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# NUKUTIPIPI ATOLL, TUAMOTU ARCHIPELAGO; GEOMORPHOLOGY, LAND AND MARINE FLORA AND FAUNA AND INTERRELATIONSHIPS

BY

F. SALVAT AND B. SALVAT

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# NUKUTIPIPI ATOLL, TUAMOTU ARCHIPELAGO: GEOMORPHOLOGY, LAND AND MARINE FLORA AND FAUNA AND INTERRELATIONSHIPS

by

FRANCINE SALVAT (1) AND BERNARD SALVAT (1)

## ABSTRACT

Nukutipipi atoll (5 km2), of volcanic origin 16-17 million years old on the Pitcairn (hot spot) Hereheretue line, presents a land flora and fauna of low diversity but with a *Pisonia* forest and hundreds of resident red-tailed tropic birds. Nukutipipi suffered from the 1983 hurricanes : destruction of vegetation and motu as well as sand lagoon mollusc populations. The north and south rims present original geomorphological structures. Lagoon without patch reefs reaching the surface is characterised by dome patch reefs all constituted of dead *Acropora* with few scleractinian and mollusc species, but an important algae coverage. All these characteristics indicate the precariousness on a time scale of such a so tiny atoll, land and marine, with a closed lagoon.

## INTRODUCTION

Nukutipipi atoll is one of the tiniest low-lying islands of the Tuamotu archipelago and in the world (with a maximum length of some 3,5 km and a surface area of about 5 $km^2$).

It lies within two other small atolls (Anu Anunaro and Anu Anurunga), all three known as the Duke of Gloucester Islands, at 20-21° south latitude and 143-144° west longitude. These islands are in the southern central part of the Tuamotu archipelago (figure 1) and lie 700 km off Society Island Tahiti, to the north west, and 857 km off Mangareva, Gambier Islands, in the south east. Although no more 40 km distant from each other, they are separated by an ocean as deep as 2,000 m.

Observations on Nukutipipi atoll which we are reporting were mainly in November 1988 but also previously in August 1982 and July 1986. We had at our disposal an aerial cover of the entire atoll from "Aéronautique navale française (Ref. VTTA ANF/ 26/65, 278 CEP/EM/DPS/SC) 11 th July 1965 - 37 prints - 1/5000 ème).

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(1) Laboratoire de Biologie Marine et Malacologie, Ecole Pratique des Hautes Etudes, URA CNRS 1453, Centre de Biologie et d'Ecologie Tropicale et Méditerranéenne, Université de Perpignan, 66860 Perpignan cedex, France.
Centre de l'Environnement d'Opunohu, BP 1013 Papetoai, Moorea, Polynésie française.

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## DISCOVERY AND HUMAN ACTIVITIES :

The atoll was discovered by Carteret on 12th July, 1767, observation being reported by Emory (1939) : "On the 12th, we fell in with two more small islands, which were covered with green trees, but appeared to be uninhabited. We were close in with the southernmost (Nukutipipi), which proved to be a slip of land in the form of a half moon, low, flat, and sandy : from the south end of it a reef runs out to a distance of about half a mile, on which the sea breaks with great fury. We found no anchorage, but the boat landed. It had a pleasant appearance, but afforded neither vegetables nor water ; there were, however, many birds upon it, so tame that they suffered themselves to be taken by hand. The other island very much resembles this, and is distant from it about five or six leagues." On 1841, the atoll was visited by Ringgold of the Wilkes Expedition. On the 6th January, 1841 he identified Nukutipipi, using for the first time the native name of the atoll, as the atoll previously named by Turnbull as Margaret's island during his expedition. Ringgold mentions (Emory, 1939) : "On the 6th, Nukutipipi or Margaret's island was made, a small round lagoon island, two miles in circumference, high and well wooded on the north side, with a flat submerged reef on the southeast and east sides".

Nukutipipi was an uninhabited low-lying island covered with natural primitive vegetation. Between 1911 and 1926 (date not precisely known) the atoll was a concession of the "Société Commerciale de l'Océanie" and part of the atoll was reclaimed and planted with coconut trees. After failure of the Société the atoll was sold to MM. Cassiau and Pomel in 1935, then to M. Gonin, then to M. Madec in 1980, the present land owner of the atoll. In 1982, an airfield was inaugurated. On 1983 two violent hurricanes (Orama and Veena) struck Nukutipipi destroying almost all the coconut plantation and all bungalows. New plantation and reconstruction took place in 1985. In 1991 Nukutipipi is to be sold to a Japanese Society.

No scientific observation nor contribution has previously been published on Nukutipipi related to its remote position in the archipelago. However, in the vicinity of the Duke of Gloucester islands numerous papers have been published on Mururoa - 430 km on the east - (see Chevalier et ali., 1968 and Renon, 1989), on Fangataufa - near Mururoa - (see Salvat, 1970), and on Hereheretue - 210 km to the west (see Richard, 1970).

## CLIMATE :

Nukutipipi enjoys a hot and humid tropical oceanic climate. It lies in the south tropical convergence zone between two anticyclonic zones. The first of these on Easter Island brings heat and humidity along with east and north-east trade winds. The second, on Kermadec, brings fresh air along with south-east trade winds. The frontier between these two anticyclonic zones shifts to the north of Nukutipipi during the austral winter and to the south during the austral summer. Lacking climatic information specific to the atoll, we refer to the nearby atoll of Mururoa - 1° latitude more - (Renon, 1989). Figure 2 gives monthly mean temperatures of air and sea, and monthly precipitation and evaporation. Air temperature is between 22 and 27°C. There are more than 2,600 hours sunshine during the year (average of 7 h 30 per day), and about 12 storm days per year. If hurricanes are unusual in French Polynesia (the last periods go back to 1874, then 1903-1906), no less than 6 occured between december 1982 and april 1983, two of them striking the atoll (Orama in February and Veena in April).

ORIGIN OF THE ISLAND :

According to plate tectonic theory, Nukutipipi atoll - as all French Polynesian islands (118 islands of which 84 are atolls) - is affected by two movements : drift of the Pacific plate to the west north-west and subsidence. Volcanic migration rate have been estimated between 10.4 and 12.7 cm/year for different Pacific Island chains (Spencer, 1989). According to Brousse (1985) the sequence Gambier - Mururoa has been affected by a migration rate of 10.7 - 11 cm/year. Subsidence is about 0.1 cm per year (or 10 cm per century).

The floor near the Duke of Gloucester islands is 50 millions years old, moving to the west-north-west since its creation at the East Pacific Ridge. It is currently maintained that the Tuamotu islands are the remants of a micro continent which emerged on the west side of the East Pacific Rise 40 to 63 million years ago. All other archipelagoes of French Polynesia (Society, Marquesas and Austral) are of hot spot volcanic activity (Scott and Rotondo, 1982). However, according to Okal and Cazenave (1985) many islands of the south Tuamotu and Gambier islands are related to hot spot activity. Nukutipipi is part of a sequence from Pitcairn (vicinity of the hot spot) to Hereheretue atoll. Some volcanism has been dated along this line : Gambier is 5 to 7 millions years old. Mururoa is 11 millions years old. According to distance from the hot spot and with these values and the speed of drift, Nukutipipi at 1,500 km from Pitcairn is estimated to be as old as 16-17 millions years. Figure 3 shows the distribution from Pitcairn to Hereheretue.

BRIEF DESCRIPTION OF THE ATOLL :

Nukutipipi is half moon shaped and oriented west-north-west and east-south-east, with its long axis of 3.5 km and small axis of approximatly 2 km. Two little islets (motu) of different length constitute the north and curved rim of the atoll : the north-west motu is 673 m long and the north motu is 2,745 m long. They are separated by a narrow channel (hoa) communicating ocean and lagoon waters, which is maximally 150 m wide and 1 m deep. The south rim of the atoll is a submerged reef where ocean water enters the lagoon, which is 1.500 m wide and no more than 2 m deep. The lagoon consist of a shallow platform, 0 to 2 metres deep, well developed on the south submerged rim, surrounding a deeper part (about 100 hectares, 17 m maximum depth). No patch reef rises up from the lagoon floor to the surface. When trade winds blow from the south or from the east, ocean waves break on the algal crest of the south rim and die towards the lagoon ; lagoon waters exit to the ocean via the hoa. Figure 4 shows a map of the atoll and two sections along the longitudinal and transversal axis.

The tidal range is between 20 and 40 cm according to neap or spring tides but meteorological and oceanographical conditions have more effect on the lagoonal water level than the tide. Salinity in the region is 36‰ throughout the year and sea surface temperature between 23 and 27°5 C.

## LAND FLORA AND FAUNA

Flora and fauna of low-lying islands are poor in species diversity due to very low habitat diversity. All species have to be adapted to oceanic conditions and to carbonate soils. As islanders all species may have reached the island by themselves (anemochory, hydrochory or zoochory) or introduced by man. The remoteness of an island in relation to

others in the vicinity, the size of an island to enable species to expand and the inhabitance or not by man, are some of the ecological factors of major importance which help explain the composition of flora and fauna. The Tuamotu atolls are more than 5,000 km from the American and Australian continents, and Nukutipipi, one of the 76 low-lying islands lying to the south of the archipelago, is remote. The nearest atoll to the Duke of Gloucester islands (Nukutipipi, Anu Anuraro and Anu Anurunga), Hereheretue, lies 200 km to the West. Nukutipipi was uninhabited either by native polynesian or since the beginning of the century, except for a temporary period for coprah or pearl oyster harvest (no more than a few persons). We offer a comparative description of the flora and fauna of Nukutipipi based upon our knowledge of some other atolls in the Tuamotu group.

FLORA :

A total of 21 species have been collected and identified (some with the assistance of Florence, Orstom, Tahiti) and are listed in Table A. In view of to the small size of the two islets (motu) no tree or shrub escaped our inventory. So poor a flora is composed of very common plants found on atolls both in Polynesia and Micronesia (Fosberg, 1990) and there are no endemic species. Nevertheless, some comments are pertinent : on certain Tuamotu atolls more species were reported : 48 on Fangataufa (Jolinon, 1989), 39 on Rangiroa and 37 on Takapoto (Florence, 1986), as well as in the Society Islands : 48 on Tupai and 44 on Tetiaroa (Florence, 1986) but fewer on Scilly : 25-30 (Sachet, 1983). Comparison with Fangataufa flora shows that if all trees and shrubs on this atoll are also found on Nukutipipi, the opposite is not true. Four species exist on Nukutipipi but are absent from Fangataufa. The first is a very important one : *Pisonia grandis*, a tall tree which is the major element of the native vegetation (Fosberg, 1990) before being be cleared for coconut plantations. The absence of *Pisonia grandis* on Fangataufa is unexplained, as we note that there were only a few coconut palms before human settlement (1965) for the purpose of nuclear experiments, as is the situation today. The three other species have been introduced to Nukutipipi for food or ornament (*Artocarpus altilis, Musa troglodytorum* and *Gardenia taitensis*) and not on Fangataufa.

VEGETATION :

The largest motu consists of a 10 hectare primitive forest, the centre part being constituted of *Pisonia grandis, Pandanus tectorius, Guettarda speciosa* and some rare *Cocos nucifera.* Under the trees, and specially in some clearings, grow *Portulaca lutea, Laportea ruderalis* and *Lepidium bidentatum.* The ocean edge of this vegetation is mainly *Argusia argentea, Suriana maritima* and *Scaevola taccada* with tufts (or wisps) of *Lepturus repens* and *Heliotropium anomalum.* In some places *Triumfetta procumbens* entirely covers the sand from the beach to the primitive vegetation. The lagoon edge is dominated by *Scaevola, Argusia, Pandanus, Guettarda* and *Cocos*. The remains of the largest motu is a coconut plantation. About 200 coconut trees survived the 1983 cyclones. Since that time many thousands of coconut have been planted with about a thousand *Casuarina equisetifolia.* Food and ornamental species occurred near the bungalows on the lagoon edge of the largest motu.

The vegetation of the little motu, almost completely destroyed by the cyclones with no more than 50 surviving coconuts was recovering well in 1989. There was no *Pisonia* on this motu and dominant species are *Guettarda* and the massive shrub *Scaevola. Pemphis acidula* occurs only near the hoa.

## LAND CRUSTACEANS AND REPTILES OF NUKUTIPIPI :

We did not collect any land invertebrates except for some land crabs. Only one *Grapsidae* was present but not abundant : *Geograpsus grayi. Cardisoma carnifex,* usually very common near the littoral where it digs deep burrows, is totally absent from the atoll. Four species of hermit crab where collected : *Aniculus aniculus,* a small species inhabiting small gastropod shells *(Muricidae, Cerithiidae),* and 3 larges species inhabiting *Turbo* shells *(Turbinidae)* and whose distinction can be made by their colours : *Coenobita perlatus* (red), *Coenobita brevimanus* (violet) and *Coenobita spinosus* (black). Due to the heavy mortality of *Turbo setosus* by cyclones (gastropods being torn away from the algal crest of the outer reef and deposited in the motu) and the abundance of shelter, the hermit crabs were very abundant.

Reptiles, including the green turtle - *Chelonia mydas* - which lays its eggs on the beaches of the atoll, are of special interest due to recent discovery of lizards which are parthenogenic. Presence or absence of species, parthenogenic or not, parasitised or not with competition between them on any atoll is a matter of biogeography (Blanc et Ineich, 1985 ; Ineich, 1987 and 1989 ; Bertrand et Ineich, 1989). Three species of Scincidae [*Emoia pheonura* (Ineich, 1987), *Cryptoblepharus poecilopleurus* (Wiegman, 1835), *Lipinia noctura* (Lesson, 1826)] and two species of Gekkonidae [*Lepidodactylus lugubris* (Dumeril and Bibron, 1836) - parthenogenic species - and *Gehyra oceanica* (Lesson, 1830)] have been collected.

