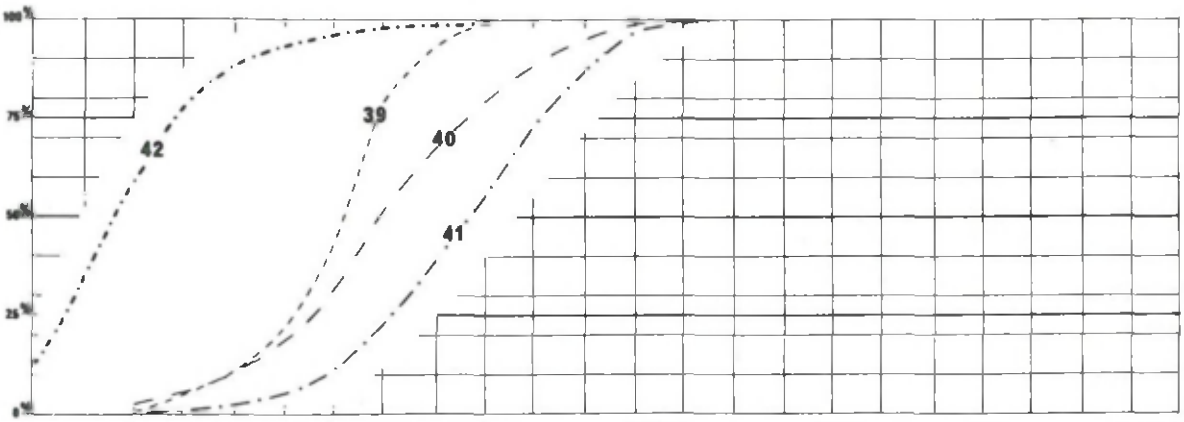

Figure 7: Grain size of sediments from northeastern part of Reef Island, around Rowa Island.

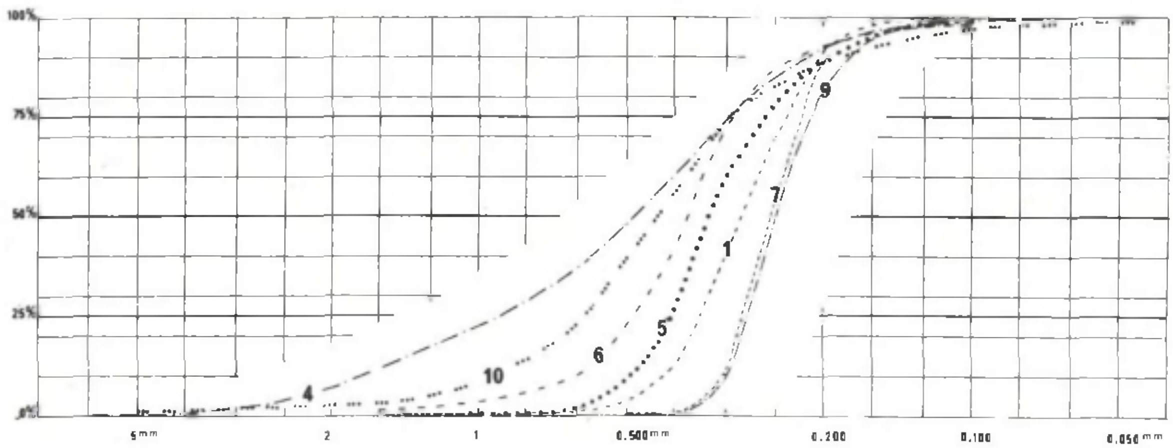

Figure 8: Grain size of sediments from beaches in median isles of Reef Island.

