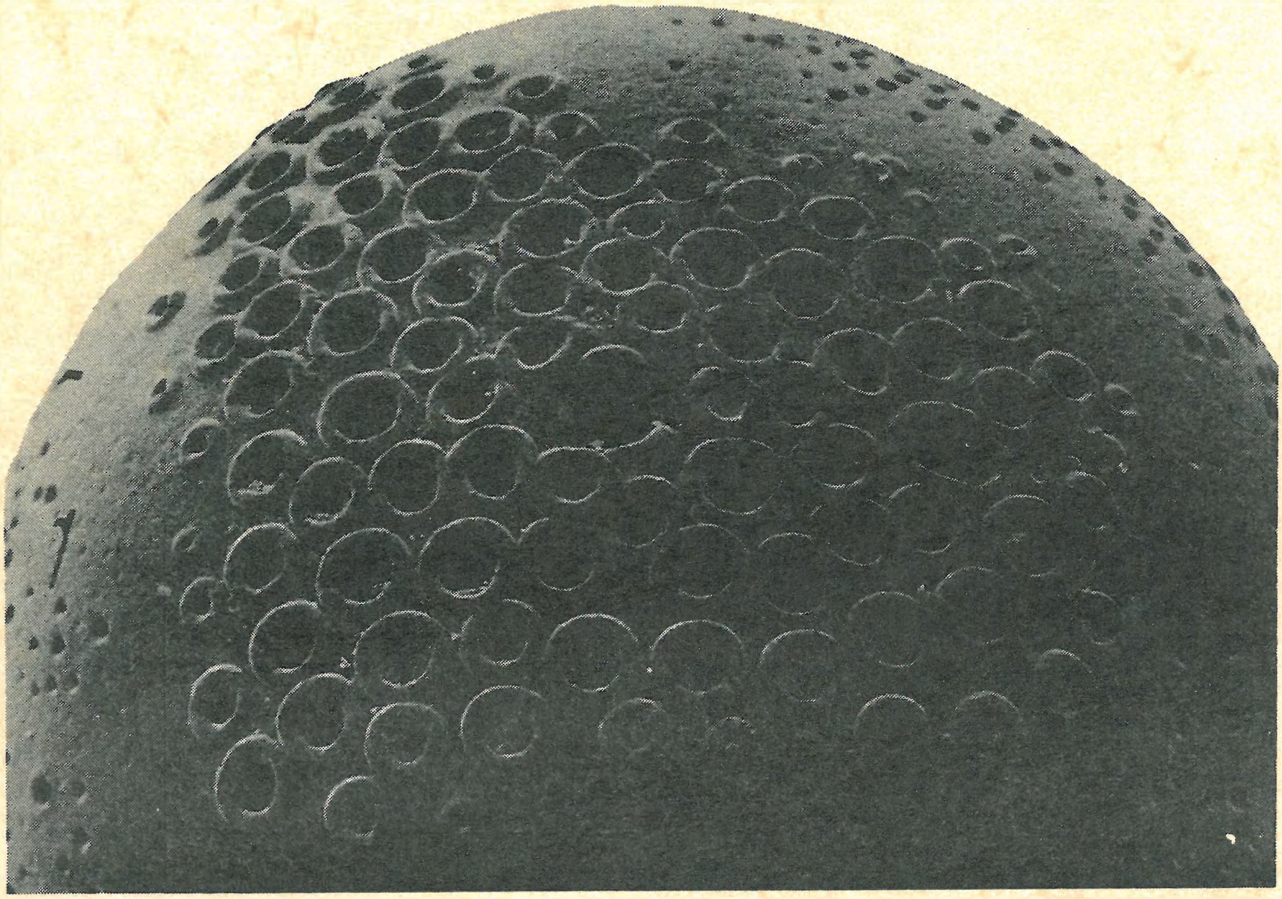
DISTRIBUTION PATTERNS AND TAXONOMY OF BENTHIC FORAMINIFERA IN THE LIZARD ISLAND REEF COMPLEX, NORTHERN GREAT BARRIER REEF, AUSTRALIA



1 DISTRIBUTION PATTERNS

UNIVERSITE DE LIEGE - C.A.P.S. - LABORATOIRE DE BIOSEDIMENTOLOGIE

THESE DE DOCTORAT
EN SCIENCES GEOLOGIQUES ET MINERALOGIQUES, 1987

Jan BACCAERT

" The ultimate goal of a paleontologist should be the morphogenetic understanding of petrified biological structures. "

L. HOTTINGER

Aan mijn lieve vader, die de voleinding van dit werk niet meer heeft mogen meemaken.

LIST OF VOLUMES :

1. Distribution patterns
2. Taxonomy
3. Atlas of Foraminifera
4. Annexes - Annex 1
5. Annexes - Annex 2 to 5

REMERCIEMENTS

Un grand nombre de personnes ont contribué, d'une façon ou d'une autre, à la réalisation de ce travail. Je les en remercie vivement; je ne puis malheureusement les citer toutes ici car la liste en serait trop longue; cela n'enlève cependant rien à la gratitude que je leur porte.

Je rends hommage à l'homme qui a réalisé l'expedition Belge à la Grande Barrière de Corail, et obtenu les programmes de recherche interuniversitaires ultérieurs : feu le Recteur DUBUISSON de l'Université de Liège. Quoique ne l'ayant pas connu personnellement, je me rends compte que le présent travail aurait été impensable sans le "rêve australien" du Prof. DUBUISSON; c'est pourquoi je me suis permis d'honorer sa mémoire en lui dédiant une des espèces nouvelles de foraminifères de Lizard Id. : *Monspeliensina dubuissoni*.

En même temps je voudrais témoigner ma gratitude envers les deux personnes qui n'ont jamais cessé de me soutenir, tant du point de vue scientifique que du point de vue moral : le Prof. Dr. Cl. MONTY, mon promoteur à l'Université de liège, qui m'a de plus livré ses notes de terrain, et le Prof. Dr. L. HOTTINGER de l'Université de Bâle, Suisse, qui ont supervisé la réalisation de cette thèse pas à pas.

Je remercie le Fonds National de Recherche Scientifique pour son appui financier; l'étude des matériaux provenant de la Grande Barrière d'Australie faisait partie du programme F.R.F.C. n° 10215 jusqu'à fin 1976; en plus le F.R.F.C. a participé au frais de la mission à Lizard Id. en 1975.

Ce travail a également bénéficié de l'appui financier de la Compagnie Française de Pétrole qui, à l'initiative de M. MAURIN, a bien voulu participer au frais de réalisation de cette thèse.

Je tiens aussi a remercier :

- MM. CH. CABRON et J.J. ROUSSEAU, C.S.T. au centre d'Analyses Paléoécologiques et Sédimentologiques qui ont aimablement collaboré à la réalisation de tableaux et diagrammes ainsi que de prise de vues et le montage des planches couleurs. Nous exprimons par la même occasion notre profonde gratitude à M. le Ministre de l'Emploi et Travail, et M. le Ministre du Budget;

- M.E. SEGERS qui m'a accompagné à Lizard Id. et qui m'a aimablement permis d'utiliser les résultats inédits de ses recherches sédimentologiques sur Lizard Id.;

- M.S. DOMM, à l'époque Directeur de la Station de Recherche de Lizard Id., qui nous a permis de séjourner à la Station et d'utiliser son infrastructure;

- Dr. Ir. DELMER, à l'époque Inspecteur - Directeur Général du Service Géologique de Belgique, pour sa permission d'utiliser l'infrastructure du Service Géologique pendant les phases préliminaires de la présente étude.

- Dr. J. BOUCKAERT, Directeur au Service Geologique, et Dr. P. LAGA qui m'ont permis de consacrer partiellement mon temps de travail à ma thèse lors de mon séjour au Service;

- Dr. X. MISONNE, Directeur de l'I.R.Sc.N.B. pour sa permission d'utiliser le SEM de l'Institut Royal à Bruxelles; ainsi que Dr. K. WOUTERS et Dr. P. GROOTAERT pour la manipulation du SEM. Dr. A. DHONDT de l'Institut Royal a bien voulu reviser les problèmes de nomenclature taxonomique;

- Dr. F. LOX de l'Université d'Etat à Gand, pour son aimable offre d'utiliser la machine à photocopier de son service.

Finalement je profite de cette occasion pour remercier vivement les deux personnes qui m'ont respectivement initié, il y a un nombre d'années, à la Paléontologie et l'étude des foraminifères, à l'Université de Gand : le Prof. Dr. J. DE HEINZELIN et Dr. Ir. T. MOORKENS.

La personne qui m'a persuadé, par son encouragement continu, d'achever cette thèse malgré les circonstances les plus défavorables, mérite ma gratitude la plus profonde : mon épouse, Mayke.

CONTENTS

LIST OF TEXTFIGURES AND TABLES

INTRODUCTION

General

This study deals with distribution, ecology, population dynamics and taxonomy of recent Foraminifera from a particular reef complex in the northern part of The Australian Great Barrier Reef. The reef complex chosen for investigation is the Lizard Archipelago north of Cooktown and Cape Hatteras. The reasons for this choice are explained below.

The importance of the coral reef environment for naturalistic research in all disciplines, and for geological and paleontological research in particular should be stressed. Many reef-building or reef-inhabiting organisms such as hermatypic corals, coralline Algae, molluscs, Foraminifera and other marine skeletal organisms are major contributors to tropical carbonate sedimentary facies, either directly or through bioerosion (up to half of the total carbonate production of coral reefs can be yearly bioeroded and redeposited as loose sediments). Beside being a fascinating ecosystem coral reefs have also much contributed to the edification of oil reservoirs.

Actualistic research on Recent Foraminifera has been expanding during the last decades and gradually contributes to a better knowledge of some of the rules governing the formation and distribution of Recent foraminiferal thanatocoenoses and their fossil counterparts. The ever-growing value of this research for paleoecology in general, foraminiferal paleoecology in particular, and stratigraphy, cannot be underestimated.

Early researches on Recent Foraminifera focused mainly on thanatocoenoses; this attitude originated in the difficulties encountered in the recognition of living specimens in the sampled sediment or substrate. Even today study of thanatocoenoses often constitute the only reliable source of information we dispose of, notwithstanding the development of techniques for recognition of living Foraminifera (e.g. Rose Bengal or Sudan Black methods - see Ch. 1) yielding results sometimes subject to serious caution as it is generally agreed nowadays.

The correct knowledge of the ecological factors determining foraminiferal distribution is however a primordial condition for more or less reliable applications to fossil material. These ecological factors form a dense network of : 1) primary physical and physico-chemical energies (such as light, pressure, temperature, densities, salinities, water energy and - turbulence, ...) and

2) their relation to - and effects upon secondary environmental elements and purely biological processes (nature of substrate, symbiosis, ecophenotypical adaptation, variations in test thickness, ...).

To obtain this knowledge it is necessary to have at least an approximate idea of the distribution of living faunas; the most reliable method (seasonal observation of living specimens in situ - see e.g. ARNOLD, 1974) being however difficult to apply in large-scale studies on smaller Foraminifera, a combination of Rose Bengal - and direct observation methods is often used in practice. The comparison of bio- and thanatocoenoses yields information about test transport, -fragmentation and -deposition. This forms the necessary link between the knowledge of the ecosystem and of the thanatofacies with which the palaeontologist is confronted.

REISS (1977) stated that "distributional patterns of living Foraminifera are attributed to ecological factors mainly by empirical correlation with observed environmental characteristics of presence, absence, dominance and diversity of taxa." He continued : "All distributional studies indicated for many taxa a definite depth pattern, usually interpreted as a result of temperature-, salinity- and water energy- gradients, as well as of changes in the nature of the substrate. However, in many cases, in greatly different seas from a physico-chemical point of view, bathymetric zonation boundaries occur at or around certain depths which can not be directly correlated in a simple manner with the positions of temperature, salinity or energy boundaries."

The importance of the choice of model areas for the study of these primary ecological factors influencing foraminiferal distribution patterns has been emphasized by REISS (1977) and HOTTINGER (1977) while commenting upon the reasons for the choice of the Red Sea and the Gulf of Elat as their study area. These authors state that the Gulf of Elat is of particular interest to studies of distributional patterns of Foraminifera in tropical regions; indeed the absence of any significant thermocline, halocline or pycnocline greatly restricts the range of influential factors to light and substrate. This is why the Gulf of Elat shows some remarkable relationships between depth distribution of Foraminifera on one hand, and light and algal symbionts on the other. (See e.g. LEUTENEGGER, 1977; FERMONT, 1977; MEULENKAMP, 1977; THOMAS, 1977; HANSEN & BUCHARDT, 1977; LARSEN, 1977; DROOGER, 1977; ZOHARY e.a., 1980).

As the foraminiferal fauna of the Gulf of Elat belongs to the Indopacific faunal province as does our Lizard Island one, comparisons between the Gulf of Elat and the Great Barrier Reef promised to be fruitful; furthermore the foraminiferal faunas had much in common although the physical-physiographic and climatic conditions differred greatly, which could be hoped to result into some clarification of primary ecological data influencing foraminiferal distributions (see Chapter 4 - Conclusions). This constituted the principal aim of this study. The reasons why the Lizard Island Reef Complex may be considered as a model area of a somewhat different nature as the Gulf of Elat, are explained below.

About the realisation of this study

In 1967, as opposed to the present-day situation, the Lizard Island Reef Complex was a quasi unknown and undescribed area in the Northern Great Barrier Reef Province; neither maps nor physiographic data were available and the 1967 Belgian expedition was the first one to investigate this area in a scientific way. This expedition, an idea and a realisation of the late Rector DUBUISSON of the Belgian State University of Liege, was conducted by Prof. DISTECHE, while Dr. Cl. MONTY was in charge of the scientific program. He mainly studied reef structures, sampled sediments as well as corals. The expedition investigated mainly the Capricorn-Bunker Group in the South, some islands and cays in the Central Region (Swain Reefs) and headed up as far North as Lizard and Nymph Islands, and the Outer Barrier (Yonge Reef) in the Nortern Great Barrier Reef Province.

Upon coming back to Belgium, an interuniversitary centre was created (under the auspices of the Belgian National Foundation for Scientific Research) for the study of the collections and materials brought home by the expedition. Several years later I was invited to join this centre; I worked at Liege in MONTY's laboratory and studied foraminiferal distributions in relation to sedimentary facies of the Lizard archipelago and surrounding shelf, an area receiving particular attention by MONTY and his collaborators at that time because of its particular reefal and sedimentary features. Since the sampling mesh was too wide for a detailed study of this highly interesting archipelago and as detailed observation on living Foraminifera was almost lacking, funds were obtained enabling me to reinvestigate and resample the area during the months June-July 1975 together with SEGERS, a sedimentologist working in MONTY's laboratory. The present study deals largely with the samples taken during this mission.