## BIRDS OF NUKUTIPIPI :

On discovering of the atoll, 1767, Carteret was impressed by "many birds, so tame that they suffered themselves to be taken by hand". Nukutipipi is the island of the Red-tailed tropicbird, *Phaethon rubricauda,* which nests on the sand, along with others species of marine birds.

Ten species have been checked (observations in June, August and November), 8 are marine and 2 are terrestrial birds. These are listed in Table B. The Reef Heron, *Egretta sacra* both black and white, together whith the only warbler found on atolls, the Long-billed Warbler, *Acrocephalus caffer,* form the two terrestrial avifauna of the atoll. One may note that after the cyclones of 1983 only one individual of this last species remained in 1988.

Visiting marine birds include the Wandering Tattler, *Tringa incana,* and the Bristle-Thighed curlew, *Numenius tahitensis,* with its long curved beak. Both these migrators from Alaska are present all the year round on Nukutipipi reefs. However, in November 1988, the most important populations of birds were nesting marine species except for Frigates, *Fregata minor.* Only a few specimens of this species occur in the atoll, with some others visiting from time to time, sometimes for the evening, from Anu Anurunga, the nearby atoll. All these nesting marine birds are permanently on the atoll : *Phaethon rubricauda* is the most abundant (many hundreds). Tern *(Sterna fuscata* or *Sterna lunata),* White Tern *(Gygis alba),* Black Noddy *(Anous tenuirostris)* and hundreds of Red-footed Booby *(Sula sula)* are the other species.

All recorded species are known in French Polynesia (Holyoak et Thibault, 1984) By comparison with Fangataufa atoll (Thibault, 1987), we point out the absence on Nukutipipi of *Phaethon lepturus* (White tailed Tropic Bird), of *Sula leucogaster* (Blue-footed Booby), of *Pluvialis dominica* (Lesser Golden Plover) and of *Sterna bergii* (Crested Terns). No introduced species to French Polynesia are present on Nukutipipi (Thibault and Guyot, 1988), neither *Acridotheres tristis* (Indian Mynah) nor *Columba livia,* respectively introduced on Gambier islands and Mururoa atoll.

No cats, dogs, pigs or other mammals are found in the atoll and the past land-owner, Mr. Madec, was very sensitive to the natural ecosystem of the island, remaining vigilent about introductions. *Rattus exulans* is present.

## REEFS : GEOMORPHOLOGY AND COMMUNITIES

The preliminary description of Nukutipipi (see introduction) defines 3 units between the ocean and the land or the lagoon - A) islet reefs - B) submerged reef - C) hoa.

### ISLET REEFS :

These reefs, facing to the ocean, back on to the motu with or without vegetation but nevertheless back on to the emerged part of the atoll rim. Such are the reefs back to the two motu. They have been prospected for geomorphology and communities along 8 transects from the reef front where ocean waves are breaking to the beach leading to the vegetation of the motu. These transects (A to H) are shown on figure 5 with a schematic representation on figure 6 of different geomorphological units.

The largest of these transects, A : 250 metres, backs on to the little motu. Other reefs are no more than 150-180 metres between the reef front and vegetation. The outer slope has not been prospected.

The reef front is an algal crest on all transects apart from on A, the north-west part of the rim where hydrodynamism is less important. Opposite to A, the reef front at transect H is high and large algal ridge. *Melobesia*, with *Porolithon onkodes* are dominant giving a pink or yellow - green colour at the reef front. In the case of transect A (low reef front without algal crest) coral cover is more than 70 % with *Pocillopora, Montipora, Millepora* and *Acropora*..

For all other transects (B to H) the algal crest has no coral except in some protected pools and crevices and only certain gastropods can settle : Patellidae *(Patella flexuosa)* and Turbinidae *(Turbo setosus)*. The inner part of the algal crest is inhabited by Muricidae *(Drupa ricinus, Drupa clathrata, Drupa morum, Drupella fenestrata, Morula granulata* and *Thais aculeatus*). The density of these gastropods is from 1 to 12 / $m^2$. The most abundant species follow with mention of their maximum densities / $m^2$ : *Drupa ricinus* (10), *Morula granulata* (3) and *Turbo setosus* (2) at transect F according to prospected quadrats of 6 $m^2$. Presence and quantitative distribution of these species is in agreement with prospections on Fangataufa (Salvat, 1970).

A fossil algal crest or remnants of such a crest lie a few tens of metres behind the present algal crest on most of the transects. This fossil crest appears in the form of domes which are smooth on the surface ; they are eroded as usual by boring and scraping organisms and by mechanical action. Large plates of the crest are dislocated and thrown up on to the beach by waves during stormy weather. On transect B two samples of the fossil algal crest were dated : 2235 $\pm$ 80 B.P. and 3475 $\pm$ 100 years B.P. A similar fossil algal crest has been recorded both in the Tuamotu (Mururoa, Chevalier et al., 1968) and in the Cook islands (Woodroffe et al., 1990).

The reef flat without any remnants in elevation or depression is completely exposed at low tide. It is only partly exposed at high tide when the weather is calm. The reef flats are without organisms except boring algae of the genus *Entophysalis* giving its brown color to the carbonate substrate of the reef flat. On the inner part of the reef flat at transects C

and D, remnants of organisms were collected for dating : Serpulidae calcareous tube, 2115 ± 90 years B.P., and coral in growth position : 2410 ± 100 years B.P. These ages attest a higher sea level more than 2000 years ago when these organisms were alive.

Some megablocks occurs on the reef flat at different distances from the reef front where they have been torn out by cyclones. These blocs are not very big and not so numerous as they are in front of the hoa (between transect A and B) and around the western edge of the atoll (between transet A and K).

Conglomerate and remnants of conglomerate are present in some places. These horizontal flagstones stand 0.70 to 1.50 m higher than the reef flat. Old coral conglomerates were investigated in many other French polynesian atolls. Close petrological inspection of thin sections of rocks has shown that there is a consistent difference between the lower and the upper part. The lower had a cementation occurring in the marine phreatic zone when the upper was in the marine vadose zone. The limit between the two zones is correlated with the mean low tide of a previous sea level. Tens of datings on conglomerates of many Tuamotu atolls gave an age of 2000 - 3000 years B.P. related to a sea level 0,9 - 1,0 m higher than today from 5000 to 1500 years B.P. (Pirazzoli and al., 1985 and 1988). The same results were observed in the Cook Islands (Woodroffe et al., 1990) but with differing relative sea-level falls according to the island considered. A *Porites* cemented on the conglomerate was dated at 2140 ± 180 years B.P. Gastropods Littorinidae are the only ones living on the conglomerate : *Tectarius grandinatus* and *Littorina coccinea* whose densities are very low comparatively to those observed in Fangataufa. A third species, *Nerita plicata*, is unusual on the external reefs on Nukutipipi.

Beach rocks are present on transects A, B and C, on the northern part of the atoll. They attest the previous existence of motu or sand accumulation which has been removed.

From these observations and datings, the following conclusions point out the main features of the reefs back to motu :

1 - the reef flats of Nukutipipi are entirely exposed at low tide and without benthic organisms except boring algae *(Entophysalis)*. This is an originality of Nukutipipi not yet reported either on Rangiroa (Stoddart, 1969) nor in Mururoa (Chevalier et al., 1968)

2 - a fossil algal crest, remnants of organic skeletons on the reef flat, and old conglomerate have been dated. They attest a previous sea level higher than the present one, at a time 3500 to 2000 years B.P. This is in agreement with research results on other Tuamotu atolls.

3. There is no "feo" on Nukutipipi as they exist on Rangiroa (Stoddart, 1969) or other Tuamotu atolls : Anaa (Newell, 1956 and Pirazzoli and al. 1985) and Kaukura (Ranson, 1962). We know that these remnants of post inter-glacial reefs are only distributed on atolls in an arc as a result of flexing of the lithosphere beneath the load of Tahiti Moorea.

SUBMERGED REEF :

From the north-west to the south-east the atoll rim is linear. From transect K to I (figure 8) the ocean waves breaking on the reef front spread over the submerged reef at both low and high tide. The situation of this reef is very different to the previous ones (islet reefs) as it is submerged all the time by at least 0,50 m water.

This submerged reef is in two parts. The first is equivalent to the reef flat and the second to a lagoon sand platform. They are separated by a line of scattered remnants of old conglomerate, lying between the south parts of the two motu. These remnants, 30 to 40 cm above low tide level, are actively eroded. A sample was dated at 4375 ± 95 years B.P. The reef front is a very high algal crest due to the important hydrodynamic action of the south swell. Calcareous red algae have their maximum development with construction up to 2.5 m above low tide level. This situation at Nukutipipi is the same as at Mururoa (Chevalier et al., 1968), at Gambier (Brousse et al., 1974) or on northern atolls such as Rangiroa (Stoddart, 1969) or Takapoto (Chevalier et al., 1979). In this high-energy environment some molluscs

and echinoderms settle. Among the first are polyplacophore *(Chiton sulcatus)* and gastropods *(Patella flexuosa, Turbo setosus* and *Drupa ricinus)* and an Opisthobranch Atyidae, *Smaragdinella calyculata,* with a very large foot. Among the second are echinoids *Heterocentrotus mammillatus* and *Colobocentrotus pedifer.* The fauna is more diverse along and just behing the creviced inner edge of the algal crest with scleractinians *(Porites, Pocillopora, Acropora, Millepora),* green algae *(Caulerpa urvilliana, Codium sp.),* zoantharia *(Scleroderma),* holothurians *(Actinopyga mauritiana)* and molluscs *(Drupa ricinus, Morula uva, M. granulata, Dendropoma maxima).* An edge with more than 50 % coverage of *Porites, Millepora, Pocillopora* and *Acropora* leads to the reef flat. Some very scattered remnants, 1 m above the low tide level, can be observed some ten metres behind the inner edge of the algal crest. A sample, boundstone with foraminifera and calcareous algae, appeared to be a remnant of a fossil algal crest and was dated at 3560 ± 110 years B.P.

The submerged reef flat is a smooth surface covered by a very thin algal mat (some millimeters) holding fine sediments. From place to place some scleractiniains are present but coral coverage is less than 1 % : *Pocillopora verrucosa, Acropora sp.,Montipora danae, Pavona varians, Coscinaraea columna, Fungia sp., Porites lichen* and *Leptastrea purpurea .* Benthic organisms on this reef flat are only echinoderms and molluscs : *Holothuria atra* whose abundance increases towards the inner part of the reef flat but never more than 0,2 individuals / $m^2$ - gastropods with dominance of Conidae *(Conus ebraeus, C. sponsalis, C .miliaris, C. chaldeus, C. nanus, C. flavidus)* most of them being worm feeding, along with some other species : *Drupa speciosa, D. grossularia, Morula uva, Cypraea moneta* and *Cerithium citrinoides*

From the geomorphological point of view the submerged reef of the south rim is also a special feature not previously mentioned in other atolls. It consists of a reef flat, some remnants of old conglomerate and a sand lagoon platform, all in continuity with a constant inflow of ocean waters. Such a unit has not been reported either from Rangiroa (Stoddart, 1967) nor from Mururoa (Chevalier et al. 1969) and from all other atolls surveyed since these observations.

## HOA AND MEGABLOCKS :

The channel, on the north rim of the atoll, between the two motu, is a communication between the ocean and the lagoon. Most of the time, unless there are strong northerly winds or and cyclones, water flows from the lagoon to the ocean. The hoa is not deeper than 1 m. In its inner (lagoon side) and central parts it is a smooth flagstone as on the submerged reef flat. Its outer part near the ocean is depressed comparative to the reef flat facing the islets and the coral coverage is from 10 to 50 % with dominance of *Pocillopora, Porites, Acropora, Montipora* and *Millepora.* Many megablocks are scattered over this outer part of the hoa and on its edges. Some are more than 25 $m^3$. They have been placed on the reef flat by cyclonic events as in many Tuamotu atolls (Bourrouilh-Le-Jan et Talandier, 1985). Most of them are grey in colour being incrusted with *Entophysalis* (boring algae) but some are white having recently been positioned by the two cyclones at 1983. These blocks were part of the present reef front where the waves break and have been torn out from the reef front facing the hoa. An aerial view of this edge clearly shows deep indentations on this reef front.

# LAGOON AND COMMUNITIES

The lagoon is bordered by the motu, by the hoa or by the linear remnants of old conglomerate on the submerged rim. Facing the motu the limitation of the lagoon is the intertidal zone which is either narrow with coarse material or large with large beaches of white sand . Such beaches occur when there is a large sand platform before the lagoon slope. The inner part of the hoa is sand banks - 2 to 4 metres deep - between the lagoon slope and the flagstone of hoa - less than 1 m deep. The limit of the lagoon on the linear submerged reef is marked by the scattered remnants of old conglomerate. Entering the lagoon from this point one can observe, a sand platform of no less than 400 metres before the lagoon slope. Such a delimitation of the lagoon gives a total surface of about 2,20 $km^2$ for a total atoll of 5,64 $km^2$. As mentioned in the introduction, half this surface (about 110 hectares) is shallow sand substrate (less than 2 m deep) the other is the deep lagoon with a mean depth 15 m and without patch reefs reaching the surface.

## HYDROLOGY AND HYDRODYNAMISM :

Ocean waters entering the lagoon over the submerged reef flow out by the hoa. Such is the regular circulation of the sea water, except when very strong winds and/or swell occur from the north or in the case of catastrophic events such as hurricanes . The tide is about 40 cm, but the level of the water in the lagoon is more related to sea conditions (more or less swell, and its direction) and to wind conditions. In quiet atmospheric and oceanographic conditions we observed in a 25 cm difference between low and high tide during springs. However, with a strong southerly swell we observed a 44 cm amplitude. Taking into consideration a total lagoon surface of 2,20 $km^2$, the volume of water due to a 25 cm amplitude is 550,000 $m^3$ and 880,000 $m^3$ for a 40 cm amplitude.