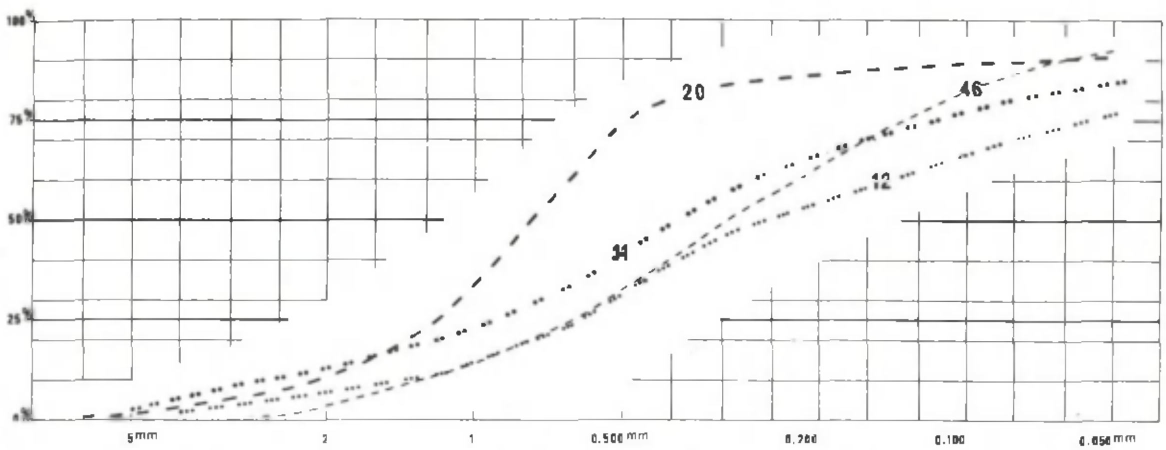

Figure 9: Grain size of sediments near channel between Anouit Island and outer islands, Reef Island, and in pond near northwestern island on the same reef.

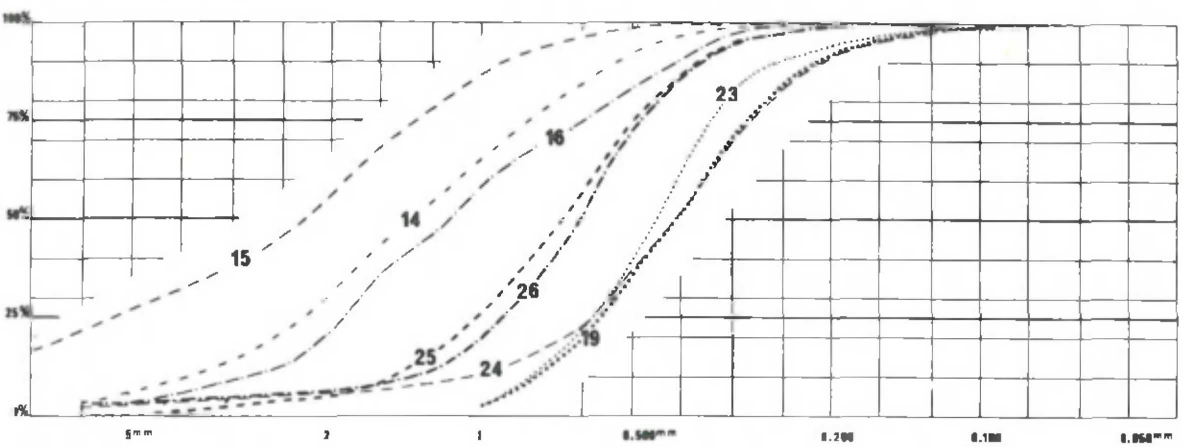

Figure 10: Grain size of sediments in lagoon and northwestern island, and on outer reef flat, Reef Island.

some unknown volcanic plug in Reef Island; much more likely they were brought by native fishermen from near-by high islands to make "lap lap" hearths, as the people used to do in the New Hebrides.

The forces at present in action were obviously the same as those operating when the old reef was built, since the orientation of Reef Island fits with these forces. Adaptation to the forces is reflected by the contrasts in structure of the windward and leeward sides (Figs. 6 and 12). The parts exposed to the swell display a typical spur and groove pattern, but, as is usual in such cases (e.g. in the Tuamotus, Polynesia), the spurs are carved into the old ledge and only coated by a thin veneer of living organisms. The pink calcareous alga *Porolithon* grows on the spurs, but it does not form an outer ridge as in the Marshalls, nor is its colour so remarkable as in the Tuamotus or in the Societies. It tends only to build overhangs on the sides of the grooves. The modern corals live just below the surf on the outer slope and contribute elements to the sediments.

The bay on the inner, western side of Reef Island is completely different. The spurs and grooves are replaced by a host of subcircular coral knolls, rising from a sandy bottom which slopes very gently to the west. This structure, which reminds one of the leeward side of Cook Reef (Fig. 5), is quite visible on air photographs (Fig. 12). The knolls bear a large number of thriving colonies.

The pools carved by coastal corrosion into the old ledge are infested with innumerable moray eels which dwell in the cavities and oblige one to be very cautious when walking on the reef.

Reef Island is unusually complicated in that it bears three types of low islets instead of one or two.