The Lizard Island Research Station, a scientific field station at that time (1975) dependant of the Australian Museum, Sydney, stood under the direction of Resident Director S. DOMM and offered relatively low-cost facilities for our mission, viz. small dinghy's, a field laboratory, diving tanks and a compressor. A generator produced electricity a few hours a day; food was to be flown from the mainland by small aircraft on a weekly schedule whereas everything else had to be brought with us from Belgium.

Notwithstanding the initial lack of some essential ustensils (such as e.g. a winch which we had to construct ourselves), and difficulties ranging from rough wheather and very strong southeasterlies (up to 8 Beaufort) to tropical disease, we managed in providing in a fairly complete sampling of the different marine environments in the Lizard Island area, and in making intertidal and underwater observations wherever possible.

Already during the 1967 expedition, Lizard Island had received MONTY's particular attention because of its diversified marine and terrestrial geological and biological features. The island had initially been chosen as an anchorage site offering shelter against the SE trade winds and swells and being at the same time not too distant from the Outer Barrier (Yonge Reef). MONTY had, during a fortnight's stay, sampled some of the main reefal structures and sedimentary environments and had made a fysiographic description of Lizard Island. His purpose was to compare reef structure and builders of such middle shelf fringing complexes with more coastal ones, bathed by very turbid waters.

During the years following the 1967 expedition, the Lizard Archipelago and surrounding shelf would become an important investigation subject at MONTY's laboratory for the following reasons : first, from a sedimentological point of view the Lizard Archipelago is composed of three granitic islands acting as a local source of terrigenous sediments in an otherwise mainly skeletal carbonate sedimentary facies; this produces interesting small-scale fluctuations in the sedimentary facies patterns, being studied at that time by SEGERS (see Ch. 2).
Furthermore the Lizard Archipelago shows a great diversification in its reefal structures (see Ch. 2). Observations on abundant foraminiferal occurrence in most of these environments had been reported by MONTY whereas the sediment samples taken at the Lizard Island location during the 1967 expedition contained considerable amounts of foraminiferal tests. As a result we urgently felt the need of a foraminiferal distribution study completing the preliminary survey of the Archipelago during the 1967 expedition. Our 1975 mission

enabled us to reach this goal.

Finally it had become clear that the Lizard Island Reef Complex could stand as a model area for the study of Northern Great Barrier Reef geomorphological, biological, ecological and sedimentological features mainly because its different reefal and sedimentary environments represented small-scale examples of most structures and facies which could be met in this Northern Barrier Reef province. We therefore hoped to infer and deduce, from the study of foraminiferal distribution in this reef complex, some principles which would be valid on a larger scale than for this particular reefal environment alone and which could be directly compared with studies conducted in other Indopacific areas, like e.g. the Gulf of Elat.

Previous scientific research in the Great Barrier Reef

General

Research on the Great Barrier Reef, in its Northern Province in particular, has been carried out more intensively during the last decade. Sir YONGE (1978) stated that "Recent interest in the Barrier springs largely from the activities of the Queensland Branch of the Royal Geographical Society of Australasia, which in 1922 established a Barrier Reef Committee ... The need for biological work led to the invitation to the British Association which resulted in the expedition of 1928-9 when we established a marine station on Low Isles ... The Barrier Reef Committee later established a field station on Heron Island in the Capricorn Group, while the Australian Museum, Sydney, has also been active, first at One Tree Island in the South and, very recently, at Lizard Island. Transcending all came the establishment ... in 1972 of the Australian Institute of Marine Science at Townsville."

After the Belgian "DE MOOR" expedition, a number of international expeditions were organised, visiting selected parts of the Great Barrier Reef. Very little attention has been paid to the Northern Great Barrier Reef Province until the years 1973-1974.

Much recent geological and biological information about the Great Barrier Reef (as well as about other Indo-Pacific and Atlantic reef regions) became available through the publication of the Proceedings of the First (1969), Second (1974) and Third (1977) International Coral Reef Symposia (under the auspices of the Committee on Coral Reefs - International Association of Biological Oceanographers), whereas some results of the 1973 expedition to the

Northern Region were published and discussed in the Philosophical Transactions of the Royal Society of London (1978). Several articles of interest about Barrier Reef topics appeared in the three-volume work "Biology and Geology of Coral Reefs" edited by O.A. JONES and R. ENDEAN (1973).
A summary of research on the Great Barrier Reef up to 1968, with emphasis on reef morphology and sedimentary facies, is to be found in MAXWELL's (1968) "Atlas of the Great Barrier Reef" as well as in recent work of the AGS.

Previous foraminiferal research

Studies about Great Barrier Reef foraminiferal faunas are not very numerous. A review of these has been given by COLLINS (1958); I shall briefly enumerate them and complete the list with some more recent work.

First I should mention BRADY's (1884) "Challenger" report (apparently mainly confined to Torres Strait Islands as far as tropical Pacific stations are concerned), remaining up to the present day a work of fundamental interest in recent Foraminifera in general and in tropical faunas in particular.

COLLINS points out that since the "Challenger" report, only short papers giving faunal lists or dealing with particular species have been published (this remains true for post-1958 work). JENSEN & GODDARD (1907) listed species from Townsville. CHAPMAN (1898, 1908, 1931) listed and commented some species from Torres Straits, Cairns Reef and reported on bore samples from Michaelmas Reefs. CHAPMAN & PARR (1938) studied the species of Operculina and "Operculinella" occurring in the region. CUSHMAN (1942), CUSHMAN & Mc. CULLOCH (1940, 1942, 1950) described new species, reported on a boring at Heron Island, described new species from West Molle Island (ALLAN HANCOCK Pacific expeditions). PARR (1947, 1950) referred occasionally to Barrier Reef species.

Next comes COLLINS's(1958) report itself; it deals with the Foraminifera collected at Low Islands and other Barrier Reef localities by the Great Barrier Reef expedition of 1928-29, and stands up to the present day as the only monography ever published about Great Barrier Reef Foraminifera in particular; it deals mainly with taxonomy in a fairly complete way; four new genera and 46 new species and subspecies have been proposed and are accompanied by camera lucida drawings. It is a pity however that the remainder of the foraminiferal faunas described by COLLINS has not been illustrated.

Since COLLINS's report, only a few articles dealing with Great Barrier Reef Foraminifera have been published. JELL, MAXWELL & MC. KELLAR commented on mainly larger Foraminifera from Heron Reef (1965). ROSS (1972) cultured Marginopora vertebralis from some reefs off the Queensland coast near Innisfail and Bowen and commented upon gigantism in Barrier Reef Foraminifera (1974). PONDER (1972, 1974, 1975) commented and revised several miliolid species and genera, mainly Hauerina, and created the genus Pseudohauerina. His material has mainly been dredged between Magnetic Island and Rowes Bay and further originates from mainland coasts and near-shore islands between Port Douglas and the Capricorn Island Group.

Previous research in the Lizard Archipelago

General (See Ch. 2)

Until a few years ago no scientific publications dealing with this particular area have seen the light. As already mentioned above, investigation efforts in the Great Barrier Reef Province were mainly concentrated upon the Southern and Central regions for practical reasons (poor accommodation facilities and difficulty of access to the Northern Region). This situation changed mainly since the creation of the Lizard Island Research Station in 1973. Biological, geological and oceanological research upon the island, adjacent reefs and waters is now being actively carried out, publications remaining however up to the present day in a more or less preliminary form (see e.g. ORME & FLOOD, 1977; KINSEY, 1977; DAVIES, 1976, 1977).

About Foraminifera

JENSEN (1905) is the only one to mention some foraminiferal species (from beach sands) of Lizard Island. Het identified 25 species among which the Marginopora-form with irregular outline ("Orbitolites complanata LamK., var. laciniata, Brady" as he states).

As far as I know, no research upon Foraminifera of this area has been carried out ever since JENSEN's publication, and the present study is the first one to deal with Northern Barrier Reef Foraminifera in general and with Lizard Island foraminiferal faunas in particular for more than three quarters of a century.

CHAPTER 1

MATERIAL AND METHODS

1.1. Field Work

1.1.1. Generalities

This study deals largely with the material collected during the six weeks joint mission with E. SEGERS at the Lizard Island Research Station (June-July 1975).

Although comparisons with material collected during the "DE MOOR"-expedition (BACCAERT, 1976) are reported whereas some of MONTY's original field observations have been incorporated in this study (see Ch. 2), I shall essentially focus on the observations and material collected during my Lizard Id experience.

The major two aims of our field mission were (1) to thoroughly sample the reefal and perireefal environments and (2) to make additional underwater observations on substrates and sediments.

Sampling was carried out in three ways : shallow intertidal areas were sampled while walking over the beaches and reef flats, whereas deeper seabeds were sampled either by skin-diving or with a grab handled from a small dinghy.

The location of sampling stations is figured on the map, Annex 3. It should be remembered that in several cases more than one sample was taken per station (e.g. algal-microbial substrate and sediment samples); samples less than 10 m apart are mapped under one station number.

1.1.2. Manual prelevation (supra- and intertidal environments)

During normal low tides the reef flats were not entirely uncovered; accordingly we had to sample during neap tides. However the heavy swell caused by the strong SE trade winds at that time prevented the tide from being as low as would have been normally the case on such occasion; this situation generated difficulties in extensive sampling of the deeper backreef structures.

Sediment samples were normally taken by scraping off the upper cm of sediment by means of a plastic pot with a capacity of 150 or 250 cc. These pots were immediately filled to the rim with seawater, and tightly closed.

Substrate samples were also taken by carefully removing algal tufts and finer algal-bacterial coatings, or mollusc shells and coarser coral debris covered with an algal coating; these were then equally placed in plastic pots or bags filled up with seawater. Afterwards, in the Research Station lab, most samples were rapidly checked for their foraminiferal content with the binocular microscope.

In several reef flat stations, separate samples were taken of the algal substrate and the immediately underlying sediment or a sand pocket in the immediate vicinity.

Some shallow reef patches and beach sediments have been sampled in the same way as the reef flats. In the case of higher supratidal sands the sediment was kept dry and no staining has been carried out.

1.1.3. Grab samples

We used a small dinghy equipped with an outboard engine for our grab sampling tracks. These grab samples were taken by means of a winch fixed upon the boat.

The grab we used was a "snap-grab" from the JAMES COOK University at Townsville.

As no adaptable winch could be found in time, neither at the Research Station nor at JAMES COOK University at Townsville or elsewhere in North Queensland, we had to construct one on the spot; for the construction we used wood available at the Research Station as well as some metal parts to be adapted into a handle and a drum for the nylon rope brought with us from Belgium. This winch was afterwards completed by a support for the transducer of the echosounder. The whole set was fixed upon the boat by means of hemp rope.

An unexpected though convenient situation resulted from the fact that the grab probably never penetrated deeper than 6 à 7 cm into the bottom sediment due to the rather blunt jaw edges; if this resulted in a somewhat reduced amount of sediment per sample the quality of the latter was improved as no significant mixing of the superficial layers with deeper sedimentary layers occured.

Grab sampling has been carried out in the perireefal areas windward and leeward of the Lizard Archipelago, as well as in part of the Lagoon and deeper patch-reef locations.

The reason why we decided to work with some type of grab sampler excluding other types of sampling devices are multiple. We considered that small coring devices such as the PHLEGER corer or the LANKFORD sampler (PHLEGER, 1960; BOLTOVSKOY & WRIGHT, 1976) would not probably have worked at all in the Lizard

Island sediments because of their very high content in coarse to very coarse fraction (such sediments are not usually retained in the coring tubes (BOLTOVSKOY & WRIGHT, 1976)) as a result of a lack of cohesiveness of the sediment. Large piston corers like the KULLENBERG or EWING corers (BOLTOVSKOY & WRIGHT, 1976) could not be considered as these can only be handled from larger oceanographic vessels. Surface scraping of slicing devices like the constructions used by BLANC-VERNET (1969), or the HULME surface dredge (HULME, 1964; BOLTOVSKOY & WRIGHT, 1976) would perhaps have been suitable for our work to a certain extent, as long as no coral shingle or boulders were met.

So our "snap-grab", except for its difficult handling, was not that bad a tool with its 6-7 cm of penetration depth and its more or less constant sampling surface of about 1200 to 1500 cm^2.

1.1.4. Skin-diving and sampling

Scuba diving was mainly done to carry out submarine observations and to take additional samples by hand. The basic personal diving equipment had to be brought with us from Belgium; the Research Station offered diving tanks and the use of a compressor.

Sampling in the shallower patch-reef areas was done either while snorkeling or while diving with tanks; we also dived and took samples in parts of the Lagoon and Lagoon entrance, the patches at Watson's Bay and the fringing reef at North Point. Diving at the windward reef fronts of the fringing reef and windward barrier could not be done because of the strong southeasterlies prevailing most of the time and the lack of logistic support. The few days of relatively calm wheather have been entirely devoted to grab sampling on the Eastern Perireefal Area. Submarine observations in these windward areas have however been done during the "DE MOOR"-expedition (MONTY, 1967).

Nevertheless, a good deal of information and documentation about substrates and the nature of the bottem sediments has been gathered in the more protected leeward reefal areas.

Underwater sampling while skindiving was executed as follows : pre-marked plastic pots, previously completely filled with seawater, were taken down in a net. I scraped off the upper cm of sediment in the same way as described for the intertidal environments : great care was moreover taken in order to avoid disturbing the finer sediment fraction or the eventual delicate organic film lining the sediment-water interface by uncontrolled movements. Scraping with the pot was done very slowly and the pot was closed by means of the double plastic cap immediately after sampling. Water depth and information about the sampling place was noticed on a plastic underwater-notebook.

1.1.5. Positioning and depth recording

All positionings from the boat as well as on land were carried out with a horizontal sextant, measuring the angles between landmarks, and completed by compass readings. Every sextant reading was done at least twice, using the angles between at least three landmarks; every compass reading was done twice (using two compasses). After sampling those readings were reported on aerial photographs, and charted. Afterwards the positions were corrected for compass deviations where necessity arose. This system always worked well as we took the time to go at achor at every station while sampling with the boat. (This revealed to be necessary because of the strong wind drift which moved the boat very rapidly leeward when the engine was off.) On land there were no problems whereas for samples taken while diving, positions were read from the boat at anchor and corrected on aerial photographs wherever necessary or possible.

A double system was used to record water depth from the boat : first we marked the nylon rope at every half meter with strips of red tape. This method of reading was mostly used in shallower water (less than 10 m); on the boat we used a Bendix-echosounder, powered by a 12-V battery; the transducer was supported under water by means of a wooden construction fixed upon the winch. Most of the echo profiles reproduced in this study (see Appendix 4) have been redrawn from such recordings.