Oceanic water entering the lagoon is between 23°C and 27.5°C during the year (reference to Mururoa in the vicinity of Nukutipipi), with maximum temperature from February to April and minimum in September-October. Year-round salinity is 36 ‰. Nutrient concentrations are very low, which is a common feature for oceanic waters in French Polynesia. According to Renon (1989) nutrients in oceanic waters are the following in $\mu$ at g/l = $NO_2$ : 0,1 ; $NO_3$ : 0,1 ; $PO_4$ : 0,4-0,6 ; Si $(OH)_4$ : 1,5.

In calm weather, lagoon water temperature can rise to 30°C (25 to 30°C) on the sand platform near the beach, and up to 29.5°C (25 to 29.5°C) on the sand platform after the submerged reef flat, and up to 26.5°C (26 to 26.5°C) on the lagoon floor. These temperature variations were recorded over a few days in November 1988. Salinity variations due to rainfall were observed in shallow water on the lagoon platform near beaches (less than 2 ‰). Nutrient concentrations in the lagoon were identical to those in the ocean. A secchi disc (30 cm diameter) disappears at a depth of more than 25 m in the ocean, but becomes invisible at 7 or 10 m in the lagoon.

## SAND LAGOON PLATFORM :

More than half the total surface of the lagoon has a sand substrate without any patch coral reef. Maximally 2 metres deep these sands are medium to fine, with a mean diameter between 400 to 600 microns and with a fraction of coarse elements, mainly lamellibranch shells. Nine stations were surveyed (Figure 7) on November 1988. At each station dead Cardiidae shells of the local and common cockle in Tuamotu lagoons (Richard, 1982 a), *Corculum fragum (Cardium fragum)*, are abundant both within and on the surface of

the sediment. Such was not the case during the preliminary survey of the lagoon in 1982 at which time a very important alive population of the cockle covered these shallow white sand flats. The disastrous cyclones in 1983 completely removed the substrate and entirely destroyed the population of *Corculum fragum* which, five years after the event has not yet recovered. We were unable to find even a young population of the cockle. Some *Holothuria atra*, another very common inhabitant of shallow sand flats in Tuamotu atolls, are present but very scare (a few individuals per hectare) as opposed to important concentrations in other atolls (Salvat, 1975). With the exception of two molluscs (*Vexillum cadaverosum* - gastropod Costellariidae - and *Codakia divergens*, lamellibranch Lucinidae), the only macro invetebrate living in these sands is an Enteropneust (acorn-worm) ot the genus *Balanoglossus*. Their density was between 16 and 124/$m^2$, with a mean value of 12/$m^2$.

DOME PATCH REEFS LAGOON:

As mentioned in the introduction, the central lagoon has no patch reef emerging from or near the surface. From the air, the lagoon - bordered by green shallow waters - appears entirely blue. However, a multitude of small submerged patch reefs can be seen very close to one another from a plane flying over the lagoon and on the aerial photograph we had. A bathymetric survey has been undertaken with a sounder along 5 lines, 3 of which are indicated in Figure 8. The mean depth of the lagoon is between 12 and 15 m with some zones or points going down to 17-18 m. Many indentations on the profile of the sounder recording are no more than 2 to 4 m high from the bottom but some are higher with a maximum of 6 m. Observation of the aerial view covering the entire lagoon leads to the conclusion that the bottom of the lagoon is 85-90 % sand and 10-15 % patch reefs. This percentage of hard substrate is very high compared to other closed or open Tuamotu atolls where sand substrate is always more than 95 %.

Patch reefs in the lagoon are in the form of a hill or a dome as observed during more than fifteen dives which enabled us to characterise these coral hills : ten to fifteen metres in diameter, 2 to 4 metres high, round at the base, sometimes with a massive coral construction at or near the summit but always consisting only of dead branches of *Acropora*. This was the first time we have seen such a lagoon patch reef morphology which we will call a "dome patch reef" with the characteristic of being so numerous and widespead in the lagoon. An estimate of the number is about 2 500 for the 110 hectares of the deep lagoon.

Dead branches of the *Acropora* branched form species are tangled on the entire thickness of the dome patch reef in a cavernous structure. This is the case of all the patches indicated on figure 9 with their geomorphological characteristics shown in table C. When present, coral at the summit of the dome patch reefs is as dead as *Acropora* on the slopes. Dome patch reefs with surfaces, of 100 to 225 $m^2$ (diameter from 8 to 12 m), have only a few square decimeters of living scleractinians. Information on these scleractinian species and their very low coverage on the lagoon dome patch reefs is given in table C. At the time of the prospections there were no living branched scleractinians. Two species are more abundant than others : *Leptastrea transversa* (7/10 patches) and *Psammocora contigua* (4/10). We noted only dead *Acropora* without a living population, very poor diversity, very poor coral coverage of other species and spatial homogeneity in the entire lagoon.

Along with filamentous green algae and Cyanophyceae algae, *Caulerpa* and *Microdictyon* Chlorophyceae abundant on the dome patch reefs. Presences, absences and abundances are mentioned in table C. We note that some patches have no important algal coverage (n°2, 4, 5, 9 and 12) while others are dominantly covered (n°1, 10, 11, 13 and 14).

Patch reef numbers 1 and 11 are 100 % covered by the two algae : C. *racemosa* at the base and *C. racemosa* and *C. urvilliana* mixed on the slopes. Patch reef numbers 10, 13 and 14 are entirely covered by *C. urvilliana*. Spatial homogeneity of algae population in the lagoon is the same as for scleractinians.

Molluscs are found on the dead *Acropora* branches with a dominant species, the Bivalve Chamidae , *Chama asperella,* and some other Bivalves with low densities (some scattered individuals) : *Chama iostoma, Pinctada maculata* (Malleidae), *Arca ventricosa* and *A. imbricata* (Arcidae) , *Isognomom sp.* (Isognomonidae), *Lithophaga cinnamonina* and *L. teres* (Mytilidae). We found some rare dead shells of the clam, *Tridacna maxima (Tridacnidae),* but no living specimen. Some old valves of *Pinctada margaritifera* have been found, given evidence of a past population of this species in the lagoon being to be completely eliminated some two decades ago by divers. Some thousands of *P. margaritifera* have been reintroduced during the last decade by the past owner of the atoll, M. Madec, and were alive on some patch reefs at the time of our prospection (1988).

Echinoderms are completely absent from this community which is surprising considering the echinoids and the abundance of algae on which they feed. One exception was one specimen of *Culcita novaeguineae* on patch reef number 5, a stellerid usualy feeding on corals ; the scleractinians cover on this patch reef was no more than 2 $m^2$ ($^1/_{100}$ of the dome patch reef surface).

Crustaceans are discrete but the following species were collected of the Decapod family : *Platypodia granulosa, Chlorodiella nigra* and *Thalamita integra.*

Sponges are not abundant but encrusting forms have been collected and identified : *Chondrosia* and *Spiratrella* (cff *decumbens*). It was the same for Ascidians Didemnidae : *Lissoclinum fragile.*

As being unusual on coral reef communities throughout French Polynesia, one can mention the presence and abundance, on the iron platform for pearl oyster farming (*P. margaritifera*) near station 11 (figure 9), of a Deusterostomian Hemichordate Pterobranch *Cephalodiscus* sub genus *Orthoecus* . Their calcareous tubes, tiny and crumbly, constitute large tufts of many dcm3.

SAND BOTTOM LAGOON :

The sand substrate of the deep lagoon has been surveyed near each dome patch reef as reported on figure 9 and table C, with the exception of numbers 10 and 14. Three main aspects of the bottom were observed : a) bare sand with or without relief according to animal activity, b) sand with scattered *Cyanophyceae* in a large carpet or in round colonies, c) sand covered with a thick cover of green filamentous *Enteromorpha.*

Mollusc fauna is not diverse and all the species collected are mentioned in table D : 5 Bivalves and 3 Gastropods. Two of these were only recorded in the thanatocenose : *Tellina dispar* and *Pitar prora.* The most common one is *Lioconcha phillipinarum* , either living or dead at every station. All three Gastropods are alive when present at different stations. Quantitative survey give the following results for the three dominant species, *L. phillipinarum, Cerithium salebrosum* and *Arcopagia robusta* with extreme densities, mean and standard deviation : 0-16 / 5,4 / 5,9 - 0-17 / 3,6 / 5,3 - 0-15 / 1,8 / 4,5 -.

No Actinians, nor Echinoderms were present on or in the sand substrate. Crustaceans Callianassidae were present but not identified. Sand Meiofauna showed a common composition with dominance of Nematods and of Harpacticoid Copepods and interstitial Polychete worms. Dead population of large foraminifera, *Marginopora (Soritidae)*, were very abundant in the sand and on its surface at some stations.

COMPARISON WITH OTHERS TUAMOTU LAGOONS :

Nukutipipi is the 77 th atoll of the 84 atolls throughout French Polynesia, from the largest (Rangiroa, 171 $km^2$) to the tiniest one (Tepoto Nord, 3,2 $km^2$) Absence of coral patch reefs reaching the surface in the lagoon have been underlined for Taiaro (Chevalier, 1976 - Salvat et al., 1977) and Scilly (Salvat, 1983). They are usually considered as remnants of karstic erosion after emergence during glacial periods but another explanation has been proposed in relation to the endo-upwelling theory (Rougerie et Wauthy, 1986) : rich nutrients raised by the thermal gradient inside the atoll substratrum emerged at some points on the lagoon bottom inducing prosperous coral growth in patch reefs. More than the absence of elevated patch reefs in Nukutipipi, as in Taiaro or Scilly, what is puzzeling to us are the hundreds of dead *Acropora* dome patch reefs. The state of conservation of *Acropora* branches means that mortality occured not many decades ago. If we understand that abiotic variability in such a tiny and enclosed lagoon (without a channel) is the explanation of mass mortality we don't have an hypothesis on the origin of these dome patch reefs. We plan to investigate the structure of some of these little dome patch reefs and date internal elements.

Flora and Fauna of the lagoon can be compared with other closed atolls of the Tuamotu archipelago. Each closed atoll has a poor diversity of flora and fauna compared to the open ones and qualitative and quatitative distribution of species of each of these lagoons are specific (Salvat, 1967). Very important dominance of some species has been well documented in many closed atolls for some benthic taxa : scleractinian corals, molluscs, echinoderms and algae : Reao (Salvat, 1971), Taiaro (Poli et Salvat, 1976), Mataiva (Delesalle et al., 1985), Takapoto (Richard, 1982b) and Scilly (Salvat, 1983). For each taxa the list of species living in these more or less confined environments is limited and one species can be present and dominant, in one lagoon and completely absent in another. We don't have at the moment a clear explanation of such a situation but we suspect that environmental parameters are not the main factor and that first dwellers in a new lagoon environment and species competition play a important role.

Algae (*Caulerpa* and *Microdictyon*) presents a high coverage in Nukutipipi lagoon which was not observed in other closed lagoons even when the species were present. We note also the complete absence in Nukutipipi of *Halimeda* which is mainly present in open lagoons.

Scleractinian corals *Acropora* and *Porites* are the most ubiquitous species, still living in almost all closed lagoons previously mentioned. In Taiaro *Porites* is the last surviving genus in the lagoon. The originality of Nukutipipi is the extreme dominance of *Acropora* whose branching form constitutes hundreds of dome patch reefs, and the fact that they are all dead without any new colonies.

Echinoderms are almost completely absent from Nukutipipi lagoon with the exception of some rare individuals of *Halodeima atra* which have such high populations elsewhere. The absence of echinoids is also very surprising.

Mollusc species of the hard substrate are few and with low densities. *Pinctada maculata*, a very common species of closed lagoons is there as well as *Chama asperella*.We note the complete absence of the clam, *Tridacna maxima*. Mollusc sand-dwellers are common species of closed lagoons but Nukutipipi is unusual in having totally dead populations of two bottom species (*Tellina dispar* and *Pitar prora*) and of one lagoon sand platform species (*Corculum fragrum*).

## SUMMARY

The tiny atoll of Nukutipipi (5 $km^2$) was first surveyed in 1982, 1986 and mainly 1988. Uninhabited since its discovery by Carteret in 1767, the atoll was planted with coconut at the beginning of this century. It was seriously destroyed by Orama and Veena in 1983. The volcanic origin is estimated to be 16-17 million years old, since migration of the Pacific plate from the vicinity of the Pitcairn hot spot 1 500 km east-south-east.

If flora present a low diversity (21 species), the surviving *Pisonia* forest on the largest motu is most interesting. Land crustaceans, with large populations of hermit crabs (*Coenobita*) and reptiles, with parthenogenetic Gekkonidae, were identified. Ten species of birds, marine (8) and land (2), have been listed with hundreds of resident Red-tailed tropic birds (*Phaethon rubricauda*) as mentioned two centuries ago by Carteret. No mammal except *Rattus exulans* has been introduced to the atoll.

Reefs are described with some originalities : a) an entirely emerged reef flat on the north rim of the atoll, even at high tide, b) a fossil algal crest c) an uncommon submerged reef on the south rim.

The lagoon sand platform, less than 2 m deep, is a bare surface whose mollusc population of the common cockle, *Corculum fragrum*, was completely destroyed by hurricanes in 1983. It is characterised at the moment by a large population acorn worm (*Balanoglossus*). The deep lagoon, of 18 m maximum depth, without any patch reefs reaching the surface, is characterised by many hundreds of "dome patch reefs" exclusively constituted of dead *Acropora* coral branches. No more than 6 species of scleractinian corals present a living cover much less than 1 % on these patch reefs most of them covered by algae, *Caulerpa* and *Microdictyon*. Some gastropods have low density populations and there is no Echinoderm in the lagoon.

