Geology and Marine Biology of Makatea, an Uplifted Atoll, Tuamotu Archipelago, Central Pacific Ocean


4Université Francaise de l'Ocean Indien  
97400 Reunion Island  
France D.O.M.  
R.C.P./C.N.R.S. 510

5Université de Pau et des Pays de l’Adour  
64000 Pau  
France

ABSTRACT


Makatea Island, 245 km northeast of Tahiti, is an elevated (60 to 75 m) carbonate frame, ranging in age from the Miocene to the Late Pleistocene. It is morphologically and sedimentologically an atoll-shaped reef tract (outer coral built rim, inner fine-sized to chalky, shelly deposits). During periods of emergence, a dense karstic system has developed and, later, has been partly occulted by pyroclastic-derived phosphates. Uplifted and faulted during Pleistocene times, the island has recorded three high sea-level stands, from the Middle Pleistocene to the Late Holocene. The position of the Late Holocene peripheral fringing reef induces a marked paucity of marine flora and fauna. The algal turfs are dominated by Lobophora and, locally Turbinaria, whereas Porolithon ridges flourish on the high energy reef fronts. The coral communities are prospering along the outer slopes only (Pocillopora, Acropora, Astreopora mainly). The distributional pattern of molluscs is rather similar to those of the other Tuamotu Islands; the dominant genera are Turbo, Drupa, Mitra, Conus, Tectarius, Thais, Littorina. The echinid Colobocentrotus is common, while Grapsids and Xanthids predominate among crustaceans.

ADDITIONAL INDEX WORDS: Atoll, coralline algae, coral reef, Makatea, marine terrace, raised shoreline, sea level, South Pacific, Tuamotu.

INTRODUCTION

Rising at 245 km northeast of Tahiti, at 148° 15’ West longitude and 15° 50’ South latitude, Makatea, an isolated island, was formerly regarded as an old faro built during Eocene-Miocene then uplifted during Mio-Pliocene and bounded by a living fringing reef (DANA, 1849; AGASSIZ, 1963; RANSON, 1956; OBEILLIANNE, 1963; DOUGENGE, 1963). Investigations conducted during April and May 1982 allowed the main geological and marine biological features of this to be reviewed or described for the first time.

GENERAL GEOLOGY

Geomorphology

Makatea, 7 km long by 4.5 km wide, is a crescent-shaped carbonate high island (Figure 1). Vertical cliffs are especially prominent on the northern and eastern coastal areas (60 to 75 m in height), whereas the southern face slopes down quite gradually towards the shoreline, flanked by two lines of lower terraces (5 to 20 m). On all sides, the cliffs exhibit at least three distinct notch lines at levels of 1 to 1.5, 5 to 8, and 20 to 25 m above sea level; they are surrounded by almost totally dead fringing reefs level-

1Received March 20 March 1984; accepted in revision 18 September 1984.
upper platform capping the island displays two central basins at the maximum height of 20 m.

The whole frame is deeply dissected by a karstic system at different scales: (1) wide (5 to 30 m) and deep (1 to 75 m), sub circular, close-set hollows (pot holes), and residual pointed to planar hummocks have developed within its northern and central parts; (2) a strongly solution-rilled surface affected by channels oriented perpendicularly to the coastline (old fractures or erosional grooves) lies in its southern part; (3) along the northern and eastern cliff lines, centimeter to meter-sized furrows connected vertically to extension joints and paraclases give evidence of the downward circulation of meteoric waters; (4) the notches undercutting the coastal cliffs are laterally associated with narrow open caves and galleries displaying speleothem deposits.

Whatever the coastal area considered, an actively coral-built outer slope occurs as an upper spur-and-groove system and a lower drop-off; it possesses a badly marked terrace at about 6 to 11 m deep. Along reefless areas, the depths between 4 and 10 m are occupied by a gentle sloping furrowed coral flagstone. Whatever the zones considered, the slope becomes very steep (60° to 70°) with depth.

**Stratigraphy and Petrography**

Four major stratigraphic units have been recognized (Figure 1-2).

(1) The earliest outcropping unit was only seen along the western coast. About ten meters thick, it mainly consists of planar bedded strata of strongly dolomitized bafflestones. It is probably the product of deposition on a shallowly submerged, high-to-medium energy platform. Comparisons with similar facies from other exposed Pacific carbonate islands (BOURROUILH-LE-JAN, 1977) suggest that this unit may be of Late Miocene age or older.