Depth readings while diving were immediately noted from our depth gauges upon our underwater notebook. In some cases these readings were controlled afterwards with the echosounder.

1.1.6. Treatment of the samples on the boat and in the field laboratory

Grab samples were treated as follows : immediately after hoistening the grab aboard, a superficial description of its contents was noted down. Then the grab was opened into a plastic vial and the sediment was put in plastic bags which we subsequently filled with seawater, labelled and closed.
Upon returning to the field lab the bags were put on trays, allowed to stand

for at least some hours to let the finer fraction sink down and then decanted. The samples were afterwards transferred into plastic pots and kept in a 4%-buffered formaline solution. A smaller quartiled sample fraction was then taken apart and stained for recognition of living Foraminifera.

Substrate samples (e.g. algo-bacterial tufts and -coatings) as well as all other samples mentioned above were, in a similar way, kept in plastic pots in buffered formaline and stained. Some larger substrate samples (e.g. pieces of reef rock, dead mollusc shells with microbial coating upon them etc.) were left in the plastic bags; buffered 4%-formaline and Rose Bengal were added and the bags were, safely packed, send to Belgium for further treatment in the laboratory at Liège.

1.2. Recognition of living Foraminifera - the biocoenoses

1.2.1. The Rose Bengal staining method : reasons for the choice, critics

The use of Rose Bengal (C.I.779; $C_{20}H_2O_5T_4Cl_4Na_2$) as a foraminiferal protoplasmatic stain for recognition of living specimens has been adopted on a large scale since WALTON's (1952) publication. For a discussion about the method itself and comparisons with other methods (color reactions for protein like MILLON's reagent, Biuret Reaction; biological stains other than Rose Bengal like Menthyl Green-Eosin) I refer to lecture of WALTON's article. Rose Bengal produces a deep red-rose color to protoplasm. BOLTOVSKOY & WRIGHT (1976) exhaustively reviewed the critics formulated by a growing number of authors as to the efficiency of the Rose Bengal method; these critics can be summarized as follows :

- In thick or opaque foraminiferal tests the deep rose color of the stained protoplasm is only (if at all) visible around the aperture. It may be necessary to break some specimens to determine if stained protoplasm is present . (BENDA & PURI, 1962; DUPEUBLE, 1964; ATKINSON, 1971; MARTIN & STEINKER, 1973; personal observations).
- Tests of dead Foraminifera often display a red colour or exhibit small spots of red material on the walls, due to the presence of other organic material (bacteria, marine worms, filamentous Algae, etc. - cf. personal observations).
- In many cases coloration occurs in obviously dead specimens (BANDY in GREEN, 1960; REITER, 1959) or even in fossil specimens (LE CALVEZ & CESANA, 1972).

- Living specimens are not always stained (LE CALVEZ & CESANA, 1972); a thin organic film may prevent the penetration of the colorant into the interior of the test.

Notwithstanding these and other eventual critics about the method, the Rose Bengal staining is in wide use nowadays as it is the only cheap and easy method to be used in the field and on larger scale distributional investigations. As a matter of fact the only claimed "valid" methods for recognition of living Foraminifera (direct observation of protoplasma in the test immediately after collection, pseudopodial movement and related methods (LE CALVEZ & CESANA, 1972; ARNOLD, 1974;BOLTOVSKOY & WRIGHT,1976;HOTTINGER, 1977) cannot always be used on a larger scale especially in the amount of time and laboratory facilities at hand. Moreover even ARNOLD (1974) expresses restrictions as to the application range of the direct observation method. Finally the Sudan Black B method (WALKER, LINTON and SCHAFER, 1974), claimed to be more accurate than the Rose Bengal one, still has to prove that it can be extensively used in fields conditions (HOTTINGER, 1977).

The discussion about all the above mentioned methods, and about the Rose Bengal one in particular, being far from clearcut, I decided to use the latter staining method upon the Lizard Island samples because of its facility of application in field conditions. This method does not seem to be that unreliable when applied with some basic precautions which will be commented later. Nevertheless, no definite quantitative counts were carried on living Foraminifera; only semi-quantitative data are given in sufficient amounts as to provide a valuable comparative basis with the essentially quantitative ones provided by study of the thanatocoenoses.

1.2.2. Sample treatment in the laboratory

In the Lizard Island laboratory, sediment samples destined to staining were put on a 75 micron sieve which was then transferred for about 10 - 15 minutes into a flat tray containing an aqueous solution of Rose Bengal (approximately 1 gram pro liter water - see WALTON, 1952), no distilled water has been used because of its agressivity towards calcareous tests. As WALTON states, and as I found out myself, the concentration of the stain solution is not critical since it only alters the intensity and not the effectiveness of the stain. For reasons concerning comparison of samples and facility of interpretation it is important however to use a constant concentration and to allow the samples to stay in the solution for a constant period of time.

After staining the sample was washed on the sieve with filtered seawater to remove excess of stain as well as to eliminate the mud and part of the fraction below 75 microns. The samples were then transferred again to the plastic pots and 4% buffered formaline solution was added.

As to substrate samples, a Rose Bengal solution was merely injected into the pots or bags and formaline was added.

The samples arrived by boat (from Sydney) in Belgium at the end of 1975 (a small amount of pots had been brought with us on the plane to allow a first check of some samples in the laboratory at Liege).
I noticed at Liege that the 10 - 15 minutes staining time had not been sufficient in some cases; that is why I decided to restain all the samples for 1 hour; the procedure was the same as the one described above; after staining the samples were wet-sieved on the 75 micron sieve screen to eliminate undeterminable juveniles and silt fraction as well as to remove excess stain: the sediment was then transferred to the plastic pots again and a freshly buffered 4% formaline solution was added. Substrate samples were handled with care; they were just partly decanted, new stain was added and after one hour decanted again; buffered 4% formaline was added and decanted again several times during some weeks until the solution did not dye red any longer in a significant way.

1.2.3. Observation methods

Apart from the observation of stained foraminifera under the microscope, upon which I will comment below, some living foraminiferal communities could be recognised in the field with the naked eye or using only a small hand lens. On the reef-flats and the patch-reefs, larger soritids (Marginopora, Sorites, Amphisorus, Peneroplis), amphisteginids (A. lobifera) e.a. (Calcarina, Baculogypsina) could easily be seen attached in large numbers to their algal substrates, or to the microbial coating covering sediment or shingle. These living Foraminifera could be distinguished from dead tests by their fresh aspect and their specific colours; Marginopora vertebralis e.g. is greyish-pink in the living state whereas dead tests turn rapidly white; living amphisteginids exhibit reddish and greenish colours while being attached in large numbers to algal thalli by means of their pseudopods.

Semi-quantitative evaluations (see 1.2.1.) of the biocoenoses were executed exclusively upon stained material under the binocular microscope. The procedure was as follows : in the case of algal or microbial samples, the tufts were taken out of their pots or bags, put in petri-dishes and examined at different magnifications for their foraminiferal epifauna. Eventual fallen-off residues were equally examined. In the case of sediment samples, the content of at least half a pot (about 100 cc) was spread out in several petri-dishes (care being taken to keep the sediment wet), examined at different magnifications under the binocular microscope and evaluated upon "living" Foraminifera contents in a semi-quantitive way in terms of rare, frequent or abundant. A species was considered to be rare if less than 10 specimens were encountered; abundant, when obviously at least one hundred or more specimens were present in the sample; frequent, when intermediate values were reached.

Of all the encountered living species, representative specimens were picked out (either by means of a fine brush or a very fine mouth pipette and put in micropalaeontological slides.

The same samples were afterwards sieved, dried in the air at room temperature and then quartiled for thanatocoenose counts. Only some witness samples were preserved in formaline, as the entire original grab sample collection is being kept under formaline in the laboratory at Liege.

Facility of recognizing stained protoplasm varied according to several reasons :

-) Arenaceous Foraminifera : could be easily detected in the case of young specimens, rather translucid when immersed. Larger, full-grown and thick-walled specimens frequently exhibit a red colour near their aperture and at the sutures. In some cases the tests had to be broken to allow recognition of the deep-rose stained protoplasm, and to distinguish it from contamining living organisms (bacteria, Algae, fungi, nematods, diatoms, etc.).

-) Miliolids : behave approximately as the former group. Large and thick-walled specimens were frequently more difficult to check than arenaceous ones because of their thick, opaque tests; breaking of the test was very often necessary. Test walls of dead specimens are often finely perforated by boring organisms; the perforations frequently being hosted by red-coloured organic material imparting a slightly rose colour to the test. After some visual experience, this kind of hues could be distinguished from the faint, mostly unequal rose colour shining through the test wall and generated by coloured protoplasm. Here too, the coloration near the aperture and at the sutures was the most prominent feature of recognition of coloured protoplasm.

-) Rotaliids : In this group, containing many hyaline, translucent forms, recognition of coloured protoplasm was generally easier than in the preceding groups. Only large, thick-walled taxa like Calcarina, Baculogypsina and Elphidium craticulatum offered some problems to which breaking of the test was the only solution; however even in these specimens the typical reddish luster of the test wall will convince the attentive observer after some visual experience, though it would not be wise to use this only criterion on a quantitative level.

On these grounds we were able to conclude that, on a rather gross semi-quantitative level, the results of the Rose Bengal staining method are certainly valuable, whereas greater accuracy in methodology would be necessitated for obtaining purely quantitative results. As such a precise method does not seem to exist at present (see 1.2.1.) we have to rely on the accuracy of the Rose Bengal method in spite of its limitations.

It should be borne in mind that the comparisons between bio- and thanatocoenoses could turn out to be somewhat artificial because of the different amounts of material respectively used per sample (the thanatocoenoses having been treated in a completely quantitative way necessitated less material pro sample).

1.3. The thanatocoenoses

1.3.1. General remarks

Reviews and discussions about the methods generally used for calculation of quantitative abundance of Foraminifera are numerous and often controversial (SCHOTT, 1935; HÖGLUND, 1947; PARKER, 1948; SAID, 1950; PHLEGER, 1952, 1960; WALTON, 1952, 1955; MURRAY, 1973, 1976; BOLTOVSKOY & WRIGHT, 1976; and many others). The most recent review of this methodology is given by BOLTOVSKOY & WRIGHT (1976).

There are essentially three ways of calculating abundances of Foraminifera : these are expressed in relation to the 1) weight, 2) volume of sediment and 3) surface covered by the sample. I shall not reopen the discussion about which of these methods should be preferentially used (see e.g. WALTON, 1955; PHLEGER, 1960; BOLTOVSKOY & WRIGHT, 1976), each method having its own advocates and none being perfect.

-) Abundances expressed in relation to sediment weight :

A variant of this method has been adopted in this study (see 1.3.2.). Abundances used to be expressed as the content of foraminiferal tests in 1 gram of dried sediment (= Foraminiferal Number, FN). The method has first been used by SCHOTT (1935).

The major advantage of the method resides in the fact that the results are directly comparable to the counts obtained from fossil strata, as this is the only more or less reliable method to be used in the latter case (non-consolidated sediments).

-) Abundances expressed in relation to the sample volume :

The number of Foraminifera pro volume unit of wet sediment is calculated. BOLTOVSKOY & WRIGHT (1976) state that the results of these calculations "can be transformed to FN, if the specific gravity of the sediment grains is known and an estimate of the degree of packing (porosity) is made. A rough conversion from volumetric to weight values is accomplished by multiplying the sample volume (in ml) by 2.5.". I cannot but express my scepticism towards a general application of such a conversion. Estimates of the specific gravity of sediment grains are illusory, specifically in carbonate environments where different degrees of diagenesis of grains occur and cannot directly be detected. Estimates of the degree of packing are still more difficult to make as I could find out;in the laboratory at Liege I have experienced with own-design volumetric devices which never gave consistent or reproductable results. Comparable experiments by SEGERS at Liege led to the same conclusions. I finally dropped the volumetric method in favour of the weight method.

-) Abundances expressed in relation to sampled surface area :

This method consists of calculating the number of specimens per unit of surface area. The method (which is discussed in e.g. BOLTOVSKOY & WRIGHT (1976)) has not been adopted in this work mainly because sampling methods did not allow a very accurate sediment surface estimation. As the interest of this method resides mainly in the calculation of standing crops in the case of living Foraminifera, the method is out of consideration here because of the semi-quantitative nature of our biocoenose-evaluations (see 1.2.).

1.3.2. Laboratory methods

The samples were allowed to dry at room temperature after examination of stained Foraminifera (see 1.2.3.). For further quartiling I used a self-built splitting device inspired by the DANIELS microsplitter (DANIELS, 1970) and which essentially consists of a kind of funnell divided into four equal parts, turning around at a constant speed; the sediment is poured into another funnell mounted above the centre of the turning device, falls upon the cone at the centre of the splitter and is divided into four equal subsamples.
This procedure has been repeated until appropriate sample size; the latter was determined by regular checking of the splittings under the binocular microscope until a workable amount of sediment was obtained. This amount was generally

lower in the case of very rich, highly diversified samples (e.g. most of the perireefal ones), than in samples from poorer environments. Next, this final splitting was weighted upon an analytical balance whereafter it was strewed upon a classical rectangular micropalaeontologocal counting-tray divided into 45 cm^2; for counting facility purposes I subdivided each square cm into 16 smaller equal squares. Under the binocular microscope all complete foraminiferal tests were counted as well as all foraminiferal fragments determinable up to generic level, and finally indeterminable fragments of foraminiferal tests as far as they could be recognised as such. Representative specimens of all the encountered species were picked by means of a fine brush wetted with water, and put in slides. No glue was used because this masks some test depressions (umbilicus etc.) in the case of SEM photography.

When the amount of splitted sediment was too large to be examined on one tray, the strewing procedure was repeated until complete examination of the weighted splitting. Some representative samples were afterwards concentrated by flotation in carbon tetrachlorid (see BOLTOVSKOY & WRIGHT, 1976 and BRASIER, 1980) or in tetrachloroaethylene (MURRAY, 1969), the latter flotation agent having the advantage of concentrating more foraminiferal tests because of its higher specific gravity; unfortunately more non-foraminiferal particles are floated along. These concentrations were not intended for obtaining quantitative data, but merely served to look for well-preserved or characteristic specimens suitable for illustration purposes, and to get a clearer view upon the occurrence of some rare or very rare species.

1.3.3. Graphic representations

The results of the thanatocoenose counts, converted to 1 gr/dry sediment $>$ 74 u per sample ($\neq$ Foraminiferal Number of authors as the FN is calculated from the weight of the unsieved representative sample) are given in the synoptic table in Annex 5). The data per sample are summarized in pie diagrams showing procentual contributions of suborders, genera and species. These pie diagrams are to be found in Annex 1.