In the sediment 8 species of mollusc were identified, 2 of them exctinct and 1 alive as dominant (*Lioconcha*).

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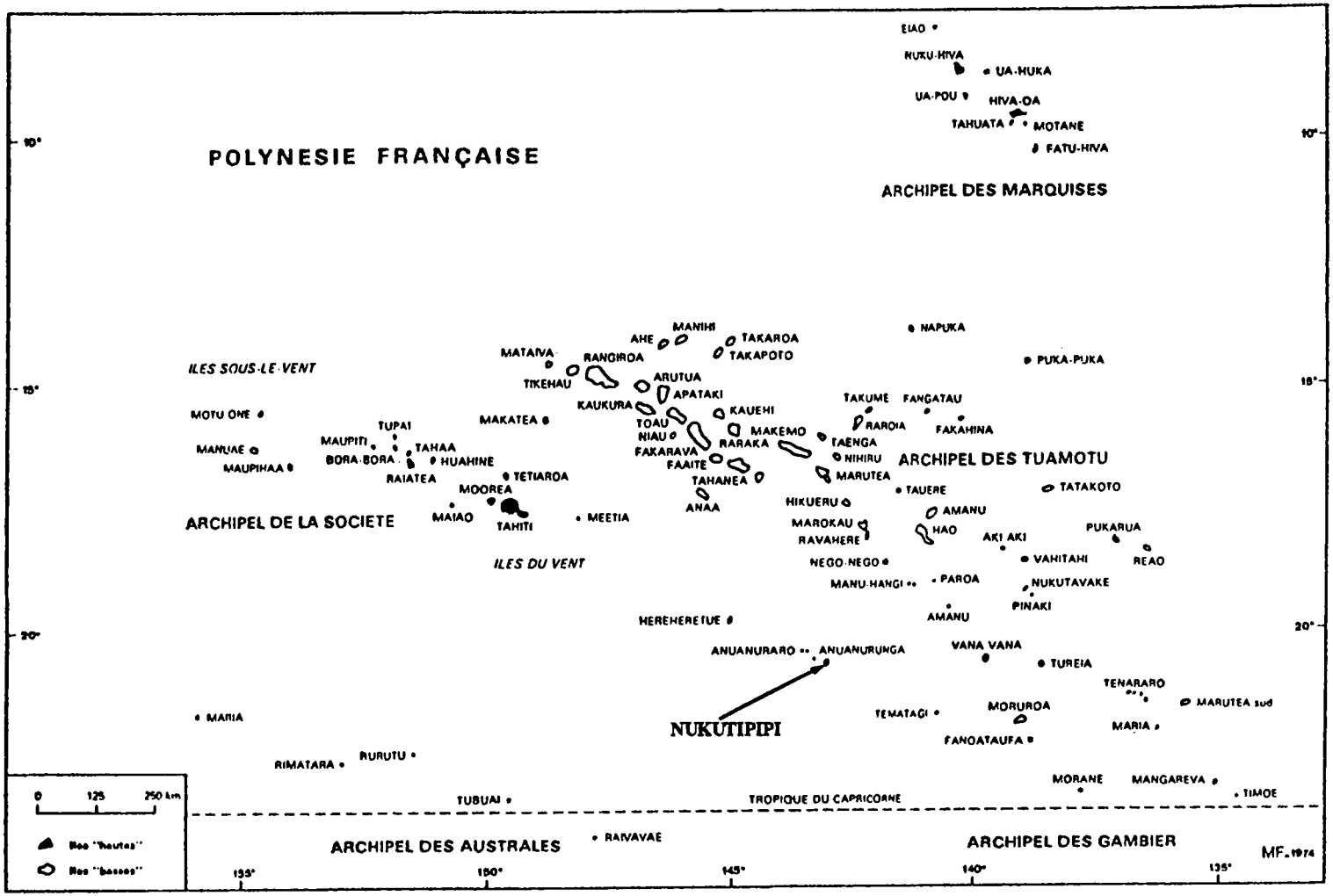



Figure 1 : French Polynesian archipelagoes . Localisation of Nukutipipi atoll in the Tuamotu archipelago.

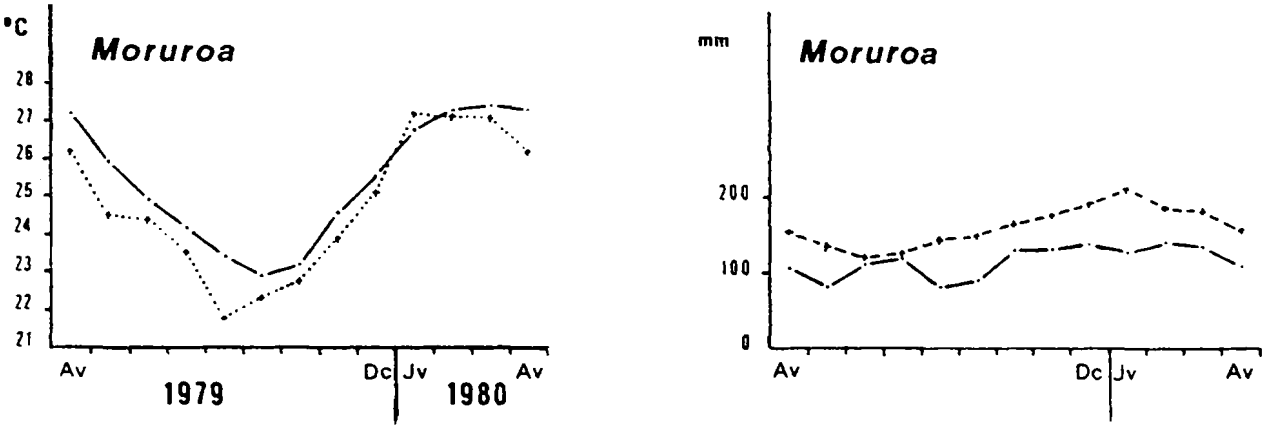



Figure 2 : Meteorological data on Mururoa, 430 km east of Nukutipipi and same latitude. Air (dashed line) and sea water (full line) temperature in C°. Precipitation (full line) and evaporation (dashed line) in millimeters. Mean monthly values over ten years (from RENON, 1989).

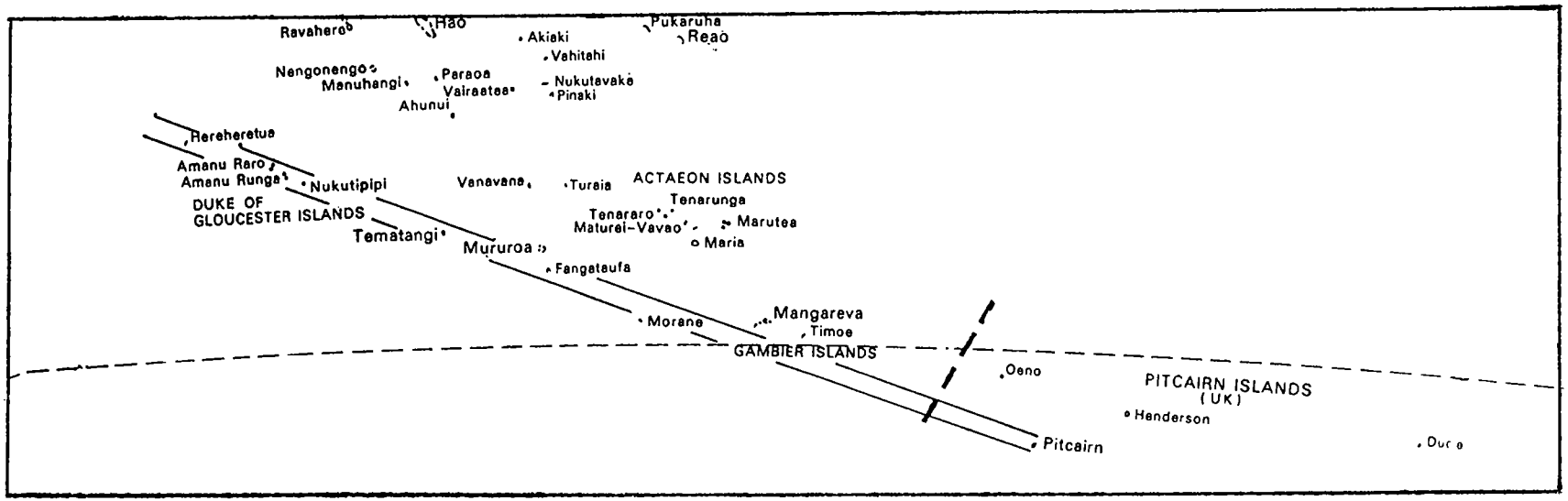
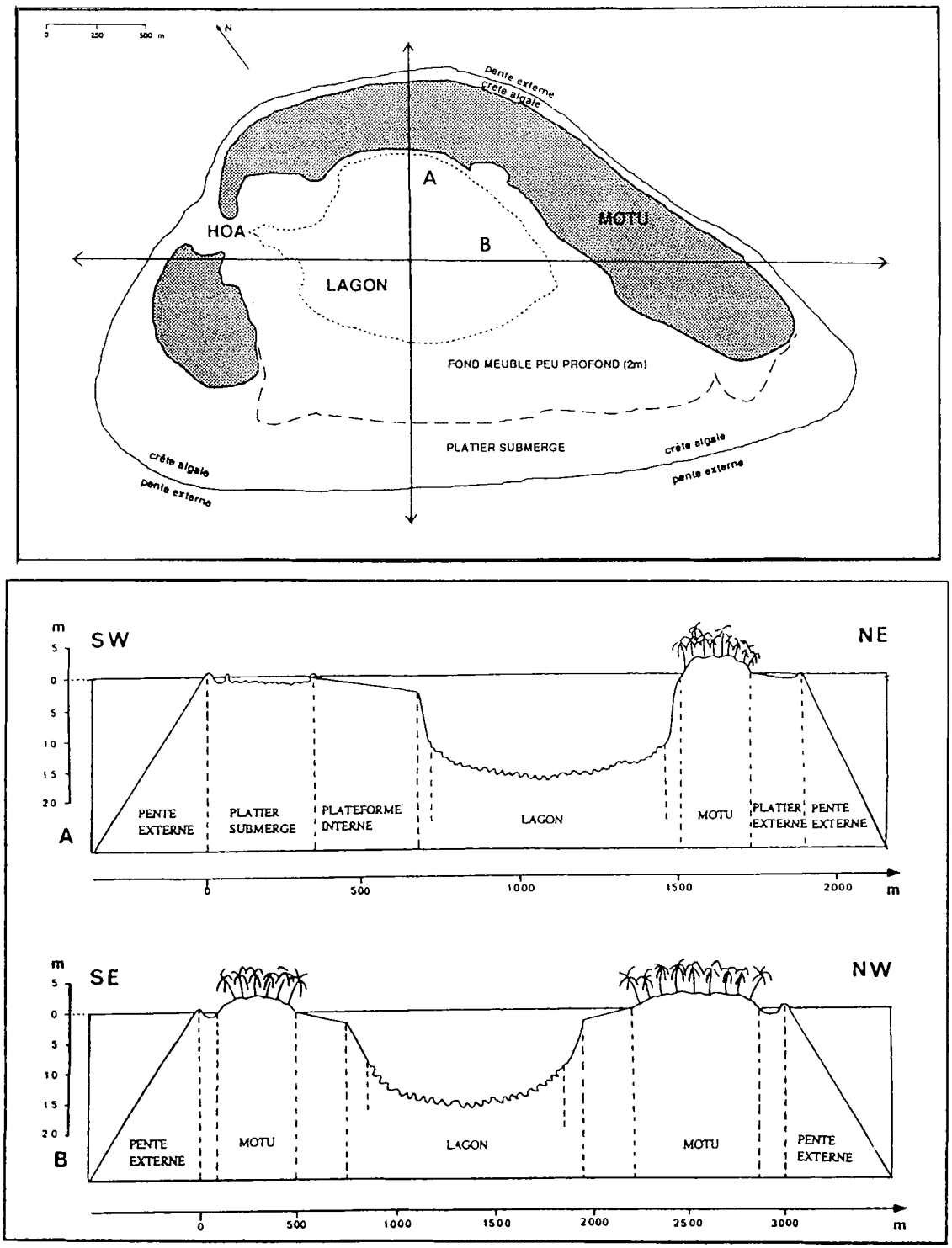



**Figure 3 : Pitcairn -Hereheretue alignment from the hot spot near Pitcairn. Dashed line separates French Polynesia and United Kindom Islands.**




**Figrue 4 : Map of Nukutipipi atoll with two transects across the island and mention of the main geomorphological units.**

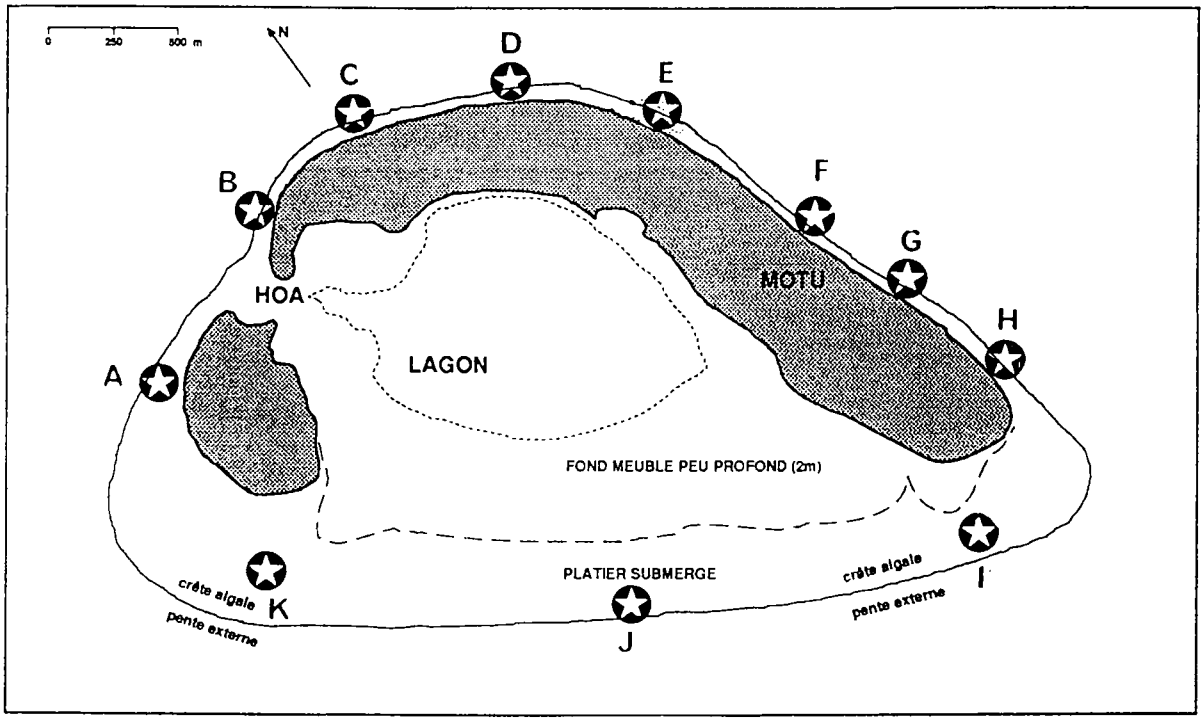



Figure 5 : Outer reef transects surveyed on Nukutipipi.