The first type is made of old reef or conglomerate on the eastern side. Except for Rowa Island, which includes a high rampart as previously said, they are extremely low (less than 2 m. above high tide level) and almost continuously washed by spray. They bear a low, thick halophytic vegetation consisting mostly of pemphis and ironwoods. Their contours are quite sinuous in detail. They are separated from each other by shallow passages, resembling the *hoa* in the Tuamotus and the Societies (Guilcher *et al.*, 1969, p. 43-48; Chevalier *et al.*, 1968, p. 48-53), through which the swash can penetrate inside the reef at high tide during periods of heavy surf. Rowa Island was the site of a village until 1939, and remnants of it may still be seen along the western, sheltered side of the rampart. The village was abandoned after two dreadful cyclones which struck the Banks Islands on 7th and 24-25th December, 1939 (local information), and the population migrated to the high islands of Vanua Lava and Ureparapara, although nobody, apparently, was drowned. Since our visit, another terrible hurricane has swept Reef Island at the beginning of 1972 and caused great damage on the coasts of Vanua Lava and other high islands.

That the surf is heaviest at Rowa Island is shown by grain size analysis of the sediments of beaches bordering this island (Fig. 7, samples 39, 40, 41, 42). The gravel is coarse, even on the inner side (sample 39), and the sorting is good. These sediments occur in pocket beaches and the reef flat is generally bare.

Islets of the second type are situated in the middle of the reef (Figs. 6 and 12). There are two isles, Anouit and Wosou, each long and narrow, and made of sand, which is very well sorted on the high beaches (Fig. 8, samples 1, 5, 6, 7, 9). The sorting becomes somewhat poorer on the lower part of the beach (Fig. 8, sample 4). Beach rock is found in small amounts near the north and the south ends of Anouit. No beach rock was found on Wosou, which has north and south extensions sub-

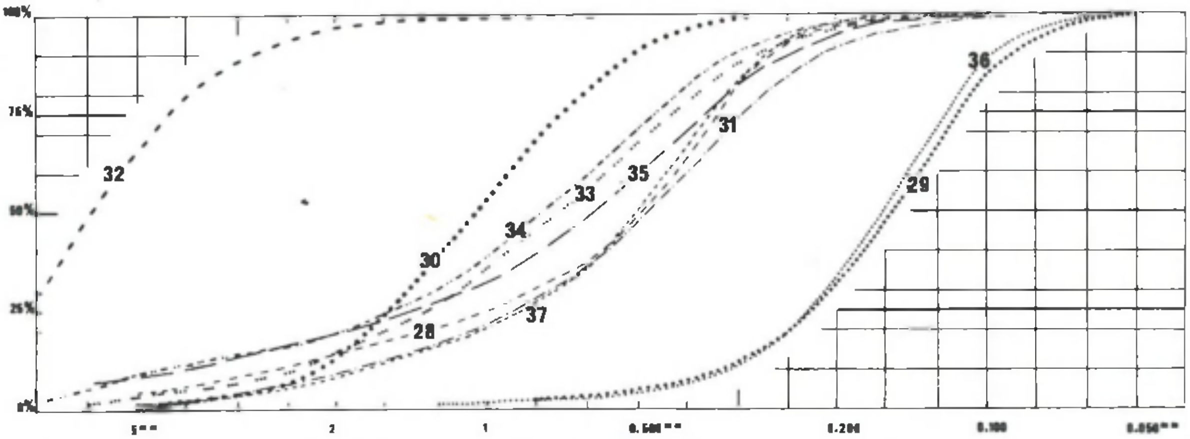

Figure 11: Grain size of sediments in southern part of Reef Island (samples 29 and 36 in southern "hole").

ject to temporary modifications, as is also the channel between the two islands; this was different in shape in 1971 from that shown on air photographs taken by the U.S. Air Force during the Second World War. This channel is kept open by tidal currents, but perhaps more efficiently by currents generated on the outer reef flat during periods of very heavy surf. Another channel exists between Anouit and the first mentioned set of islets. On its inner, western side, the sediment is poorly sorted and includes a silt fraction (Fig. 9, samples 11 and 12: notice percentages below 50 microns). Sediment with the same characteristics occurs as a very thin veneer overlying the old reef on the other side of the northern entrance of the channel (Fig. 9, sample 46). In the area in which samples 11 and 12 were taken, the sediment contains much organic matter and is more or less fetid. It is partly coated by fine green algae. Anouit is still used as a temporary base by fishermen of the Banks Islands. Anouit and Wosou Islands are thickly wooded and difficult to penetrate.