At the same time smaller pie diagrams are reproduced, showing the relative procentual contributions (gram - converted data) of three categories of grains pro sample, viz : the number of foraminiferal tests (complete or almost complete) which can be identified at the species level (= determinable Foraminifera or DET FOR), the number of broken test fragments identifiable at least up to the genus level (= FRAGMENTS), and the number of unidentifiable, mostly smaller detrital grains which can be recognised as being remnants of

foraminiferal tests (= INDET). These three classes of grains represent the complete foraminiferal contribution to the sediment/gram. The cumulative diagrams thus obtained have been demonstrated to be useful links between foraminiferal thanatocoenoses on one hand, and sedimentary environment on the other (see Chapter 3).
At several occasions the amounts of FRAGMENTS per sample clarified the thanatocoenose picture in that the amounts of larger foraminiferal fragments yield a more unbiased image of the contribution of these larger taxa to the sediment than could be produced by the relative percentage of the corresponding taxa in the DET FOR-class alone.

The procentual data per sample have been combined into several cumulative traverses allowing the visualisation of frequency variances in different environments.

These cumulative diagrams are to be found in Annex 2.

CHAPTER 2

THE LIZARD ISLAND REEF COMPLEX

2.1. Regional setting

2.1.1. Preliminary remarks

The geology, tectonics and geomorphology of the Australian continental mass in general, and of the North Queensland coastal area and the Great Barrier Reef in particular, have been treated in a large number of publications and will not be discussed here. I refer to a.o. "The Geology of the Commonwealth of Australia" (DAVID, 1950); The geological evolution of Australia and New Zealand (BROWN, CAMPBELL & CROOK eds., 1968). "Atlas of the Great Barrier Reef" (MAXWELL, 1968); several contributions to the "Encyclopedia of World Regional Geology" (FAIRBRIDGE edit., 1975); the "Earth Science Atlas of Australia" (BMR edit., Australia, 1979).

Several articles concerning geology and biology of coral reefs and of the Great Barrier Reef and its constituent elements may be found in the "Proceedings" of the 2nd International Coral Reef Symposium (Brisbane, 1974) and of the 3rd Int. Coral Reef Symposium (Miami, 1977), as well as in "Biology and Geology of Coral Reefs (4 vols., 1977). For further references these volumes can be consulted.

Articles focusing on the Northern Great Barrier Reef Province have been published in 1978-1979 (collected in 2 vols. - discussion organised by STODDART & YONGE in 1976). Attention has been paid to Holocene sea-level change in the Great Barrier Reef provinces, by HOPLEY (1978), THOM & CHAPPELL (1978) and McLEAN e.a. (1978).

One of the latest discoveries about the Great Barrier Reef has been discussed in several recent articles (see e.g. BMR Journ. 8,3,1983) and revealed that much of the reefs and sediment rested on, or were associated with karsts and fluvial deposits; previous views stated that the whole system had grown from almost uninterrupted reefs and reefal sediments eventually separated by discontinuities, a remark which still holds for MAXWELL's (1968, etc.) conclusions (see also DAVIES & HOPLEY, 1983; DAVIES, 1983).

Nevertheless the available information, particularly from the Northern Great Barrier Reef, remains scattered and insufficient.

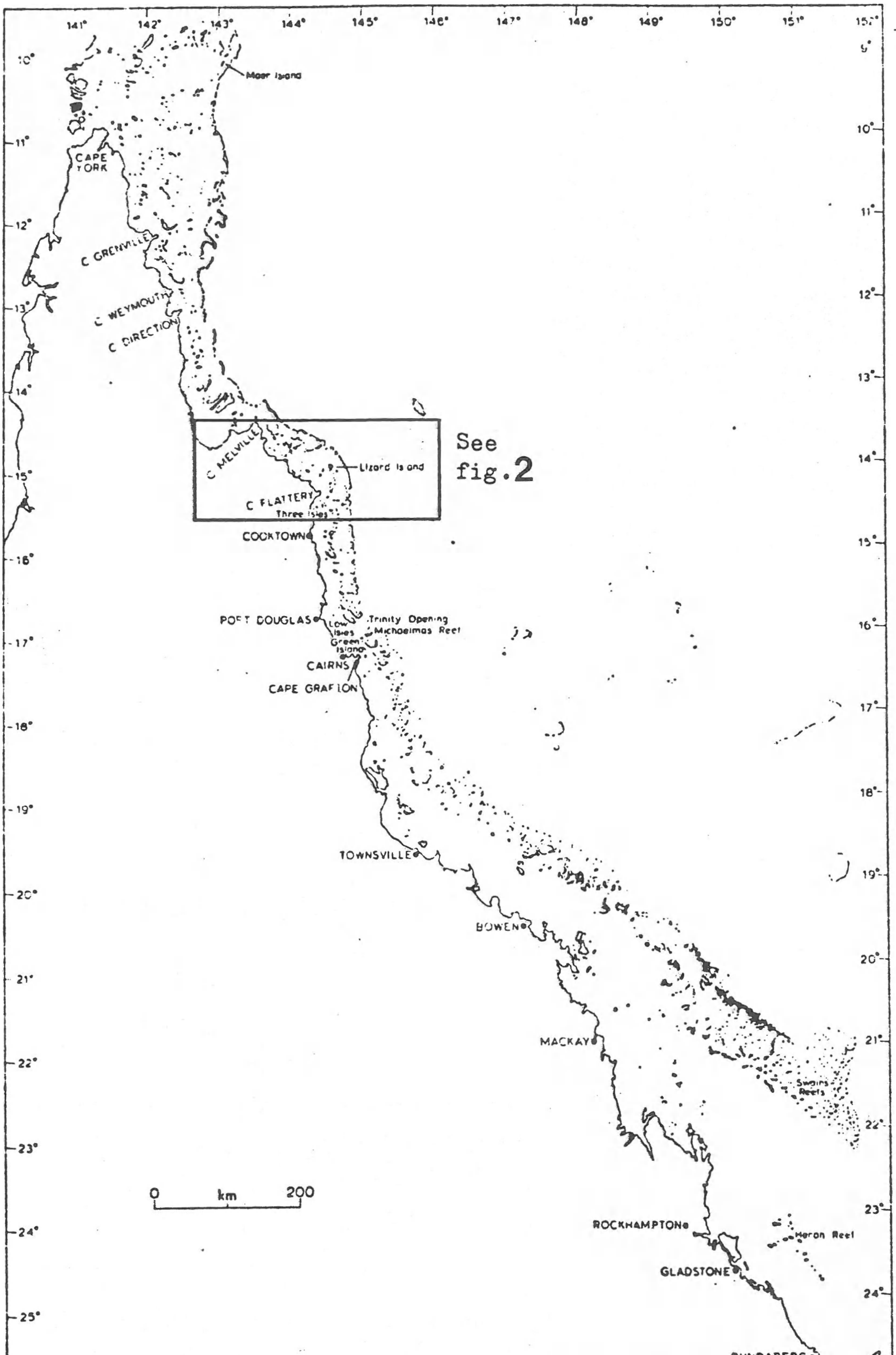


Fig. 1 : The Australian Great Barrier Reef (from STODDART, 1978)

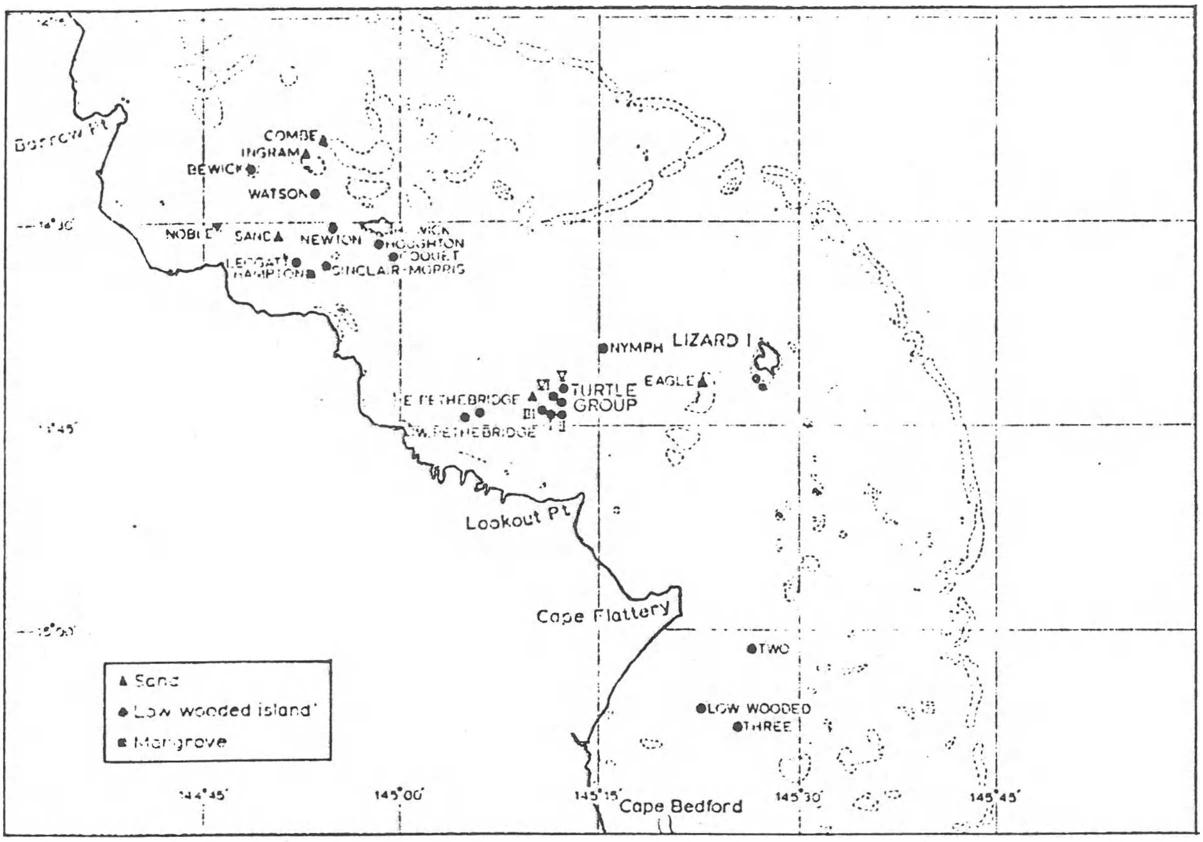


Fig. 2 : The central (Lizard Island) area of the Northern Great Barrier Reef (from STODDART, 1978)

2.1.2. Lizard Island - regional setting

2.1.2.a. The Shelf

Lizard Island is situated in the northern province of the Australian Great Barrier Reef (see Fig. 3-4), at 14° 39' Lat. South and 145° 28' Long . The reef complex has developed around three "continental" islands (Lizard, Palfrey and South Islands) forming a small archipelago and consisting largely of intrusive granite of late Palaeozoic age (Permian) (see e.g. HAMILTON, 1979).

In this northern part of the Great Barrier Reef Province the continental shelf upon which the reefs grew is much narrower than in the southern part (25 - 50 km in the N vs. 80 - 200 km in the South).

Also depth decreases towards the North. Here the three physiographic shelf zones recognised by MAXWELL (MAXWELL, 1968, 1969; MAXWELL & SWINCHATT, 1970) are gradually more and more constricted. These three shelf zones are resp. the Near Shore Zone (0 - 5 fathoms), the Inner Shelf (5 - 20 fathoms) and the Marginal Shelf (20 - 50 fathoms) which includes the Southern Shelf Embayment separating the E and W Marginal Shelfs in the southern Great Barrier province. In the northern province virtually only the Inner Shelf subsists, delimitated by the 9 m and 35 m isobaths corresponding to resp. the limit of the continental littoral zone (s.s.) and the abrupt margin of the continental shelf passing into the steep continental slope which rapidly deepens towards the Queensland Trench. Upon this margin an almost uninterrupted barrier of ribbon reefs has grown, with Yonge, Carter and Day reefs in the closest vicinity of Lizard Island.

This alignment of reefs upon the shelf edge is followed westwardly by an "external channel" characterised by reefless bottoms. A second reef series occurs in a mid-shelf position between this external channel and a coastal channel; in the North it is called the "Steamer Channel". These reefs are of two types : 1) fringing reefs surrounding the "continental islands" such as Lizard Island, North Direction and South Direction Islands south of Lizard Island and 2) platform reefs capping elevations of the shelf bottom. According to ORME & FLOOD (1977) seismic profiles of the Queensland Continental Shelf in the Cairns and Lizard Island areas revealed the presence of an ancient extensive dissected karstic surface, attesting a major marine regression and shelf emergence of presumably Weichselian low sea level phase. The shape of this surface has influenced the location and thickness of platform reefs established during the subsequent marine transgression (see fig. 3).

In the northern Great Barrier Reef province, the coastal channel is characterised by the presence of a particular kind of inner shelf reefs; they mostly show an elevated reef flat largely made up of Acropora and other coral shingle; the associated islands were classified by McLEAN & STODDART (1978) into sand cays, shingle islands or mixed sand-shingle islands flanked by beachrock ramparts and mangrove growth; these reefs are also called the "Low Wooded Islands". Examples of such reefs and islands, immediately West of Lizard Island, are Eagle and Nymph Reefs, the Turtle Group, E and W Pethebridge. Eagle Reef has a sand cay, Nymph is a composite island whereas the Turtle- and Pethebridge Islands are mixed sand-shingle islands (McLEAN & STODDART, 1978).