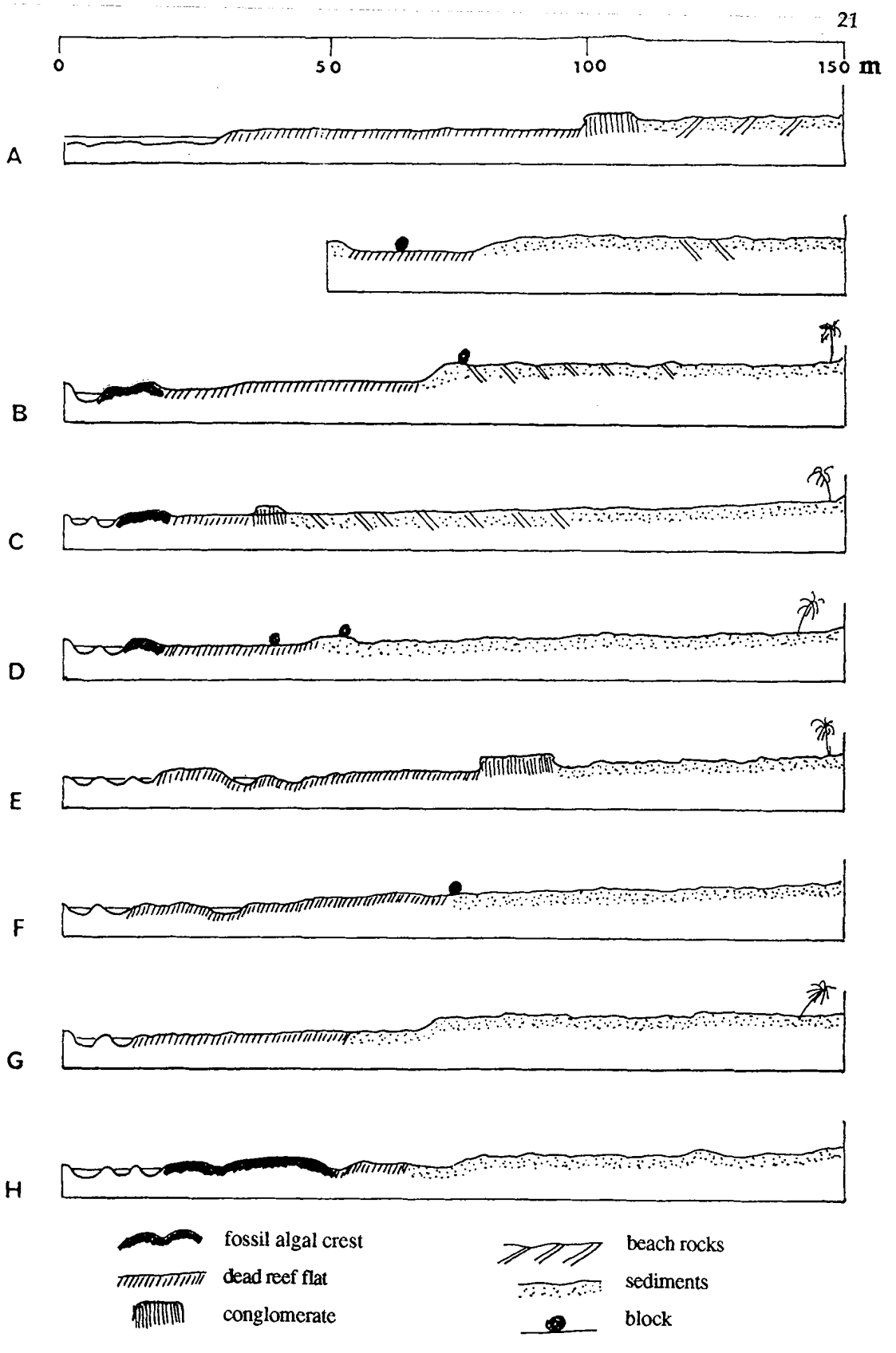



**Figure 6 : Diagram of the morphology of the 8 transects prospected on the outer reefs of Nukutipipi. Letters (A to H) refer to the position of the transects on figure 5.**

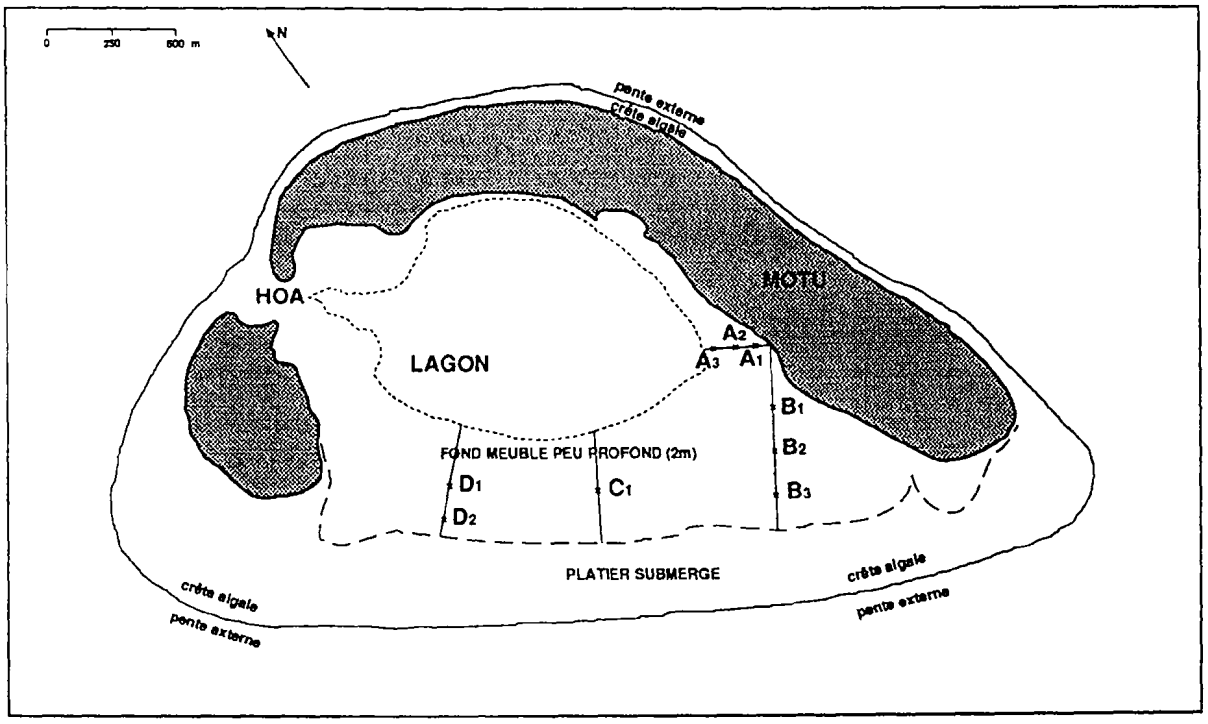
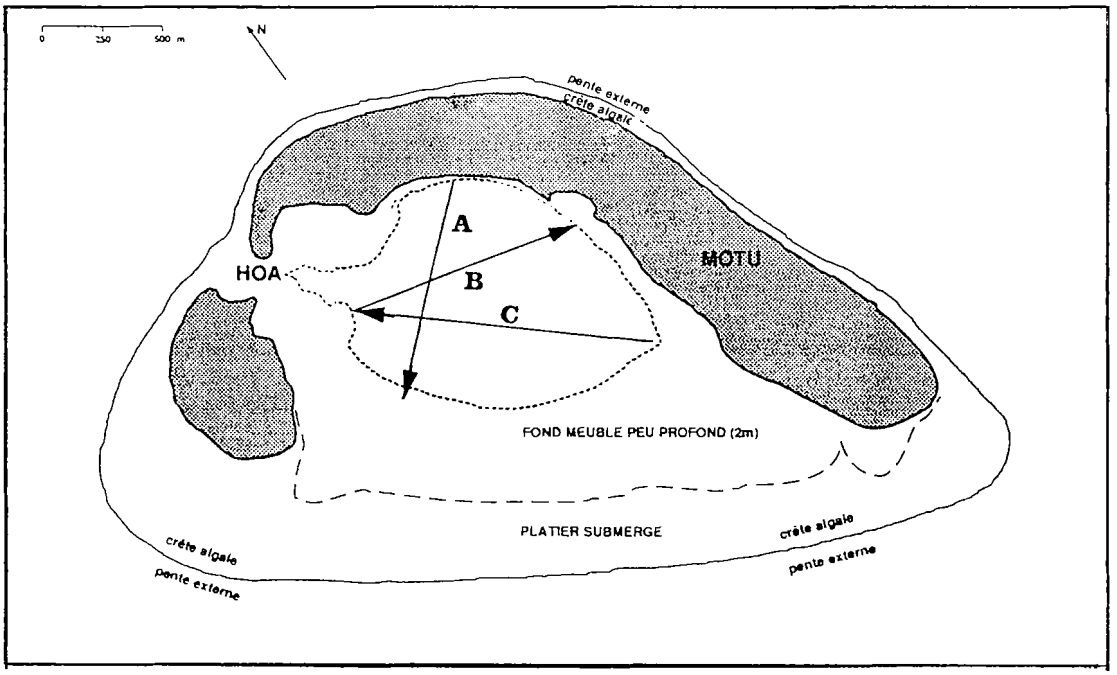
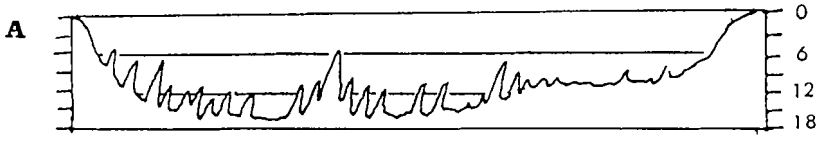
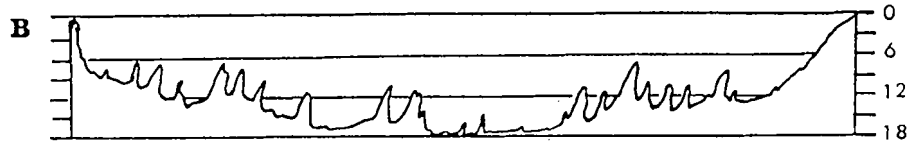



Figure 7 : Surveyed transects and stations on the sand lagoon platform .