The third type of islets is represented by a sand cay and associated features, located in the northwestern corner of Reef Island. By its leeward position this cay resembles very much the low isles described on isolated reefs of the Great Barrier of Queensland and many other similar reefs in Madagascar, New Caledonia, the Caribbean, the Red Sea, etc. From southeast to northwest, this cay comprises:

(1) an arcuate beach ridge, facing southeast, made of fine, well sorted sand (Fig. 10, sample 23); it is not submerged except during storms, and it thus bears coconut trees and smaller trees or bushes. Several recurved spits exist at its two ends;
(2) behind this ridge, a small plain coated with sand derived from the ridge, rests upon the old reef; the latter crops out in places. It bears a vegetation of Salicorniae;
(3) in the middle of the Salicorniae meadow, a shallow pond bears a cover of sea grass (marine phanerogams): the sediment in the pond (Fig. 9, sample 20) is typical of such an environment, with particles of various sizes down to silt; it cannot be well sorted because the particles are trapped by the rhizomes of the plants. There is a supply of sea water to the pond at spring tides. A few small Avicenniae and two small Rhizophorae live on the margins of the pond.

The northwestern islet and accompanying features have not been modified in the period between the taking of the American photographs and 1971.

Between the second and the third mentioned sets of islets a comparatively large lagoon is found in the middle of Reef Island. The depth varies between 0.50 and 4 m at low spring tide (whereas all the surface between Anouit, Wosou and the eastern side of the reef is exposed at low tide, except for the channels). In this lagoon the sediment consists of sand (Fig. 10, samples 24, 25, 26) covered to a large extent with turtle grass *(Cymodocea serrulata,* alias ***Halodule uninervis)***. Many turtles actually live in the lagoon, and nine of them were caught by the crew during our stay in Reef Island.

All these features are found in the northern half of Reef Island.

The southern half is not so diversified, although not devoid of interest. As a whole, this part is a large flat area, under 0.50 to 1.50 m of water at low spring tide, the sediment, on which a sand moderately sorted, is represented by samples 28, 31, 34, 35, and 37 on Fig. 11. On the inner slope of the reef flat the sediment type is the same (ibid., sample 33), with thin coatings of sand and gravel and Halimedae occurring in small holes and furrows of the reef flat. Living Halimedae are often abundant, especially around sample 34. In some

Figure 12: Reef Island, southern half, showing contrasts between eastern and western side, outer and central islets, and hole in reef flat in the South. Photo: Trimetrogon IGN, reproduced by permission of IGN.

places, very coarse gravel, well sorted, occurs in elongated accumulations perpendicular to the general direction of the reef. Sample 32 (Fig. 11) is typical of these deposits. Sample 30 represents an intermediate case. Several negro-heads exist on the outer edge of the reef: they are the result of hurricanes. This part of the outer rim is lower than the north, and more widely coated by calcareous pink algae.

The most interesting feature of the southern half of Reef Island is a wide "hole" occurring not far from the southwestern corner, very conspicuous on air photographs (Fig. 12) and 4 to 7 m deep: it is thus the deepest place in Reef Island. This depressed area is a very efficient shelter for sedimentation, and the deposits in it are distinctly finer than the surrounding sands (Fig. 11, samples 29 and 36: compare these with the other samples on the same figure), although silt is completely absent and the fine fraction consists of very fine sand. Coral patches, irregular in outline and sometimes fairly large, grow in this hole.

It is suggested that the hole might be a karstic feature, created by solution during the last glacial low sea level. This explanation fits well with the occurrence of coral blocks older than Holocene in the rampart at Rowa Island (see above): the hypothesis of a Pleistocene coral basement at Reef Island is thus strengthened. Such an occurrence of probably originally subaerial sink-holes in the coral reef is not unique. Drowned karstic features have been reported from other coral areas, as for example, British Honduras and the Bahamas, where Stoddart (1962, p.53) has mentioned them and Captain *Cousteau* has explored them by diving, discovering submarine rooms with drowned stalactites and stalagmites which he showed on television. The sink-holes in the Bahamas are called blue holes (Bourrouilh, in press). They may be compared with the karstic features reported from Mayotte Lagoon, Comoro Islands (Guilcher *et al.*, 1965, p.21) and from Clipperton Atoll (Sachet, 1962, pp.52-53).

What is most unusual in Reef Island, in the writer's opinion, is that it has a central set of low islands in the middle of the lagoon, in addition to the classic couple windward rampart — leeward sand cay. Its position in the open sea, not in a marginal sea as are the Great Barrier reefs and the Red Sea reefs, also deserves attention. It is certainly the most interesting reef in the New Hebrides, certainly more interesting than the common fringing reefs, either modern or fossil, which commonly occur in that island arc. It is not really a special type of reef, but it shows peculiarities which have to be kept in mind in the context of general reef geomorphology.

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