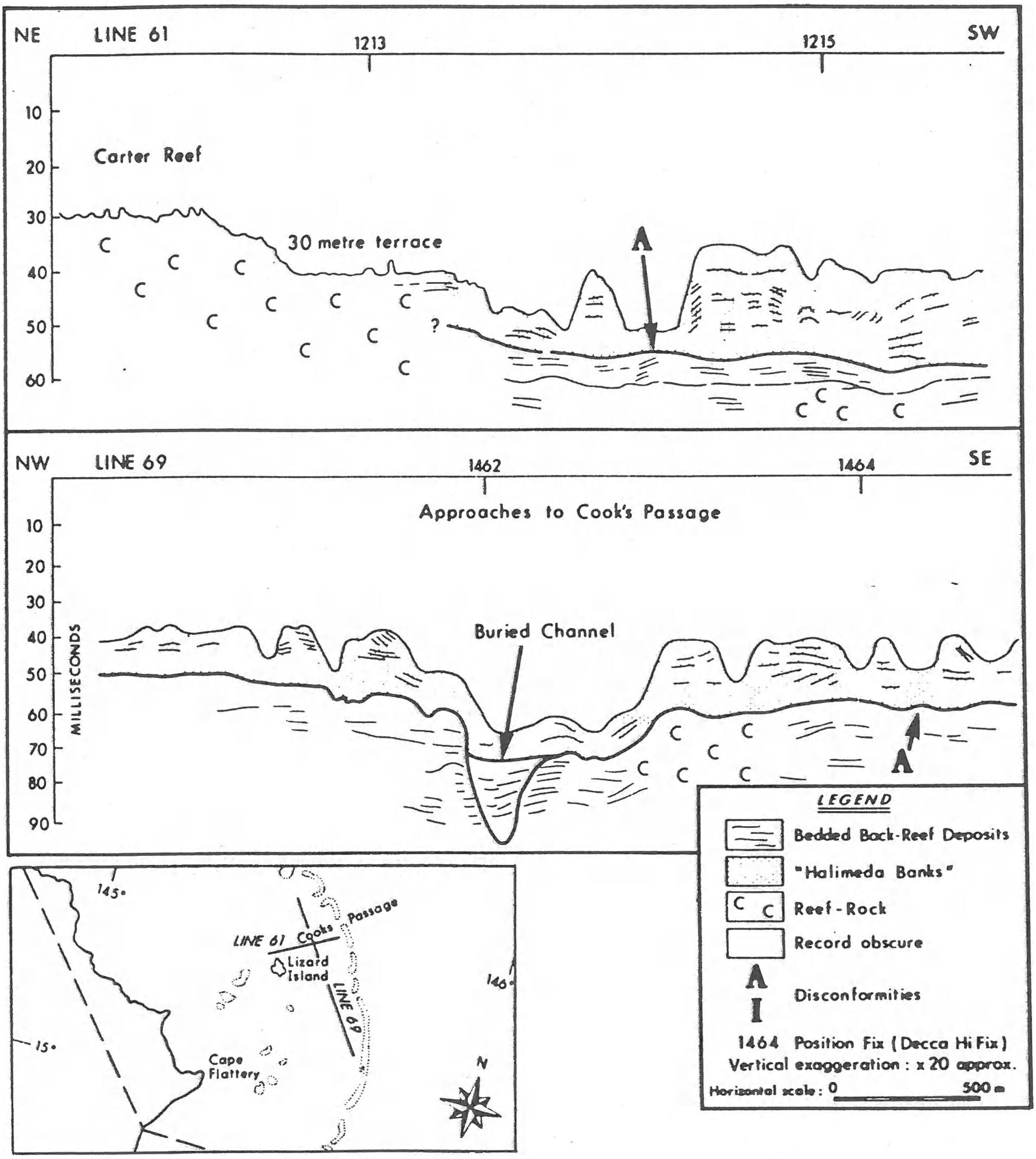


Fig. 3 : Interpretations of parts of continuous seismic reflection profiles (high resolution boomer) from the Lizard Island area (lines 61 & 69). The timing lines (vertical scale) at 0,01 second intervals correspond to an interpreted depth scale of 7,5 m per timing line. A corresponds to a disconformity interpreted as an ancient karstic surface (from ORME & FLOOD, 1977).

2.1.2.b. Climate

Lizard Island has an intertropical oceanic climate with highest temperatures from November to January (summer) and lowest temperatures from June to August (winter). Air temperature fluctuations are not very important. Temperatures noted during the "DE MOOR"-expedition varied from 22° C to 29° C during summer months and from 19° C to 24° C during winter months (MONTY, 1967). During our stay on the island in June-July 1975 (winter), temperatures as low as 17° C were noted in the early morning hours.

Water temperatures (calm weather, 3 m depth) measured during the Belgian expedition varied between the extremes of 25° C (23.9.67) and 29,4° C (4.12.67) (MONTY, 1967). The mean seawater temperature from August to December was 26,5°C. Our own measures in 1975 confirmed readings of 25° C (July 1975 - patchreefs in front of Research Station - near surface) whereas a depth of - 6 m (lagoon pinnacle in front of pass) yielded temperatures as low as 21° C.

Rainfall is variable along the Queensland coast; this is mainly due to concurrent influence of tropical cyclones, Moonsoon and Trade Winds opposing the depressions forming over the mainland. At Lizard Island the mean yearly rainfall oscillates around 1600 - 1700 mm whereas the mean of the summer months is about 1000 mm (further to the South mean values are higher - STODDART, 1978).

The wind circulation is dominated by the SE Trade Winds (see fig. 6). The integrated mileage in the SE-quadrant indeed represents 85 % of total mileage (STEPHENSON e.a., Low Isles, 1931). These Trade Winds blow "with great constancy and force in the Great Barrier Reef area for nine months of the year (March-November); mean velocities are given as 18 - 29 km/h, but north of Cairns these are frequently exceeded" (STODDART, 1978). "As STEERS (1929) noted, the Trades blow almost parallel to the trend of the coast, producing short, steep, difficult seas ... When the Trades cease, for the three months December-February, the winds are northwesterly and less regular, with days of calm" (STODDART, 1978). During our stay on the island, Trade Winds blew almost all the time with the exception of an intermittent period of 5 - 6 days when the Trades were replaced by a light northerly breeze which even culminated into one day of complete calm. For the remainder of the time the Trade Winds blew with considerable force; highest velocities registrated by Mrs. LUNDGREN during our stay, at the "Station Point" (westerly end of southern beaches) where full velocities could be measured, reached 7 - 8 Beaufort.

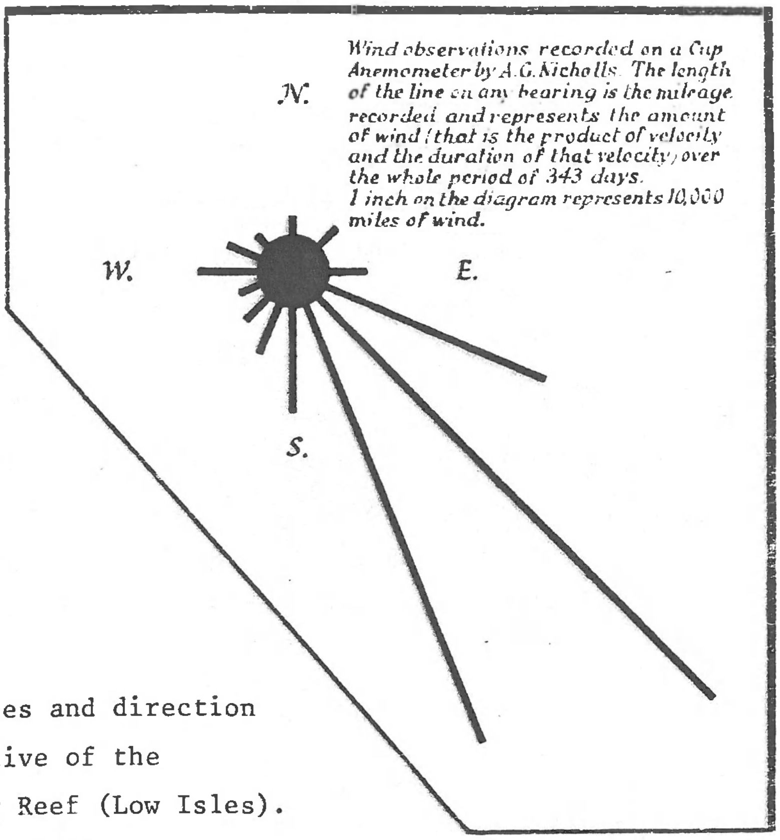
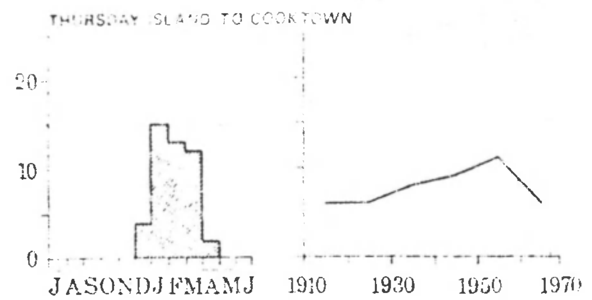


Fig. 4 : Wind velocities and direction in an area representative of the Northern Great Barrier Reef (Low Isles). (from STEPHENSON, e.a., 1931).

"Cyclones ... form a severe constraint on reef work; they are concentrated in the summer wet season. Records appear to show that they are less frequent in the northern part of the Northern Province than in the South, but this could reflect differences in recording rather than occurrence" (STODDART, 1978) (Fig. 5).



Mean monthly distribution of cyclones (left) and variation in frequency per decade (right) over the period of record (1910-69). Data from Coleman (1971).

Fig. 5 : Cyclones in the Northern Great Barrier Reef (from STODDART, 1978 - pars).

2.1.2.c. Currents and tides

Currents : The East Australian Current (see MAXWELL, 1968 etc.) has virtually no influence on the northern shelf; the only important current affecting this part of the Great Barrier Reef is the surface drift caused by the SE Trade Winds; this drift current crosses the shelf in a N-NW direction at a speed of 1/2 tot 1 1/4 knots. In the shallow littoral zone this drift generates a considerable sediment transport towards the North (SEGERS, 1970).

Tides : Tides in the Great Barrier Reef area are variable but generally large in comparison with most other reef provinces. In the North, tidal range varies from 1,7 m at Cairns to 2,5 m at Cape York, but little is known of tides between these two locations (STODDART, 1978). The table (fig. 6) shows mean tidal ranges at springs in the Northern Great Barrier Reef and tidal levels in meters at Cairns.

MEAN TIDAL RANGE AT SPRINGS IN THE NORTHERN PROVINCE OF THE GREAT BARRIER REEF

Data from Queensland Department of Harbours and Marine (1973).

locality	latitude S	range/m
Cairncross I.	11° 14½′	2.50
Hannibal I.	11° 35½′	2.44
Sir Charles Hardy's I.	11° 55′	1.83
Cape Grenville	11° 58′	2.01
Piper I.	12° 14½′	2.01
Restoration Rock	12° 37½′	1.77
Night I.	13° 10½′	1.77
Morris I.	13° 30′	1.80
Burkitt I.	13° 56½′	2.07
Pipon I.	14° 07½′	1.59
Flinders Is	14° 10′	1.86
Howick I.	14° 30′	1.77
Lizard I.	14° [illegible]	1.53
Low Wooded I.	15° 05′	1.77
Cooktown	15° 28′	1.77
Hope Is	15° 44′	1.71
Bailay Creek	16° 12′	1.28
Low I.	16° 23′	1.71
Port Douglas	16° 29′	1.77
Green I.	16° 45½′	1.71
Cairns	16° 55′	1.89
Fitzroy I.	16° 56′	1.77

Tidal levels in metres at Cairns are as follows (Queensland Department of Harbours and Marine 1973):

highest astronomical tide	2.9	mean low water neaps	1.2
mean high water springs	2.3	mean low water springs	0.5
mean high water neaps	1.6	lowest astronomical tide	−0.1

Fig. 6 : Northern Great Barrier Reef tides (from STODDART, 1978).

During the "DE MOOR"-expedition, MONTY could describe the structure and zonation of the Windward Barrier at Lizard Island in detail at the occasion of a neap tide concurring with a day of calm (MONTY, 1967); during our 1975 stay on the contrary, neap tide fell together with very windy weather and a very strong SE swell masking the neap tide effect.

2.2. The Lizard Island reef complex

2.2.1. Preliminary remarks

Description of and detailed information on the physiography of the Lizard archipelago and its reef complex are almost completely lacking in the literature (see Chapter 1). The data given in the present chapter (2.2 and 2.3) are completely original and are a compilation of SEGERS's and my own field observations (1975 mission) with MONTY's (1967, Belgian "DE MOOR" expedition) field notes. The detailed description of all supratidal island features, with the exception of supratidal beach zones, has been omitted here. It has no immediate bearing upon the distribution of Foraminifera (keeping in mind though that island granites are at the origin of the terrigenous component in reefal and perireefal sediments - MONTY, 1967 and SEGERS, 1970).

In most cases the topographical designations are not well-fixed yet in this roughly surveyed part of the Great Barrier Reef. The names used here to designate the two smaller islands of the Lizard Archipelago (Palfrey and South Islands) are those which are nowadays in common use, but these islands are also known under the names Iguana (for Palfrey) and Newt (for South) Islands. Other local designations used throughout this work are not official ones but most of them were commonly cited by the scientists working at the Lizard Island Research Station. The toponyms as they are used here (see fig. 7) were proposed by the former Resident Director, Mr. S. DOMM, who told us (June 1975) that he was about to propose these names officially. Mr. DOMM left Lizard Island shortly afterwards and I do not know whether this intention has been realised or not I use his toponymy tentatively.

2.2.2. Main physiographic units (figs. 7, 8, 11)

The Lizard archipelago is composed of Lizard Island and its two smaller sisters Palfrey and South Islands. These three islands are largely composed of intrusive granite of Permian age.