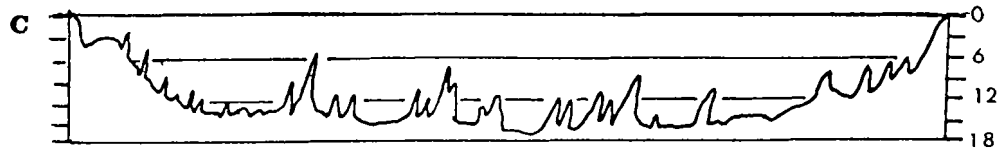




**Figure 8 : Bathymetry along three transects in the lagoon.**

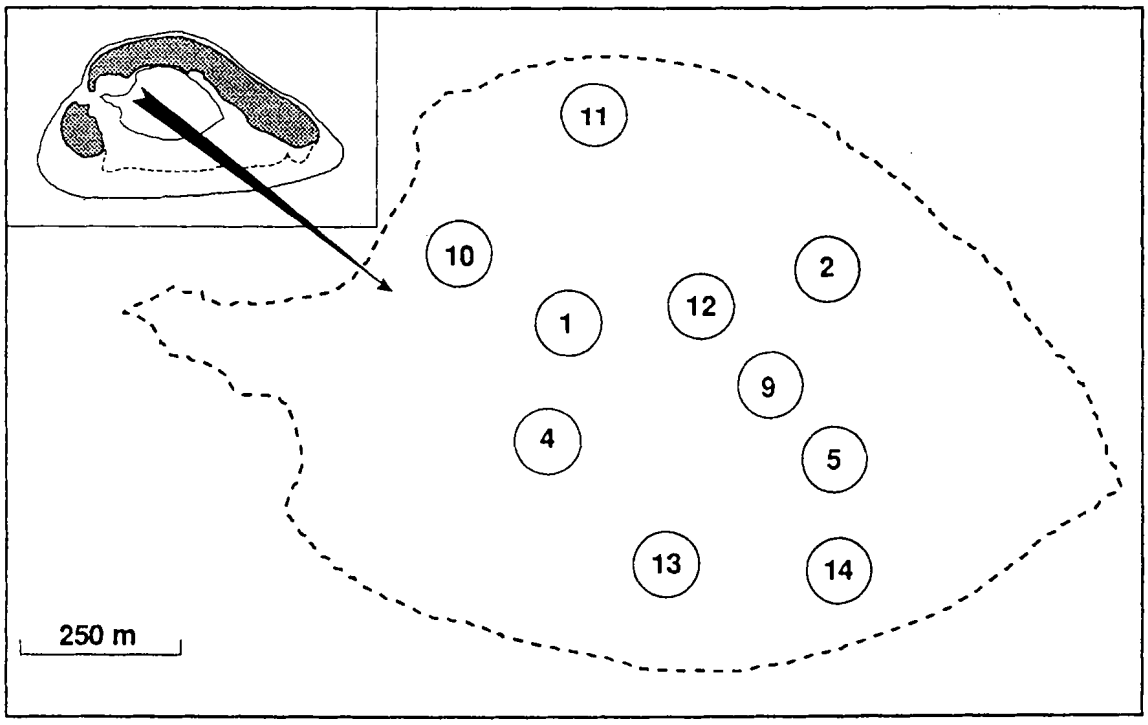



Figure 9 : Localisation of survey stations in the lagoon. Absent numbers correspond to planned but as yet not surveyed site.

- **Boraginaceae**
  *Argusia argentea* (L.f.) Heine
  *Heliotropium anomalum* Hook. & Arn.

- **Casuarinaceae**
  *Casuarina equisetifolia L.*

- **Cruciferae**
  *Lepidium bidentatum* Montin

- **Goodeniaceae**
  *Scaevola taccada* (Gaertn.) Roxb.

- **Gramineae**
  *Lepturus repens* (Forst.) R. Br.

- **Lauraceae**
  *Cassytha filiformis L.*

- **Lythraceae**
  *Pemphis acidula* Forst.

- **Malvaceae**
  *Hibiscus tiliaceus L.*

- **Moraceae**
  *Artocarpus altilis* (Park.) Fosb.

- **Musaceae**
  *Musa troglodytarum L.*

- **Nyctaginaceae**
  *Boerhavia tetrandra* Forst.
  *Pisonia grandis* R. Brown

- **Palmae**
  *Cocos nucifera L.*

- **Pandanaceae**
  *Pandanus tectorius* Soland.

- **Portulacaceae**
  *Portulaca lutea* Soland.

- **Rubiaceae**
  *Gardenia taitensis DC.*
  *Guettarda speciosa L.*
  *Timonius polygama* (Forst. f.) Rob.

- **Surianaceae**
  *Suriana maritima L.*

- **Tiliaceae**
  *Triumfetta procumbens* Forst.

- **Urticaceae**
  *Laportea ruderalis* (Forst. f.) Chew

**Table A : Flora of Nukutipipi atoll (1988 observations)**

- **Phaethontidae**
  *Phaethon rubricauda* Boddaert

- **Sulidae**
  *Sula sula* (L.)

- **Fregatidae**
  *Fregata ariel* (Gray)

- **Ardeidae**
  *Egretta sacra* Gmelin

- **Charadriidae**
  *Numenius tahitiensis* (Gmelin)
  *Tringa incana* (Gmelin)

- **Sternidae**
  *Sterna fuscata L.*
  *Gygis alba* (Sparrman)
  *Anous tenuirostris* (Temminck)

- **Muscicapidae**
  *Acrocephalus* (caffer) *ravus* (Wetmore)

**Table B : Birds of Nukutipipi atoll (1988 observations)**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numéro du paté | 1 | 2 | 4 | 5 | 9 | 10 | 11 | 12 | 13 | 14 |
| | Profondeur du plancher du lagon en m. | 12 | 11 | 12 | 12 | 12 | 10,5 | 12 | 13 | 11 | 10 |
| | Hauteur du paté en m. | 2 | 2 | 2,5 | 3 | 3,5 | 1,5 | 2 | 2 | 1 | 1 |
| | Diamètre du paté en m. | 8 | 8,5 | 8 | 11 | 12 | 10 | 11 | 11 | 7 | 6 |
| | Construction sommitale | oui | non | non | oui | oui | oui | oui | non | non | oui |
| | Flanc d'acropores cassés | oui | oui | oui | oui | oui | oui | oui | oui | oui | oui |
| FAMILLE | ESPECE | | | | | | | | | | |
| SCLERACTINAIRES | | | | | | | | | | | |
| Thamnasteriidae | Psammocora contigua | P | A | 0 | 0 | P | 0 | P | 0 | 0 | 0 |
| Astrocœniidae | Stylocœniella guentheri | 0 | 0 | 0 | A | P | 0 | 0 | 0 | 0 | P |
| Pocilloporidae | Pocillopora damicornis | 0 | 0 | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Poritidae | Porites cf. vaughani | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Faviidae | Leptastrea transversa | P | P | P | A | P | 0 | P | P | 0 | 0 |
| | Cyphastrea serailia | P | 0 | 0 | 0 | 0 | A | 0 | 0 | 0 | 0 |
| ALGUES | | | | | | | | | | | |
| Chlorophyta | Caulerpa racemosa | PD | P | P | P | 0 | P | PD | PD | 0 | 0 |
| | Caulerpa urvilliana | PD | P | P | P | 0 | PD | PD | P | PD | PD |
| | Microdictyon okamurai | P | P | 0 | P | P | 0 | P | P | 0 | 0 |

**Table C : Dome patch reefs of the Nukutipipi lagoon. Distribution of scleractinian corals (P = present only by a few dcm$^2$, A = abundance between 0,5 and 1,5 m$^2$, 0 = absent) and of algae (P = present with a cover less of 5 % of the patch reef surface, PD = Dominant with a cover more than 30 %)**

| STATIONS DU LAGON | 1 | 2 | 4 | 5 | 9 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|
| BIVALVES | | | | | | | | |
| **Lucinidae** | | | | | | | | |
| *Codakia divergens* | | B | | | B | | | |
| **Tellinidae** | | | | | | | | |
| *Arcopagia robusta* | T | | B | | | | | |
| *Tellina dispar* | T | T | | | T | | | T |
| **Veneridae** | | | | | | | | |
| *Lioconcha philippinarum* | T | B | B | T | B | B | T | B |
| *Pitar prora* | | | | T | | | | |
| GASTROPODES | | | | | | | | |
| **Cerithiidae** | | | | | | | | |
| *Cerithium salebrosum* | B | B | B | B | B | B | B | B |
| *Rhinoclavis fasciata* | B | B | B | | | B | | B |
| **Costellariidae** | | | | | | | | |
| *Vexillum cadaverosum* | B | B | | | | B | B | |

**Table D : Distribution of molluscs in sand bottom lagoon stations. B = bios, living species - T = thanatocenose , dead specimens.**

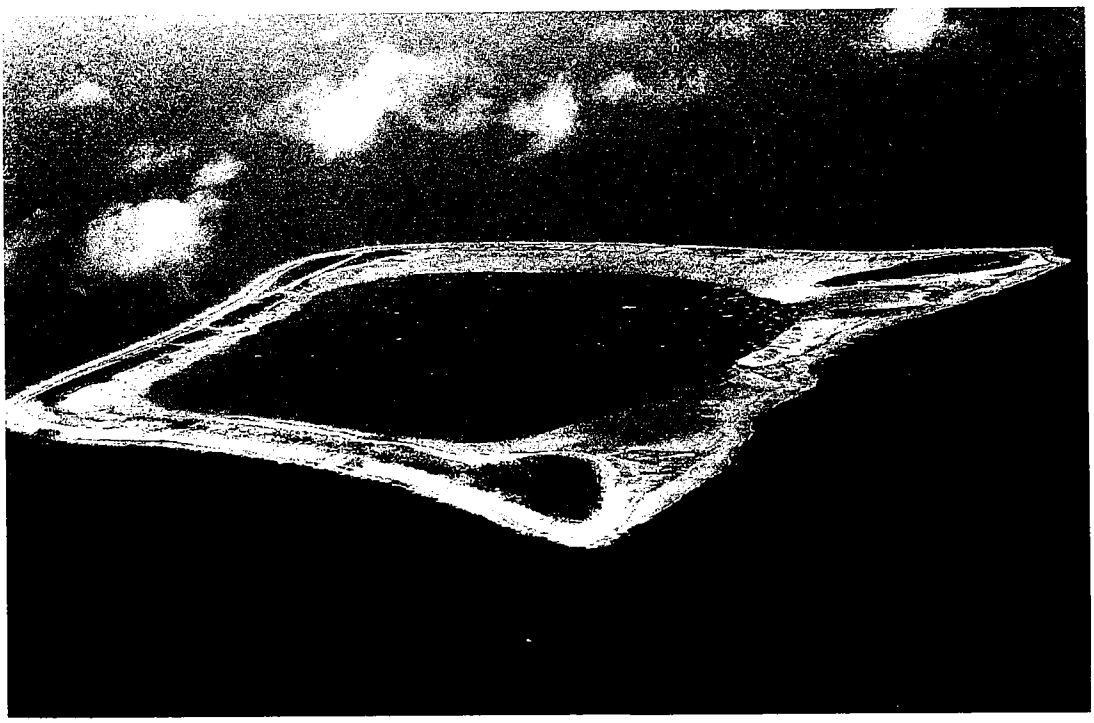


Plate 1 : Anu Anuraro Atoll, Duke of Gloucester islands, Tuamotu archipelago. (Ref . plate : 1988 / A-5).

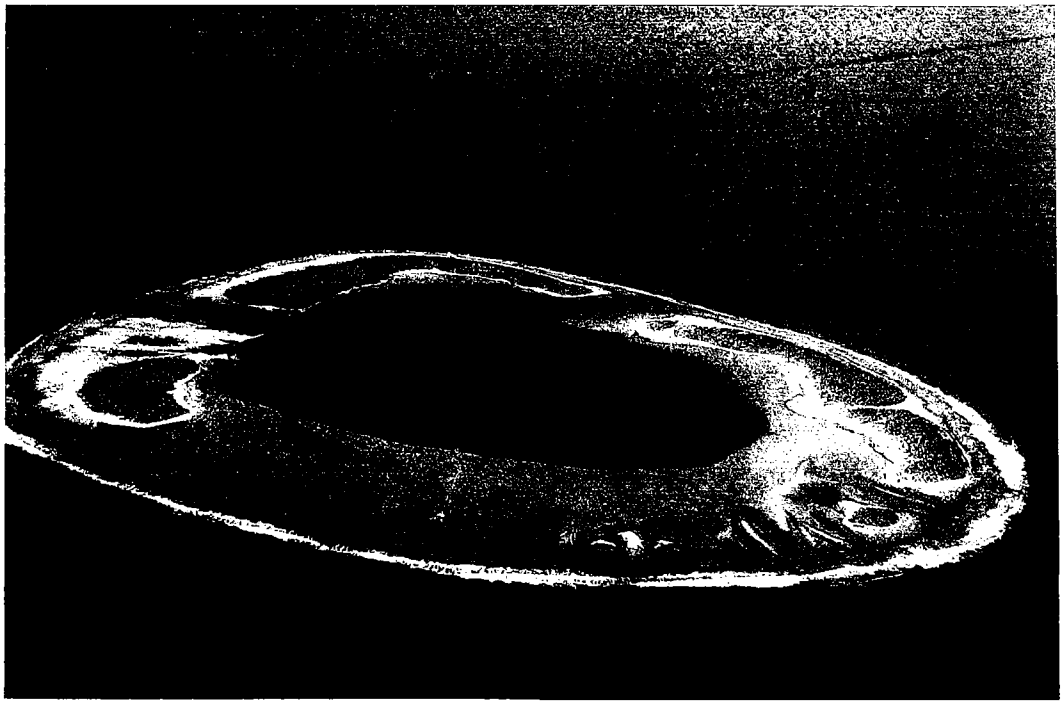


Plate 2 : Anu Anurunga Atoll, Duke of Gloucester islands, Tuamotu archipelago. (Ref. plate : 1982 / 9-24).