(2) Unconformably overlying the basal one, the upper unit forms the great bulk of the island (northern, western, and eastern coastal cliffs, upper platform) and reaches about 60 m in average thickness. Its peripheral parts exhibit large-scale oblique beddings with facies changes upwards from bafflestones (dominance of massive coral forms) to framestones (occurrence of branching forms). The internal parts, partly visible at the upper platform, shows concentric facies belts consisting of limestones and dolostones; an outer rim made up by in situ corals and various skeletal deposits (crypto to micro-crystalline grainstones, packstones, and wackestones); an intermediate zone composed of shelly wackestones or packstones rich in Pelecypods (Cardiidae, Tellinidae); and a central zone of chalky mudstones (Pelecypods, Echinids). Thus, during its main stage of development (probably Miocene +), Makatea, morphologically and sedimentologically speaking, resembled an atoll. Stratigraphical and petrological features indicate that the ultimate stage of development was that of the complete filling up of the lagoon. Karstic cavities...
were formed during several periods of emergence, and then filled in by phosphatic deposits; similar to many Indopacific islands (BOURROUILH-LE-JAN, 1980), the phosphates of Makatea may be regarded as resulting from the pedologic maturation of volcanic material from nearby volcanic islands.

3) The well-defined Pleistocene unit corresponds to two generations of reef terraces, dated at 100,000 to 140,000 and more than 200,000 years respectively (VEEH, 1966). They occur just below the two uppermost notch lines. Reaching maximum elevations of 20 meters, the exposures of the older episode are preferentially situated along the southern and eastern coastal areas. The younger "5 to 8 m" terrace occurs as either cliff-veneering apron reefs or well developed fringing reefs along all the shores. The rocks consist of aragonite to low-magnesium calcite, coral framestones and algal bindstones, associated with foraminiferal-algal grainstones and packstones.

4) The latest unit corresponds to the exposed peripheral fringing reef, ranging from 5,300 ± 130 (GAK-10709) to 4,450 ± 90 (GAK-10710) BP. Presently in the process of erosion, it probably consists of a half-meter thick veneer sitting on a pre-Holocene (Pleistocene?) marine erosional platform. It shows typical physiographic zones similar to those of present-day counterparts: from the open sea landwards, algal ridge and/or coral reef flat, shingle sheets and beachrock.

Tectonics

The uplift of Makatea is thought to have resulted from the isostatic response of the oceanic lithosphere to the load of the nearby Tahiti volcanic complex (McNUTT and MENARD, 1978; LAMBECK, 1981; SCOTT and ROTONDO, 1983). As Moorea, the oldest shield volcano, is dated at 1.5 million years (DUNCAN and McDOUGALL, 1976), this uplift may have been initiated during the Early Pleistocene.

According to CHAPPELL and VEEH (1978), MONTAGGIONI (1978), and GAVEN and BOURROUILH-LE-JAN (1981), the "120,000" and "200,000" BP high sea levels seem to have been respectively at about 5 to 9 m and 12 to 13 m above the present sea level in various Indopacific areas. If correct, and considering the present ele-


Figure 3. Distributional pattern of the main living communities across the fringing reef flats (exposed areas).

Sequence of Major Events

The geological history of Makatea can be succinctly summarized as follows: (1) Miocene development of an atoll-shaped platform on an initial sub-reef structure, infilling of the lagoon and, during periods of low sea stands, occurrence of meteoric dissolution; (2) Mio-Pliocene — filling of karst cavities by pyroclastite-derived phosphate prior to the uplift of the island; (3) Middle to Late Pleistocene — record of at least two high sea stands, and (4) Late Holocene — record of a high sea stand.

MARINE BIOLOGY

Investigations have concerned flora and dominating groups of benthic fauna (Scleractinian corals, molluscs, echinoderms, crustaceans) from the...
outer slopes, the Holocene fringing reefs and coastal reefless areas. A general distributional pattern of the living communities is considered in Figures 3 and 4.

Flora

Generally the outer reef fronts are colonized by encrusting coralline algae (Porolithon onkodes, Lithophyllum spp.). According to wave energy, these algae make up either a thin veneer (sheltered western and eastern areas) or a well-developed ridge (exposed southern area). At the foot of the cliffs, besides Rhodophyceae, other algal species typical of the reef edges of atolls (Microdictyon of okamurian, Neomeris vanbossae, Caulerpa urvilliana, Halimeda microseca, H. taenicola, acranvillea spp.) (DENIZOT in CHEVALIER et al., 1969; DENIZOT, 1969; DENIZOT, 1979) occur widely. Along the high energy outer slopes, as deep as 10 m, the coralline algal rate of covering reaches more than 60%, while that of two previously named Halimeda species varies between 10 and 15%. From 10 to 40 m deep, Halimeda and Caulerpa (C. sarati, C. racemosae) are flourishing (40% of the substrate).