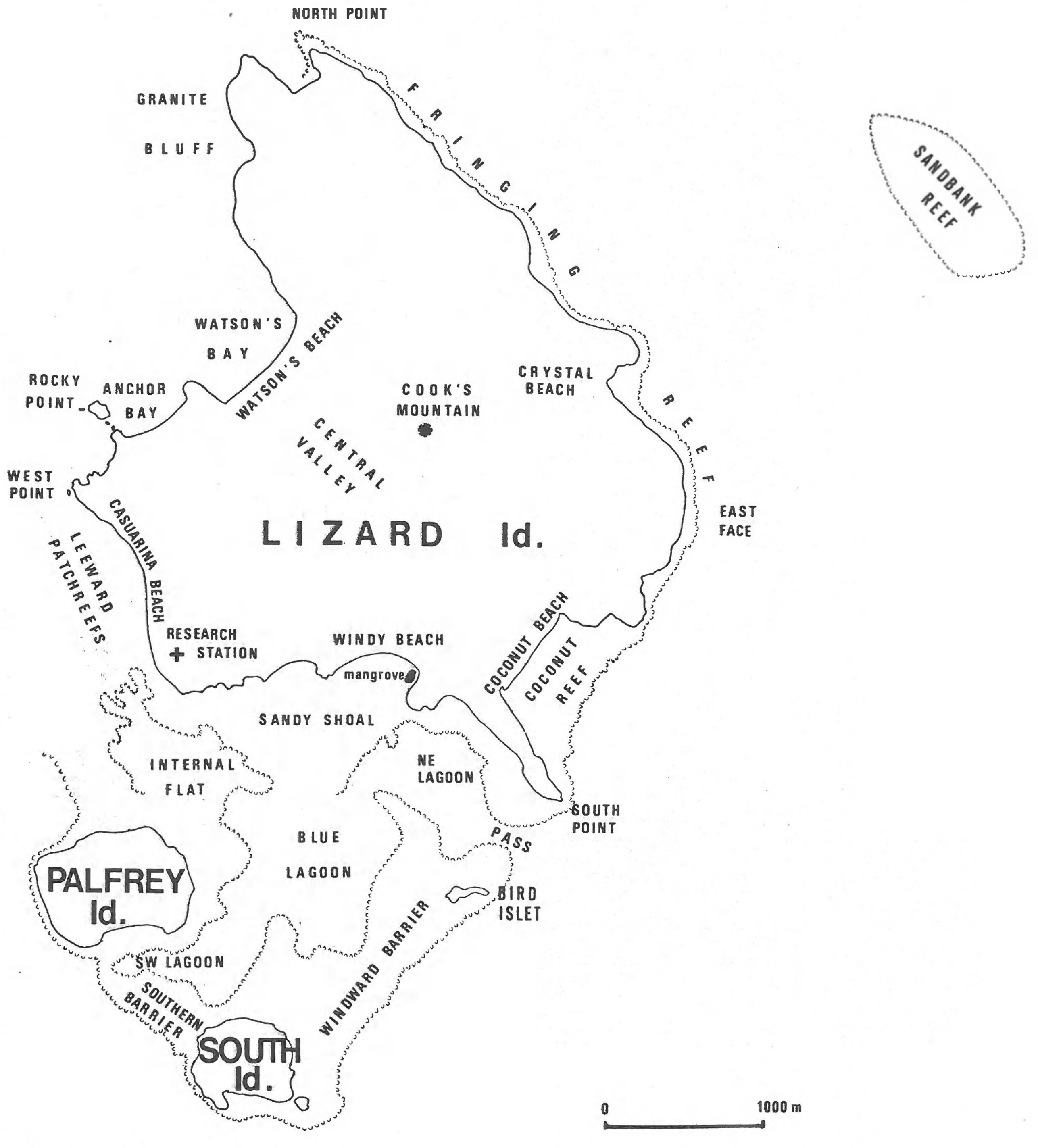


Fig. 7 : Lizard Island archipelago;main physiographic units. Toponymy as proposed by DOMM (1975, inedit.).

Fig. 8 : The Lizard Island archipelago; aerial photograph.

The structural trends of the granitic mass constitute a determinating factor of island and reef morphology in the case of the Lizard archipelago. These trends are clearly visualised in the supratidal morphological features as well as in the alignments of reefs, islands and shoals (see also fig. 8). A first structural trend is directed SE-NW, which is parallel to the main structural trend in NE Queensland. The Lizard archipelago is moreover situated in a SE-NW lineage of granitic islands also comprising North- and South Direction Islands; these islands apparently belong to the same intrusive backbone which progressively dips towards the South and disappears South of S. Direction Island.

Upon this SE-NW trend, a perpendicular SW-NE trend is superimposed. These two orthogonal trends control the development of the reefal system; the SE-NW trend is visualised by the direction of the valleys and rocky extensions upon Lizard Island and by the alignment of Palfrey and South Islands, and the Southern Barrier. The opposite SW-NE trend can be followed e.g. in the alignment South Island - Windward Barrier - Bird Islet - South Point, whereas a second, less obvious granitic elevation culminating at Palfrey Island forms the "basement" of the Internal Flat and the Sandy Shoal. These structural trends are indicated on the bathymetric map, fig. 11.
Lizard Island is about 4 km long and 3 km wide; it rises rather abruptly from a shelf depth of - 20 tot - 30 m and reaches a maximum altitude of ± 380 m (Cook's Mountain in the central part of the island). From N to S, Lizard Island shows three distinct morphological units : a mountainous area in the NE (Cook's Mountain), a broad central depression (Central Valley) and a southern granitic unit bordered by terraces and (paleo ?) dunes. The SE extremity of the central valley is closed by a complex dune system of about 30 meters high, whereas in the NW the valley bottom rises up to ± 5 m and then dips gradually, gently sloping under the water of Watson's Bay. In the northern mountainous area slopes of the granitic faces are steep and plunge abruptly towards the shelf bottom, whereas in the southern unit the coastal areas are formed by a dune- and terrace system from the SW to the NE; the NW and SE coasts of this southern unit are formed by crescentic beaches separated by granitic spurs (see aerial photograph, fig. 8).

The two smaller islands South of Lizard Id. are compact granite masses cut by tourmaline dykes; South Id. is 500 m wide and its highest point is at 180 m; Palfrey Id., slightly larger, measures 1 km x 500 m and shows a more or less rectangular outline. These three islands are linked together by a reef complex which may be divided into the following units (fig. 7) :

-) A narrow fringing reef stretches N tot S along the eastern coast of Lizard Id. from North Point to South Point; this fringing reef widens towards the South and forms a well-developed reef flat between East Face and South Point (Coconut Fringing Reef Flat).

-) A more or less continuous reefal structure, called the Windward Barrier by the "DE MOOR"-expedition, extends from South Point to South Island; this reef is cut by a narrow pass forming the Lagoon entrance. This pass is situated in the northern part of the Windward Barrier, between South Point and a smaller granitic head (Bird Islet).

-) A smaller reef, here called the Southern Barrier, structured in essentially the same way as the Windward Barrier, links together Palfrey and South Islands.

-) A central blue Lagoon (depth up to - 12 m) is bordered to the N by a Sandy Shoal (max. depth 2 à 3 m), to the NW by an Internal reefflat, to the SSW by a shallow lagoon and to the SSE by a high turbulent depression bound to the Pass. Two small areas of mangrove development occur upon the Sandy Shoal, at Windy and Freshwater Beaches.

-) The Internal Flat passes northwardly to the Leeward Patchreef Area which is roughly delimited by the - 10 m isobath. Main development areas of the patchreefs are between Palfrey Id., and West Point, facing Casuarina Beach; poorer patch developments are however found as far North as Watson's Bay and Anchor Bay. The coast between Watson's Bay and North Point is devoid of any reef growth.

2.2.3. Bathymetry

As stated above, the history of sea level oscillations and their effects upon reef- and shelf morphology is not yet fully understood.

STODDART (1978) summarises the results obtained by the most prominent investigators and compares them with MAXWELL's data : "MAXWELL (1968, 1973a) has erected a relative chronology of sea level change ...; this calls for still-stands at - 102 m, - 88 m, - 66 m, an extensive stand at - 29 m, a fall to another extensive stand at - 59 m, a rise to a further important level at - 37 m, a brief stand at - 18 m, a transgression to + 3 m, and a fall to present sea level ... It is fair to note that MAXWELL's interpretation is largely inferential, and is not yet supported either by radiometric evidence or by stratigraphic information on reef structures". By means of echosounding profiles (see Annex 4) we detected several terraces in the Lizard Id. Reef Complex; among these only the - 18 m terrace can be related to MAXWELL's still-stands; the extensive - 32 m terrace encountered in the Eastern Perireefal Area might perhaps correspond to MAXWELL's - 29 m level.

Summarizing, the following terrace levels were encountered in the Lizard Island Reef Complex (MONTY, 1967; own observations) : an extensive - 3 m level (upon which most of the patchreefs have grown), levels at - 6 m, - 15 m, - 18 m, - 27 m (shelf bottom extending from SW to N of the reef complex) and - 32 m (shelf bottom extending in a SE direction).

Except for rough data from the Australian Admirality charts, and those found in MAXWELL (1968) (See fig. 9), there is no detailed bathymetric map of the Lizard Island reef complex and vicinity; I had accordingly to compile one myself. It is based on 9 echosounding tracks (of which 4 were taken by MONTY, 1967, and 5 during our 1875 mission); these were complemented by some Bendix readings and underwater observations; the tentative bathymetric map is shown in fig. 11, whereas the location of the echosounding tracks is given in Annex 4. The detailed profiles can be found in Annex 4. Finally two of MAXWELL's echosounding tracks (from Nymph Island to the northern approaches of Lizard Island, and from the southern rim of the Lizard Id. reef complex to the shelf edge reefs) are illustrated in fig. 10. The following evidence is shown by the bathymetric map : (details are discussed in 2.3) :

-) Fringing reef and barrier reef flats, Sandy Shoal, Internal Flat and patchreefs are confined within the - 5 m isobath. The largest extention of the leeward patchreefs is on a - 3 m terrace; only one single large patch is situated somewhat westward of this terrace and remains inside the - 10 m isobath.

-) The Lagoon depth is generally less than - 10 m, except for its central area (behind the backreef area of the Windward Barrier) where a depression reaching - 12 to - 13 m occurs. In its NE part, the Lagoon rapidly deepens towards the Lagoon entrance which exceeds a depth of - 15 m in its narrow central area; only two large pinnacles ("bommies") almost reach the surface there.

-) To the NE, the fringing reef front rapidly falls towards the shelf floor at about - 25 m without showing any prominent terraces. The shelf is very irregular and displays extensive Halimeda-ridges and banks rising to depths of about - 20 to - 17 m (see also echosounding track 9 in Annex 4). This area forms the connection with the smaller Sandbank Reef rising to the surface and provided with a small, barren sandcay at its leeward end.

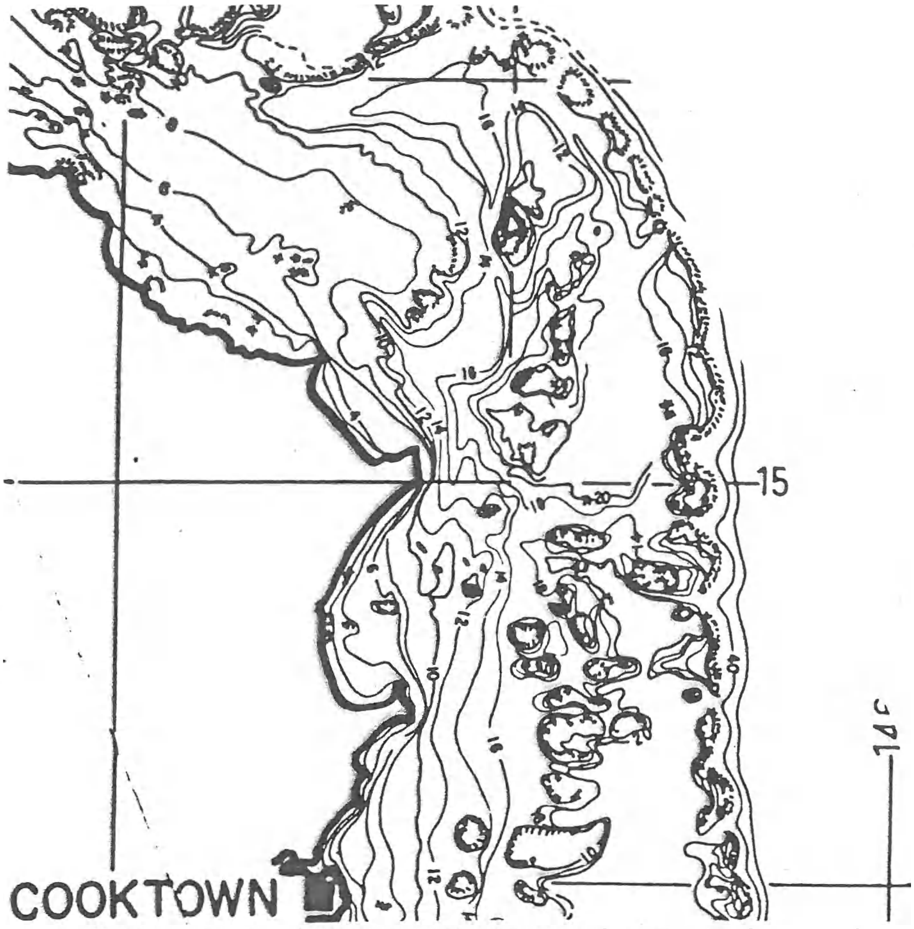


Fig. 9 : Bathymetry of the Northern Great Barrier Reef (area Lizard Island - Cooktown) (from MAXWELL, 1968 - pars) (depths in fathoms).

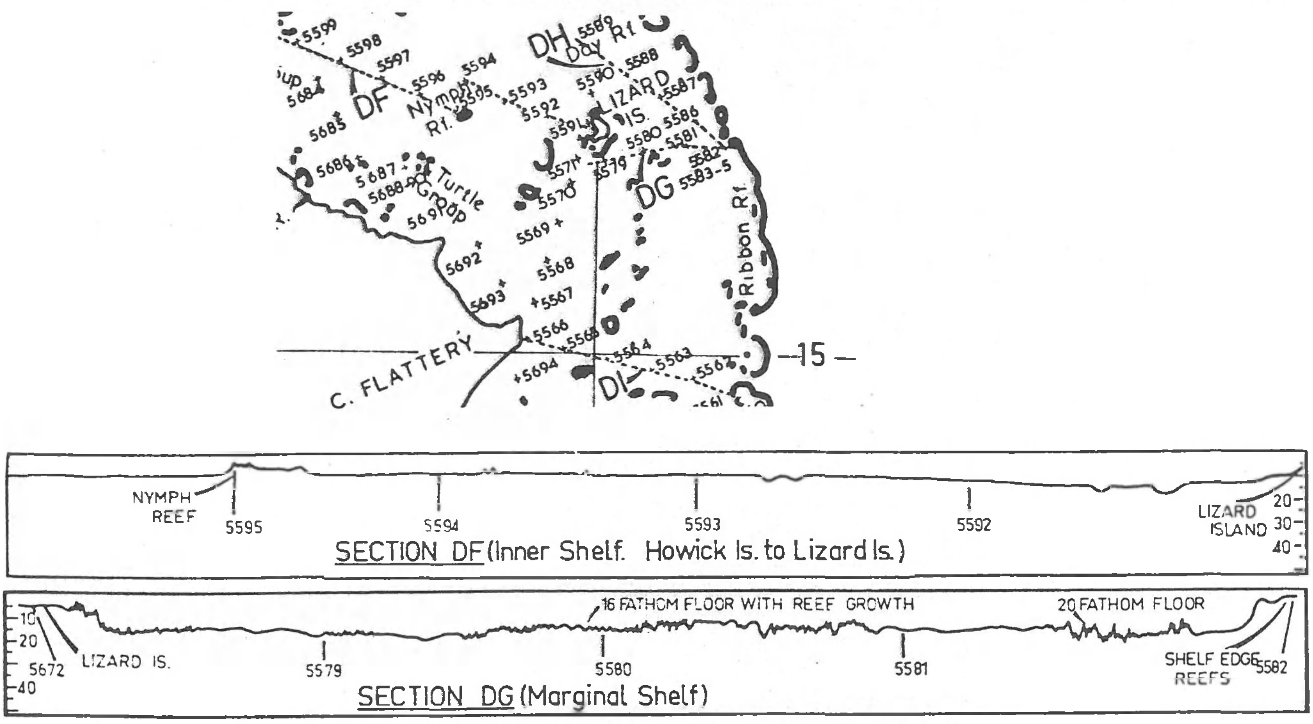


Fig. 10 : Echosounding tracks in the vicinity of Lizard Island, with localisation map (from MAXWELL, 1968 - pars) (depths in fathoms).