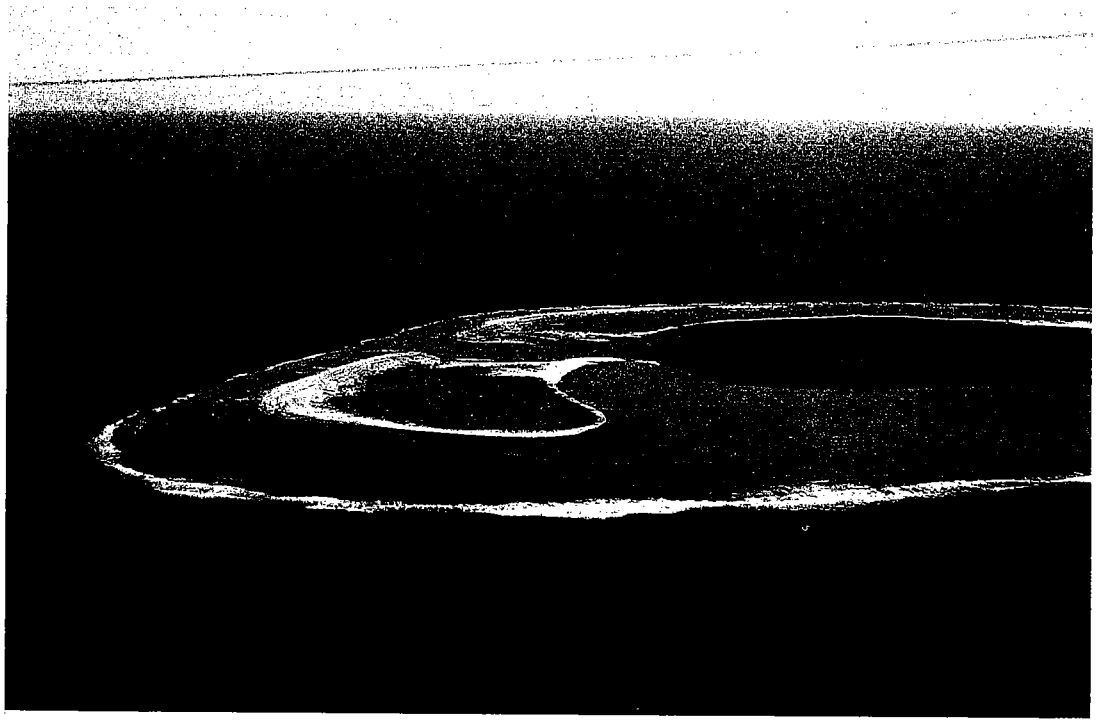


Plate 3 : Nukutipipi atoll, north-west part (from the south), Duke of Gloucester islands, Tuamotu archipelago (Ref. plate : 1982 / 9-17).

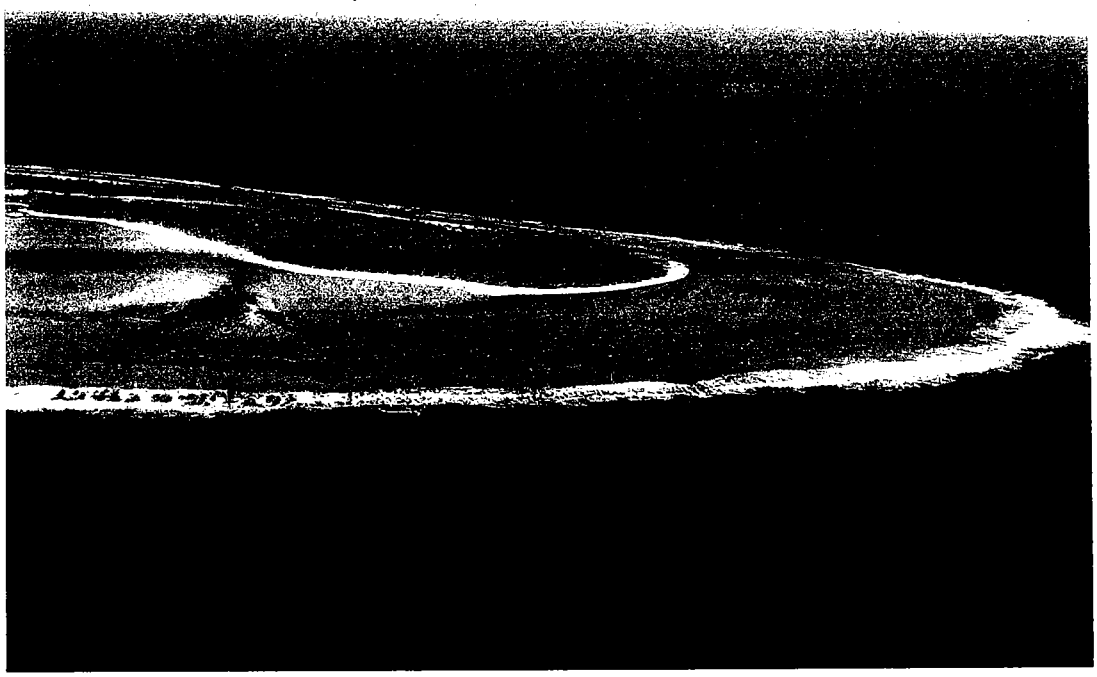


Plate 4 : Nukutipipi atoll, south-east part (from the south), Duke of Gloucester islands, Tuamotu archipelago (Ref. plate : 1982 / 9-10).

Plate 5 : Composition of the aerial cover prints of Nukutipipi atoll in 1965. Length (from reef fronts) is about 3,5 km. Surface is about 5 $km^2$. Little motu (lower left) and large motu (above).

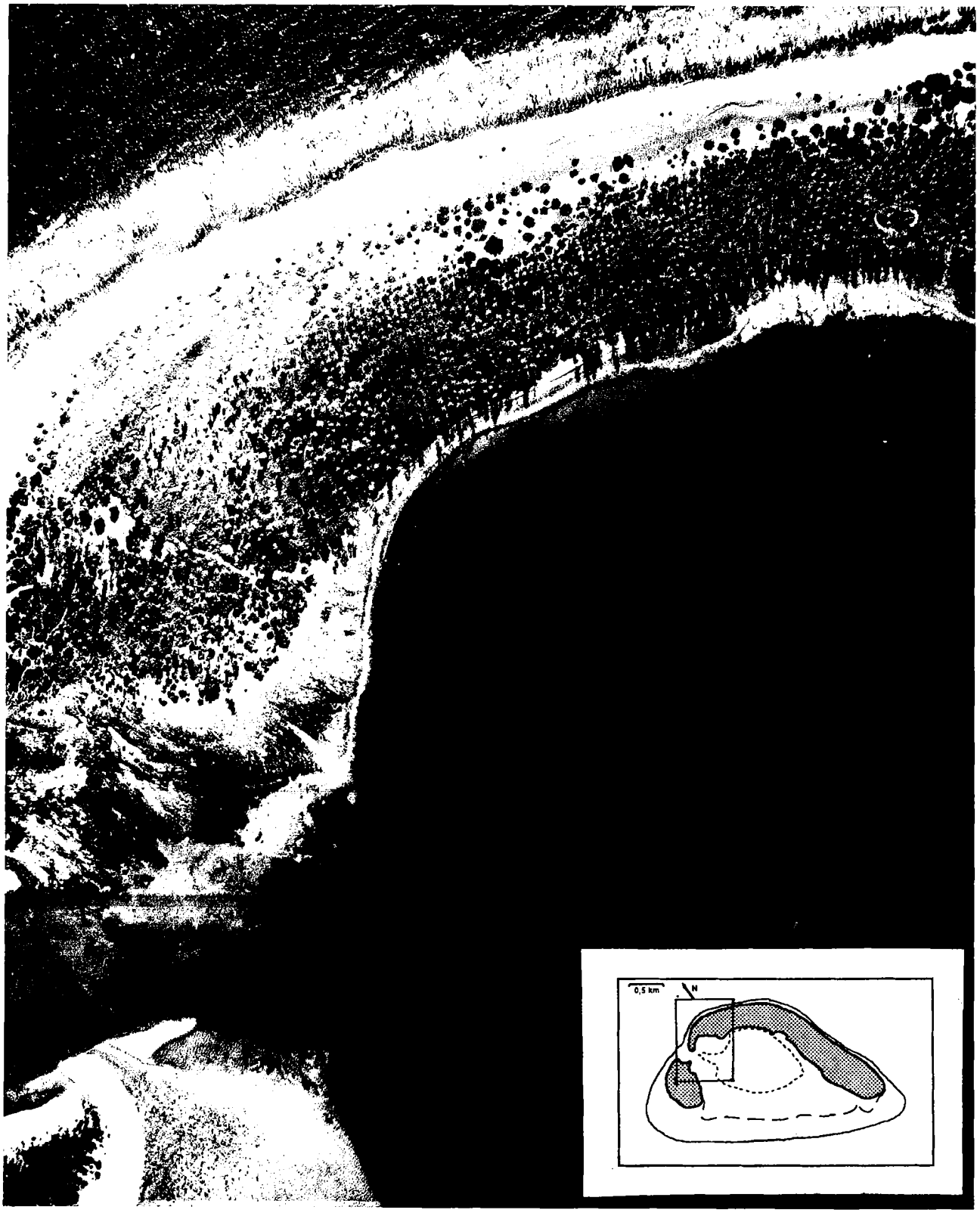



**Plate 6 : Print of one aerial view of Nukutipi atoll on 11 th July 1965. Localisation indicated on the reference map. Northern parts of the large (background) and little (foreground) motu separated by the hoa where lagoon waters (right) exit to the ocean (left).**

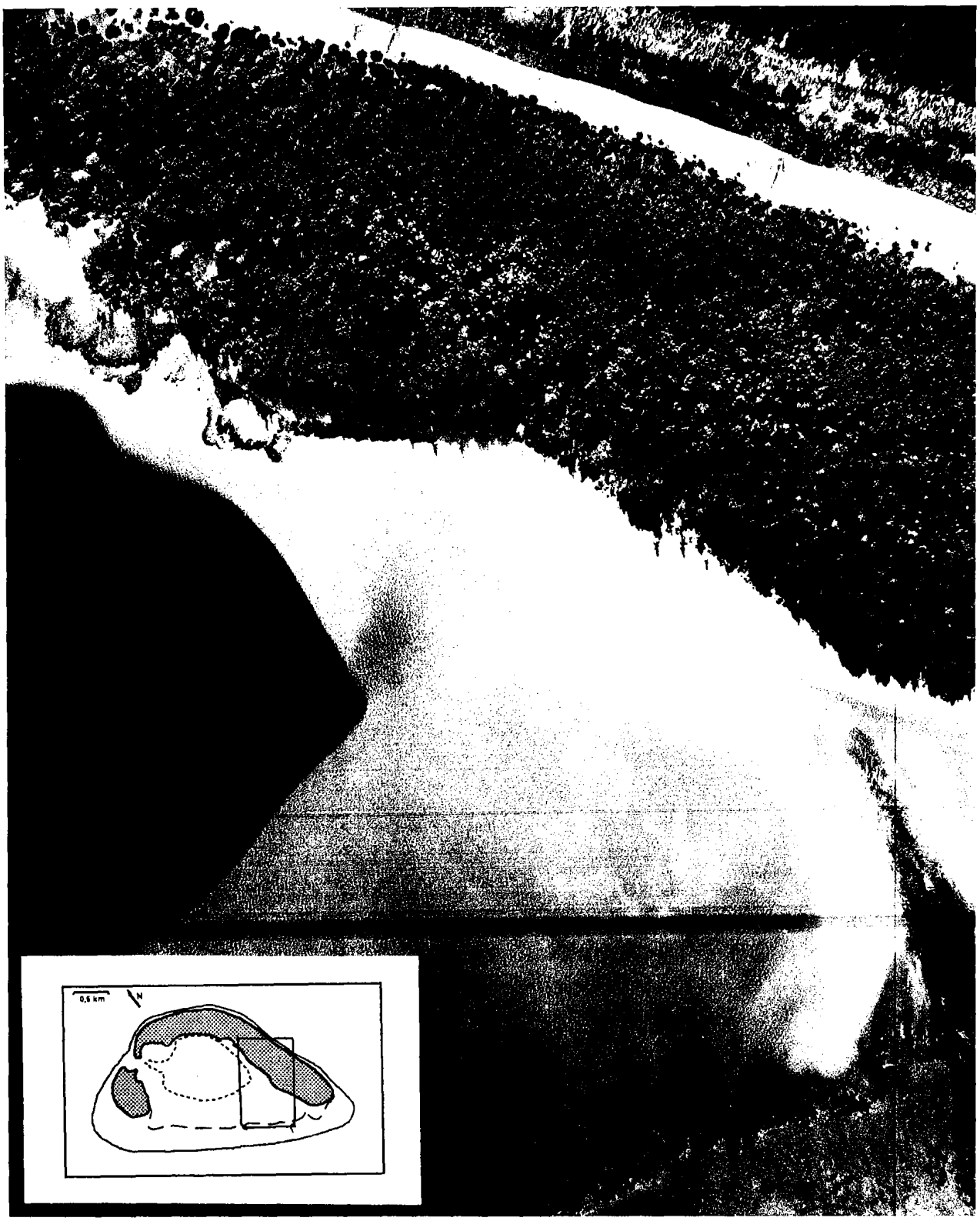



**Plate 7 : Print of one aerial view of Nukutipi atoll on 11 th July 1965. Localisation indicated on the reference map. Up : Large motu - Down : sand lagoon platform (2 m deep) - Left : deep lagoon (15 m deep) with submerged dome patch reefs.**


Plate 8 : Print of one aerial view of Nukutipi atoll on 11 th July 1965. Localisation indicated on the reference map. Southern part of large motu with primitive vegetation (*Pisonia grandis* forest), emerged reef flat of the south eastern part of the atoll, reef front and algal crest where waves from the ocean break.


Plate 9 : Print of one aerial view of Nukutipi atoll on 11 th July 1965. Localisation indicated on the reference map. From top to bottom : deep lagoon with submerged patch reefs, sand lagoon platform, remnants of old conglomerate, submerged reef flat, algal crest with breaking waves from the ocean.

Plate 10 : Southern part of the large motu - *Pisonia* forest with *Pandanus, Guettarda* and *Cocos*. Airfield on the right background. (Ref. plate : 1986 / 8-11).

Plate 11 : Vegetation on the large motu : *Pisonia grandis* (right), *Cocos nucifera* (center) and *Pandanus tectorius* (left). (Ref. plate : 1982 / 7-27).

Plate 12 : Northern part of the large motu with coconut plantation (foreground) and the little motu (background) separated by the hoa ; 1982 before hurricanes. (Ref. plate : 1982 / 7-15).