The outer parts of the reef flats display highly variable specific diversity. The species Lobophora variegata forms a continuous peripheral belt. The other floristic elements (Giffordia spp., Liagora ceramoides, Hassalia byssoides, Halimeda opuntia, H. taenicola, Caulerpa cupressoides, C. urvilliana, Dictyosphaera favulosa, Rhodymenula) are subordinate. The inner reef flat areas are widely occupied, in addition to Lobophora, by turfs of Cladophora. The total algal cover rate can reach up to 80%, four species of brown algae (Turbinaria ornata, Chloospora minima, Ectocarpus brevarticulatus, Hydrolithus clathratus) locally produce high biomass. This is particularly confusing on Makatea because the brown algae and the two
species of *Turbinaria* and *Chnoospora* are respectively uncommon or never collected as they are on the other Tuamotu atolls (DENIZOT and BAGNIS, 1974).

**FAUNA**

The main reef-building scleractinian corals reported from Makatea are the same as those reported from the majority of the Tuamotu atolls (CHEVALIER, 1979). They are, however, only prospering along the outer slopes. Their distributional patterns vary markedly according to energy and/or depth. As deep as 10 m, in higher energy zones, the coral cover rate does not exceed 25%, whereas it can reach 40 to 70% on lower energy slopes. The dominant species is *Pocillopora verrucosa*, associated with several species of *Acropora*, *Porites* and locally, with *Millepora platyphylla*. The 10 to 25 m zone is dominated by *Pocillopora verrucosa* and *P. eydouxi*. The lower parts of the slopes (25 to 40 m) are characterized by high concentrations of *Astreopora myriophthalma* and high rates of coral covering (more than 80%). The reef flats have a very low rate of covering (less than 5%); the dominant forms are *Acropora rotumana* (sheltered areas), *Porites* c.f. *compressa* and *Montastrea curta* (exposed areas).

The molluscan fauna (121 species collected) is assumed to be relatively poor by comparison with that described from the outer reef rims of the other Tuamotu atolls (SALVAT, 1967, 1970; RICHARD, 1982). On the algal ridges and reef fronts, the dominant species are *Patella flexuosa*, *Turbo setosus*, *Drupa morum* and *D. ricinus*. The reef flat zones are inhabited by dense populations of molluscs mainly including *Mitra litterata*, *M. pauperculata*, *Morula granulata*, *Drupa cancellata*, *Conus sponsalis*, *C. lividus*, *Papureta reticulata*, *Bursa bufonia*, *Tridacna maxima*, *Thais armigera*, *Cypraea moneta*, *Nerita plicata*, *Terebralia philippinensis*, *Turbo setosus*, *Patelloida conoidalis*, *Thais aculeatus*, *Cypraea catula*, and *C. caputserpentis*. Emerged beach rock and conglomerates are colonized by *Nerita plicata*, *Tectarius grandinatus*, *Thais aculeatus*, and *Littorina coccinea*. Along the reefless areas, the zonation of molluscs is similar to those of the algal ridges and beach rock; from the upper parts of the outer slopes to the cliffwalls, *Haliothis pulcherrima*, *Drupa ricinus*, *D. morum*, *Turbo setosus*, *Patelloida conoidalis*, *Thais aculeatus*, *Nerita plicata*, and *Littorina coccinea* can be found. At Makatea, as on the majority of the Tuamotu reefs, the specific diversity is greater in sheltered areas, but the greatest number of individuals occurs in the most exposed areas. The families showing the highest specific richness are omnivorous (*Cypraeidae*: 20 species) or carnivorous (*Muricidae*: 15 species), but those showing the highest concentration in individuals (*Littorinidae*, *Cerithiidae*) are grasseating.

On the whole fringing reef zone, echinoderms are not very common, except for the echinid *Echinometra mathaei* and the holothurid *Halodeima atra*. Moreover, the echinid *Colobocentrotus pedifer* is highly frequent, locally associated with *Heterocentrotus mamillatus* in the high energy zones of this island, whereas it is generally scarce in the Tuamotu archipelago (RICHARD and SALVAT, personal observation).

Concerning Crustaceans, 46 species have been collected. A few Xanthidae (*Daira perlata*) and Grapsidae (*Plagusia speciosa*, *Percnon affine*) only, typical of algal ridges and reef fronts move about towards the reef flat zones. Likewise nocturnal fore-reef-inhabiting *Planulirus penicillatus* and *Car­pilius* wander through the algal ridges. The individuals belonging to species generally living on the reef flats (*xanthid Leptodius sanguineus*) or on the supratidal substrates (*Grapsus tenuicrustatus*, *Geograpsus crinipes*) are more mobile.

**ACKNOWLEDGEMENTS**

Gratitude is due to the Bureau of Works, Civil Office of the Tuamotu (Papeete, Tahiti) for their assistance and logistic support. The field assistance of natives was greatly appreciated.

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