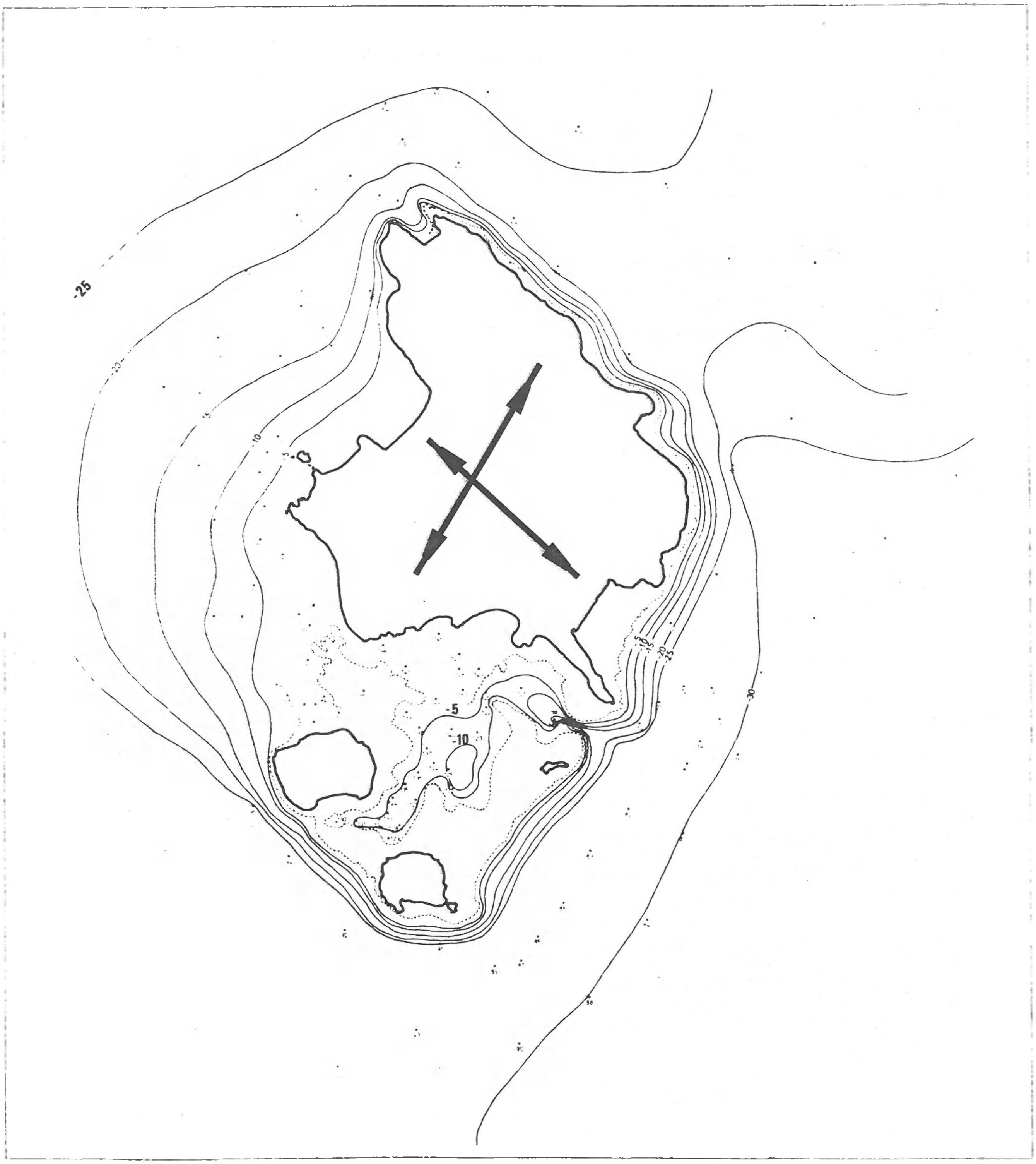


Fig. 11 : Tentative, idealised bathymetric map of the Lizard Island reef complex and its surroundings, based upon Bendix echosoundings , aerial photographs, interpretation of Admirality map and scuba-diving observations; minor seabed topographic disturbances (e.g. Halimeda-banks in the NE rising up to - 15, - 17 m) have not been taken into account. Arrows indicate main structural lineaments, followed by main physiographic features.

-) In the E and SE, terraces are well-developed in front of Coconut Fringing Reef flat and the Windward Barrier, and are only interrupted at the Lagoon entrance. Here the shelf bottom gently slopes from a depth of - 18, - 20 m (foot of the reef front) towards a - 27 m floor which then deepens towards an apparently continuous - 32 m floor.

-) In the SW, terraces are not very well developed and, when present, are rather narrow; the reef front of the Southern Barrier steeply plunges towards a depth of - 18, - 20 m and the shelf bottom then rapidly deepens towards the - 27 m floor.

-) In the NW, the sandy bottom gently slopes down from the - 3 m terrace and a depth of - 25 m is only reached at a considerable distance of Lizard Id., resulting in a much wider spacing of isobaths in this area.

2.2.4. Sedimentology

2.2.4.a. Preliminary remark

The sedimentology of the Lizard Island Reef Complex had initially been devoted to a separate PhD-thesis by E. SEGERS who unfortunately had to abandon this study and did not synthesize his observations which accordingly remained unpublished; this is why I have included below a brief summary of his bachelor's thesis to indicate the gross sedimentological trends, and illustrate the important relationships between sedimentary facies and foraminiferal distribution. Foraminiferal tests indeed are important contributors to the carbonate fraction of Lizard Id. sediments, as can be seen on fig. 12.

2.2.4.b. Origin and composition of Lizard Island sediments

Sediment components are of exogenous and/or endogenous origin. Exogenous sources are the 3 isles of the Lizard archipelago which essentially deliver terrigenous grains and diluted organic matter. Endogenous sources are the different units composing the reef complex (reefs, Lagoon ...); they provide carbonate sediments resulting from organic activity. The proportion terrigenous -

carbonate component in Lizard Island sediments, expressed in histograms, is shown in fig. 12.

Exogene sediment sources can be limited to the main lithologies characterising the supratidal environments of the islands, viz. the granite, the (palaeo) dunes and the plant cover of Lizard Id.. Granular desintegration of the granite liberates quartz, rectangular feldspars, mica flakes and tourmaline needles, in the mean dimension range of ± 1000 microns. Palaeodunes situated in the southern part of Lizard Island constitute the main source of finer eolian terrigenous grains most of which collect in the Lagoon.

Endogenous sediment sources essentially deliver carbonates through reefal fauna and flora. Non-skeletal carbonates are present in the form of coated grains and radial ooids (MONTY, 1972) (Lagoon, Sandy Shoal, Patchreef Area ...). The very low amount of accretionated carbonate grains constitutes a major difference between Queensland reefs and Caribbean reefal provinces such as e.g. the Bahamas.

The relative proportions of the different carbonate producers are illustrated on fig. 13; this table recapitulates the mean values of the samples analysed at that time (1976), samples collected by MONTY (1967) plus samples taken during the 1975 mission. Only fractions superior to 125 µm have been taken into account as components of finer fractions are difficult to identify. The table shows the modest participation of corals into the analysed sediment fraction; main fragment sources to sand are molluscs (bivalves and gastropods), followed by Algae and Foraminifera. Reef rock fragments range among the important carbonate components of the sediment. The carbonate fraction in Lizard Island samples ("DE MOOR"-samples exclusively) is explicited in fig. 15.

Comments on the most important carbonate producing organisms in the sediments :

Molluscs : Deposit feeders dominate in silty, muddy sediments because of the higher content in organic matter whereas suspension feeders predominate in coarser deposits. At Lizard Island a zonation of mollusc associations can be distinguished in the upper infralittoral zone : the hard substrates from the high energy upper area are characterised by an association of limpets (and green crabs); they are followed seaward by an association of *Tellina*, *Cardium* and *Divaricella*; these molluscs are characteristic of loose sediments. The Sandy Shoal is characterised by a predominance of cardiids and *Divaricella* (suspension feeders) whereas the Lagoon bottom is intensively colonised by *Tellina* (and several types of worms-detritus- and deposit-feeders);

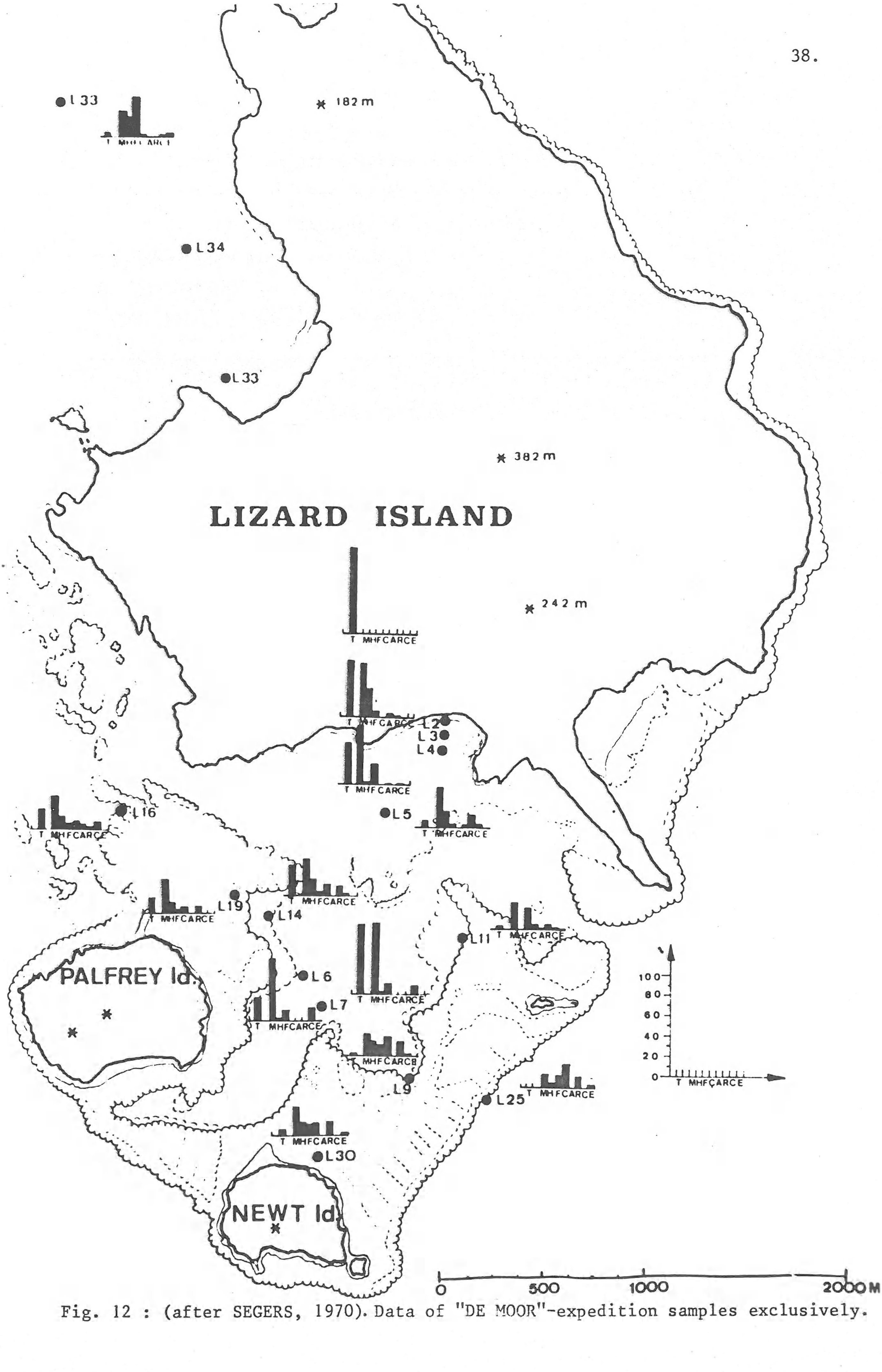


Fig. 12 : (after SEGERS, 1970). Data of "DE MOOR"-expedition samples exclusively.

Fig. 12 - legend :
Histograms express following data :
Global bioclastic carbonate fraction equals 100 %
T = % of terrigenous elements in global sediment.
M = molluscs; H = Halimeda; F = Foraminifera; C = coral;
A = alcyonarian spicules; R = red Algae; C = crustaceans;
E = echinoderms
The name "Newt" is an old name for South Island.

	Means of fractions 125 µm (%)		extreme values (%)
Molluscs	38,53		13,51 - 70,33
Algae	18,65	12,25 Halimeda	2,00 - 29,39
		6,40 Red Algae	0,00 - 13,91
Reef rock	14,58		0,85 - 34,06
Foraminifers	12,19		2,67 - 40,40
Coral	6,98		0,00 - 22,84
Crustaceans	4,21		0,71 - 14,04
Alcyonarians	1,29		0,00 - 4,44
Echinoderms	1,18		0,00 - 3,63

Fig. 13 : Main carbonate composants of the reefal sediments in the Lizard Island reef complex (after SEGERS, 1976, unpublished notes).

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this illustrates ecological patterns (suspension feeders in high-energy environments versus deposit feeders in low-energy environments) reflected into, and interrelated with, the sediment types.
Moreover the presence of carnivorous gastropods (Muricidae, Naticidae) has been observed in the Lagoon. Vagile reefal molluscs are minor contributors to the sediment, whereas on the reef slopes and in the Perireefal Area oyster- and pteriid fragments are encountered. Scaphopods are rarely found (in the Lagoon).

Algae : Three groups are encountered : Rhodophycea (Lithothamnium, Goniolithum, Amphiroa), Chlorophycea (type Codiacea : Halimeda) and filamentous algae.

Red algae are mainly encrusting and colonise the turbulent reef flat areas; here they form sediment traps, stabilise shingle and are responsible for the protection of the reef against strong wave impact. They frequently are at the origin of the predominance of coarse to very coarse sediments (reef flats, internal platform N of Palfrey Island).

The codiacean Halimeda is well represented in the Lizard Island sediments with fragments of several species : in the shallow, intertidal environments mainly narrow-branched species occur whereas in the Perireefal Area species with large segments profusely contribute to the sediment. Fragmentation of these Algae is favoured by their segmented nature and their growth pattern; as their debris suffer limited transportation in the reef complex, larger fragments are frequently encountered and often exceed 1 mm; the large, unbroken segments of H. opuntia (?) (up to 1 cm or even more) form plain Halimeda gravel in the Eastern Perireefal Area (see pls.). Minor contributors to the perireefal sediments are the aragonitic codiaceans Rhipocephalus and Udotea.