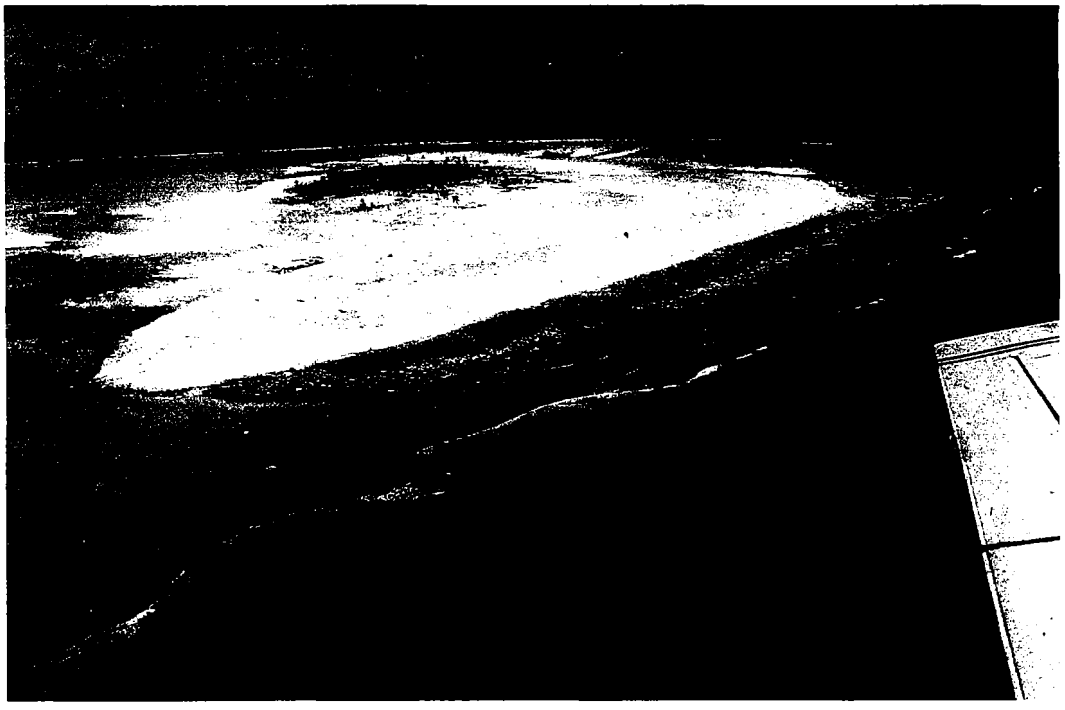


Plate 13 : The little motu in 1986 with vegetation reduced by 2/3 after hurricanes Orama and Veena in 1983 (Ref. plate : 1986 / 8-18).

**Plate 14 : The Red-tailed tropic bird, *Phaethon rubricauda*, the most representative bird of Nukutipipi atoll. (Ref. plate : 1988 / 6-23).**

**PLate 15 : Hermit crab, *Coenobita perlatus*, here in a *Turbo setosus* shell, forms a large population on Nukutipipi atoll.**

Plate 16 : Low algal crest of northern reef flat. A block torn up from the reef front to the reef flat during cyclone (Ref. plate : 1988 / 3-1).

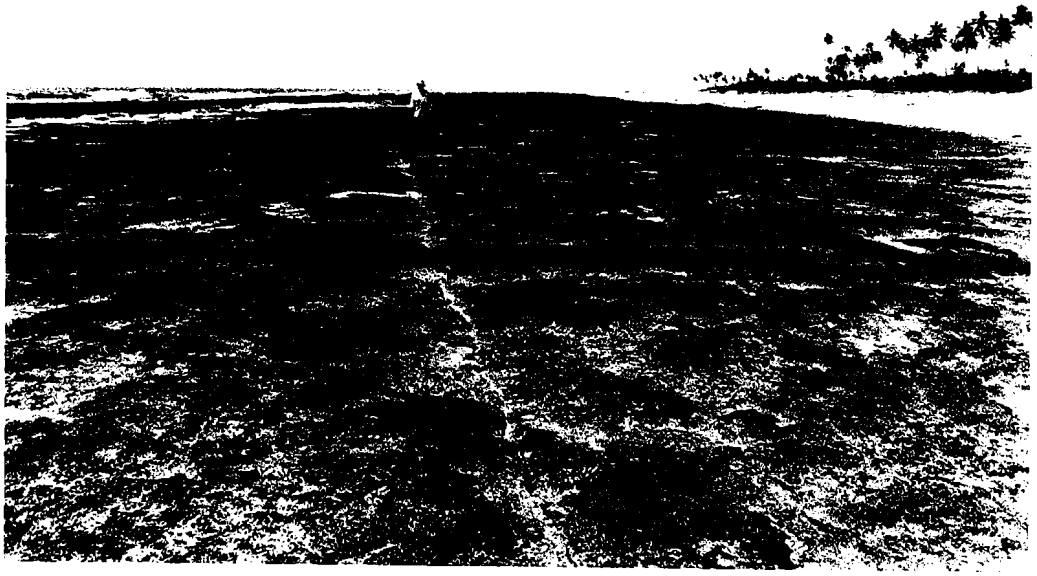


Plate 17 : Completely emerged reef flat of northern part of the atoll. A fracture parallel to the reef front (Ref. plate : 1988 / 3-6).

Plate 18 : Fossil algal crest as dome mounts (foreground) behind the present low one (background). Northern rim of the atoll (Ref. plate : 1988 / 6-32).

Plate 19: Fossil algal crest with dislocated plates which are thrown up by waves. Dated 2235 and 3475 years B.P. (Ref. plate : 1988 / 6-18).

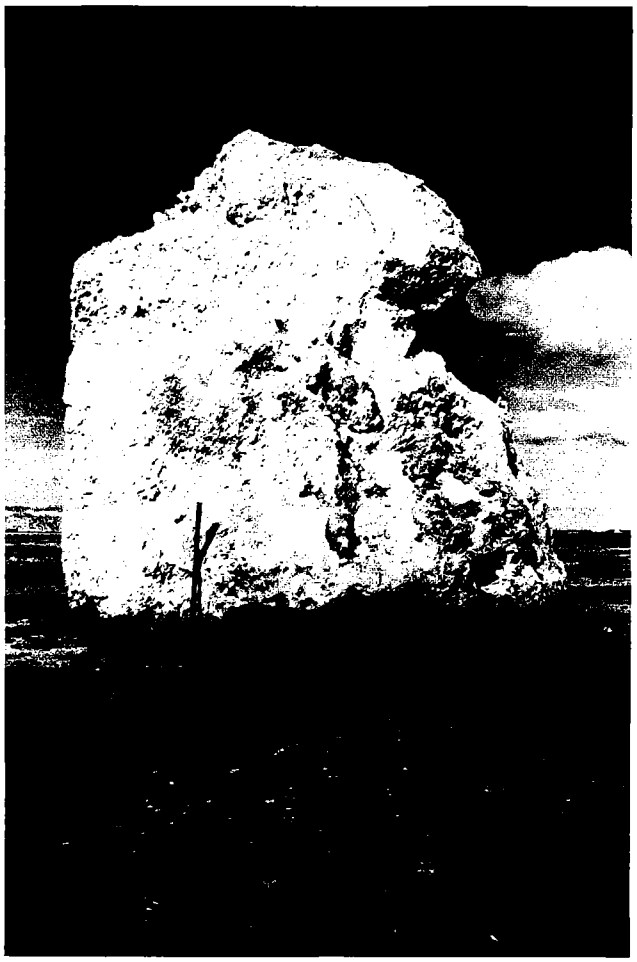


Plate 20 : A megablock, 4 m high and about 30 $m^3$ torn up from the reef front to the reef flat during hurricane Orama or Veena, 1983 (Ref. plate : 1986 / 1-29).

Plate 21 : A megablock, 10 m long and about 25 $m^3$, torn up from the reef front (background) to the reef flat during hurricane Orama or Veena, 1983 (Ref. plate : 1986 / 1-25).

**Plate 22 : Old conglomerate remnants of the south rim of Nukutipipi atoll, separating submerged reef flat (rigth) and sand platform lagoon (left). Dating gives 4395 ± 95 years B.P. Ref. plate : 1982 / 8-13, MM. J.A. Madec and R. Wan).**

**Plate 23 : Remnant of fossil algal crest on the south rim of Nukutipipi. Boundstone sample 1 m above low tide level was dated 3560 ± 100 years B.P. (Ref. plate : 1982 / 8-19, M. J. A. Madec).**

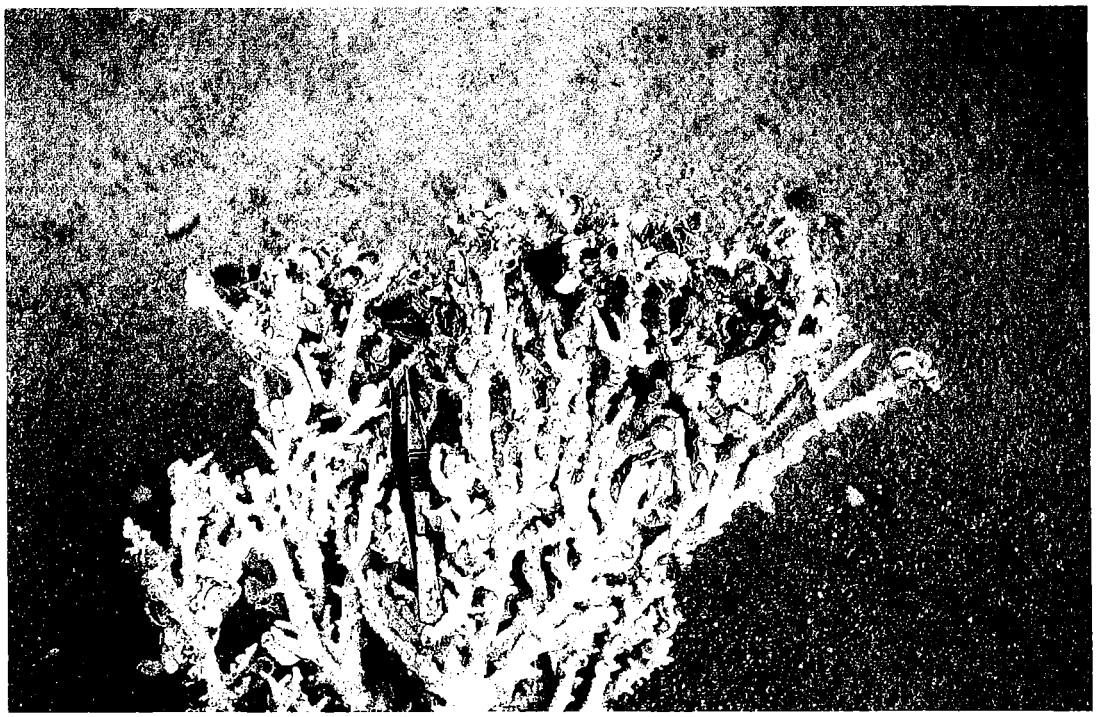


Plate 24 : Dead branches of *Acropora* constituting dome patch reefs in the lagoon. *Chama asperella* population fixed at the tip of branches (Ref. plate : 1988 / 7-19).

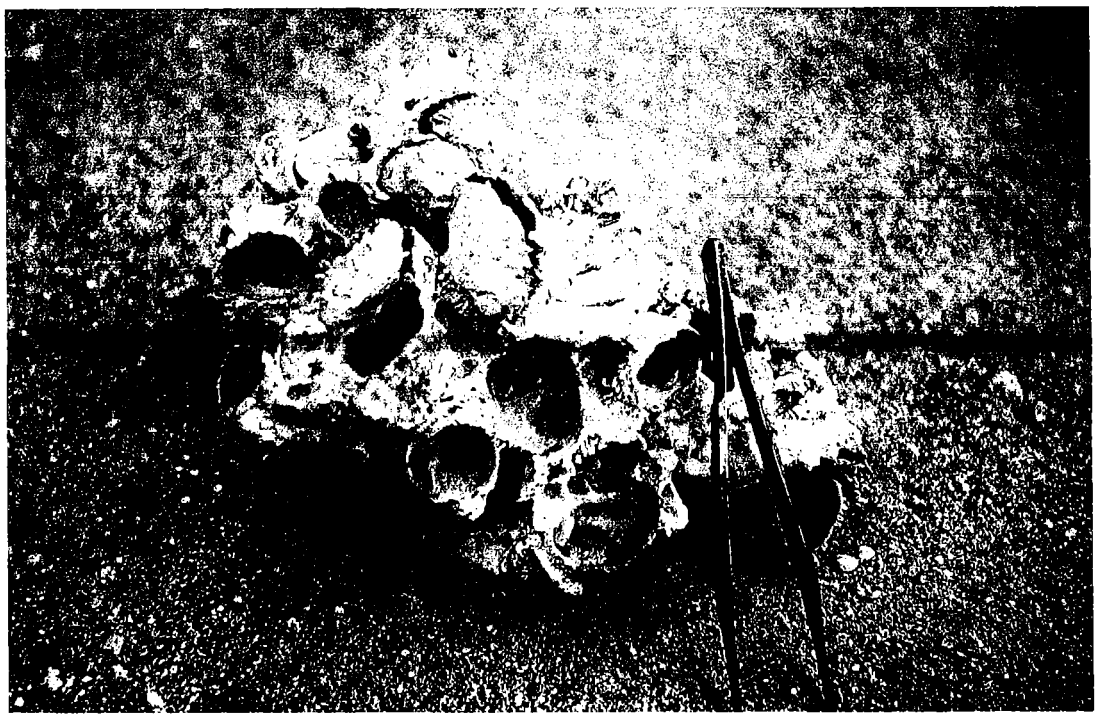


Plate 25 : Living and dead *Chama asperella* populations from the dome patch reef of the Nukutipipi lagoon (Ref.plate : 1988 / 7-20).