Foraminifera : These are an important component of the sediments and are exhaustively dealt with in the next chapters.

Corals : Relatively few coral remains, either skeletal calcareous fragments or alcyonarian spicules, are encountered in the reefal environments.

Solitary corals mainly live in protected sites of the slope and on the shelf (Cycloseris, Fungia, etc.). After death, Cycloseris cyclolithes is generally buried into the sediment whereas Cycloseris sinensis is fragmented during reproduction processes and constitutes a source of finer coral fragments in the sediments.

Alcyonarians occur in almost every marine habitat at Lizard Id. and as a result their spicules, which are not washed away, are modestly though more or less evenly distributed in these sediments.

Crustacea : The crustacean populations at Lizard Id. are mainly composed of crabs and Ostracoda. Most chitinous carapace remains of larger crustaceans occur in the fine-grained lagoonal sediments; most are crab remains and are part of a psammic necrophagous epi- and endofauna. Crabs contribute to grain size reduction of bioclast due to crushing. A relationship seems to exist between high pelecypod remains percentages in the Lagoon, and the presence of necrophagous organisms (boring gastropods, decapod crustacea). Ostracods are locally abundant in the reef complex, mainly in the Lagoon and on the Sandy Shoal, though their carapaces are to be found in almost every habitat of the Lizard Island reef complex. These organisms are even nowadays poorly studied. A glimpse at a few samples from the 1975 mission astonished Dr. WOUTERS (K.B.I.N., Brussels) : indeed several, if not most of the observed species seemed new to this ostracod specialist (personal communication, 1980).

Echinoderms : Most echinoderm remains are found in the protected areas of the reef flats and below the turbulent zone of the reef fronts, where these animals preferentially dwell. Fragments are mainly derived from asteroids, echinoids (spines, spicules and ambulacralia of several species, e.g. Diadema setosa, Echinometra mathaei), ophiuroids and seacumcumbers (ossicles).

Finally the sedimentary load contains complex grains derived from reworked ancient reefs eroded during Pleistocene regressions. These fragments have suffered subaerial attack and are presently altered and encrusted; they are easily distinguishable from recent sediment components.

Textural variations :

The physical parameters which characterise the granulometric distributions of the sediments in the Lizard Island reef complex are strongly controlled by the faunistic composition and its differential ecological requirements. Minor environmental changes often cause notable variations in the granulometric distributions. This is mainly due to the fact that the innerreef sediments are largely kept within the coral-algal belt which forms an active sediment-trap. As a result, sediment transport within this belt is strongly reduced and the sediments reflect the biocoenoses very well. The desintegration pattern of reefal organism predetermine textural differentiations.

The granulometry of the "DE MOOR"-expedition samples, expressed in histograms, is shown on fig.14 ; these data can be summarized as follows :

Median : coarse : reef front
medium : reef flat
fine : Lagoon

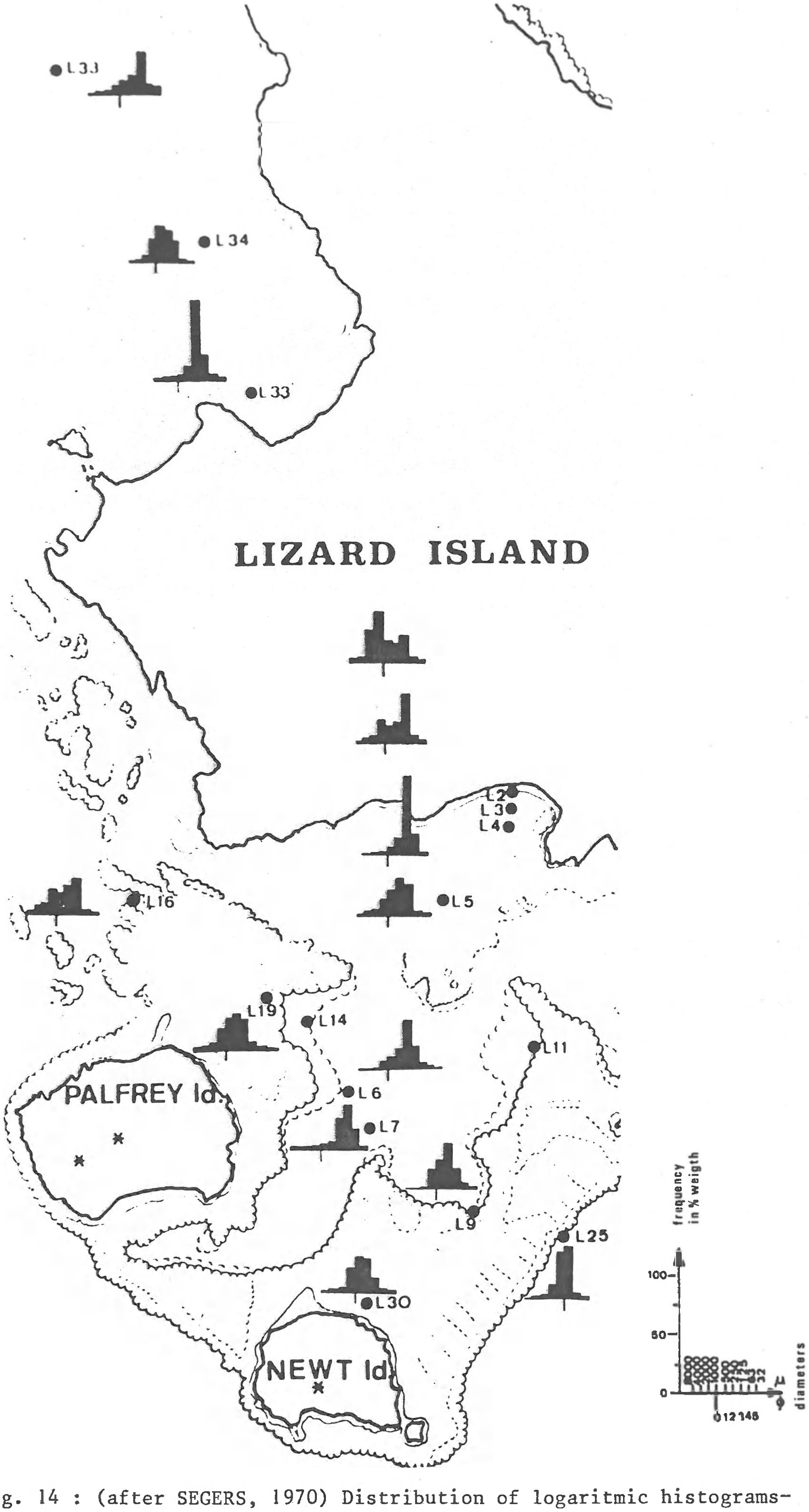
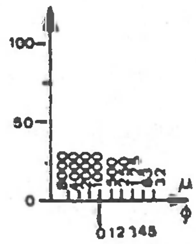


Fig. 14 : (after SEGERS, 1970) Distribution of logaritmic histograms-granulometry. Data of "DE MOOR"-expedition samples exclusively.

Fig. 14 - Legend : Histograms express following data :



Vertical : frequence expressed in weight %.
Horizontal : diameters in microns. Vertical line below histograms indicates position of the 1 mm-diameter.

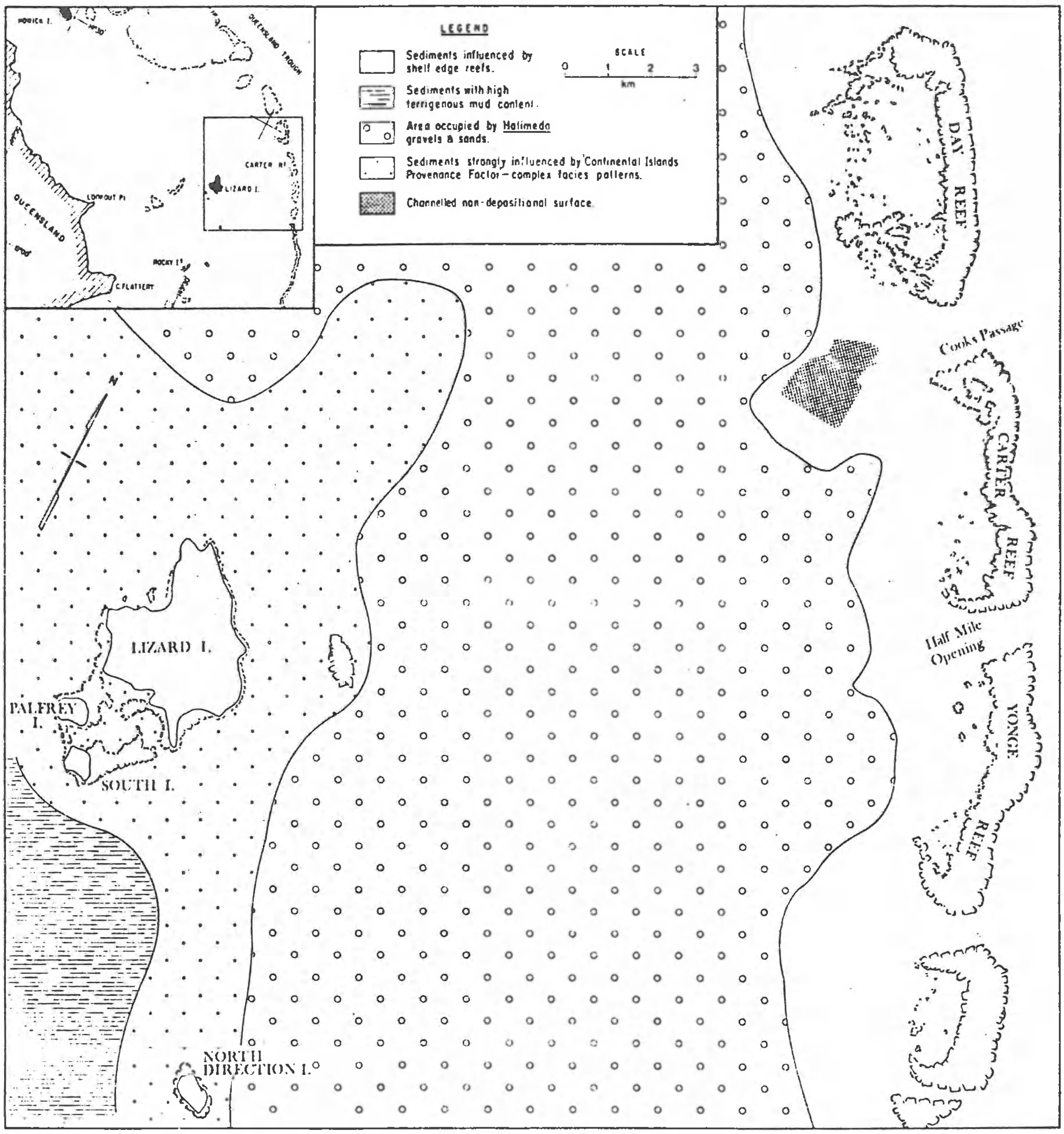
Sorting : well - to moderately well sorted : reef front
moderate : reef flat
moderate : Lagoon
Bad : Internal Flat - patchreefs.

(N.B. Values as indicated by MAXWELL and CONAGHAN - see SEGERS, 1970 :
QD $<$ 0,37 : well sorted
0,37 $<$ QD $<$ 0,75 : moderately sorted
QD $>$ 0,75 : badly sorted).

The gross sedimentation trends in Lizard Island's Perireefal Area sensu lato are shown by ORME, FLOOD and SARGENT (1978) and are illustrated on the map, fig. 15. It is to be noted that these authors classify the sediments of the entire Perireefal Area close to the Lizard Reef complex in their "Sediments strongly influenced by Continental Islands Provenance Factor - complex facies patterns".

Fig. 15 indicates the dominance of the mud component in the southwestern margin of the shown shelf area. It is believed by ORME e.a. (1978, p. 88) "to reflect mainland provenance" (see also SEGERS (1970, p. III.12) "... des sédiments vaseux, piégés entre le continent et les récifs rubans, qui résultent en grande partie du remaniement et de l'épandage de sédiments plus anciens").

The enormous quantities of Halimeda - fragments in this area cannot be explained by the in situ production of sparse, locally developed Halimeda - meadows alone; a transport factor may be involved here, as it is supposed by ORME e.a. (1978). These authors state that "the acme of production of this component (Halimeda debris) is associated with the extensive Halimeda "meadows" which cover the submarine "banks" of the backreef area. Some Halimeda debris is probably transported away from this site by tidal currents" (p. 90).



Map of the outer shelf near Lizard Island showing the general form of the sediment distribution pattern, and the salient source factors.

Fig. 15 (From ORME, FLOOD and SARGENT, 1978).

2.3. Description of the reef units and the Perireefal Area

2.3.1. Preliminary remarks

The supratidal, intertidal and subtidal environments of Lizard Island will be described macroscopically below. Detailed description of foraminiferal distribution follows in the next chapters.

A bathymetric gradient separates intertidal and supratidal structures (comprising reef flats, Leeward Patchreef Area and Internal Flat, with associated beaches as supratidal marine units), versus subtidal features (comprising the Lagoon with adjoining Sandy Shoal, reef fronts and -slopes, Perireefal Area).

A gradient in the exposure to wind produces the differences between reef crests and forereefs of fringing - and barrier reefs, recolonised smaller patchreef fronts in the Lagoon on one hand, vs. leeward structures in the Lagoon, the Patchreef Area and the leeward NW slope. On the Windward Barrier, the Southern Barrier and on the Coconut fringing reef, the same gradient produces within the reef a horizontal zonation (forereef and backreef units). Thus, the differences between forereef and backreef structures are gradually diminishing from the SE (windward side) towards the NE (leeward side). On a larger scale however, almost the entire reef complex (with the exception of the windward forereef structures) may be considered as a backreef area.

2.3.2. Reef zonation

The following reef types are present :

a) narrow, steep fringing reef,

b) large, wide fringing reef with well-developed reef flat,

c) the "barrier-reef" type and

d) inner and outer patchreef types.

Schematic cross sections of three types of reefs are shown in fig. 16 : fig. 16a shows a cross-section through a narrow fringing-reef without beach formation (fringing reefs flanking the NW, E and NE coasts of Lizard Island, and the SW coasts of Palfrey and South Islands); fig. 16b shows a cross-section through a more broadly developed fringing reef with beach formation (cf. Coconut fringing reef), whereas fig. 16c shows a cross-section through a "barrier"-type of reef (cf. Windward- and Southern Barriers).

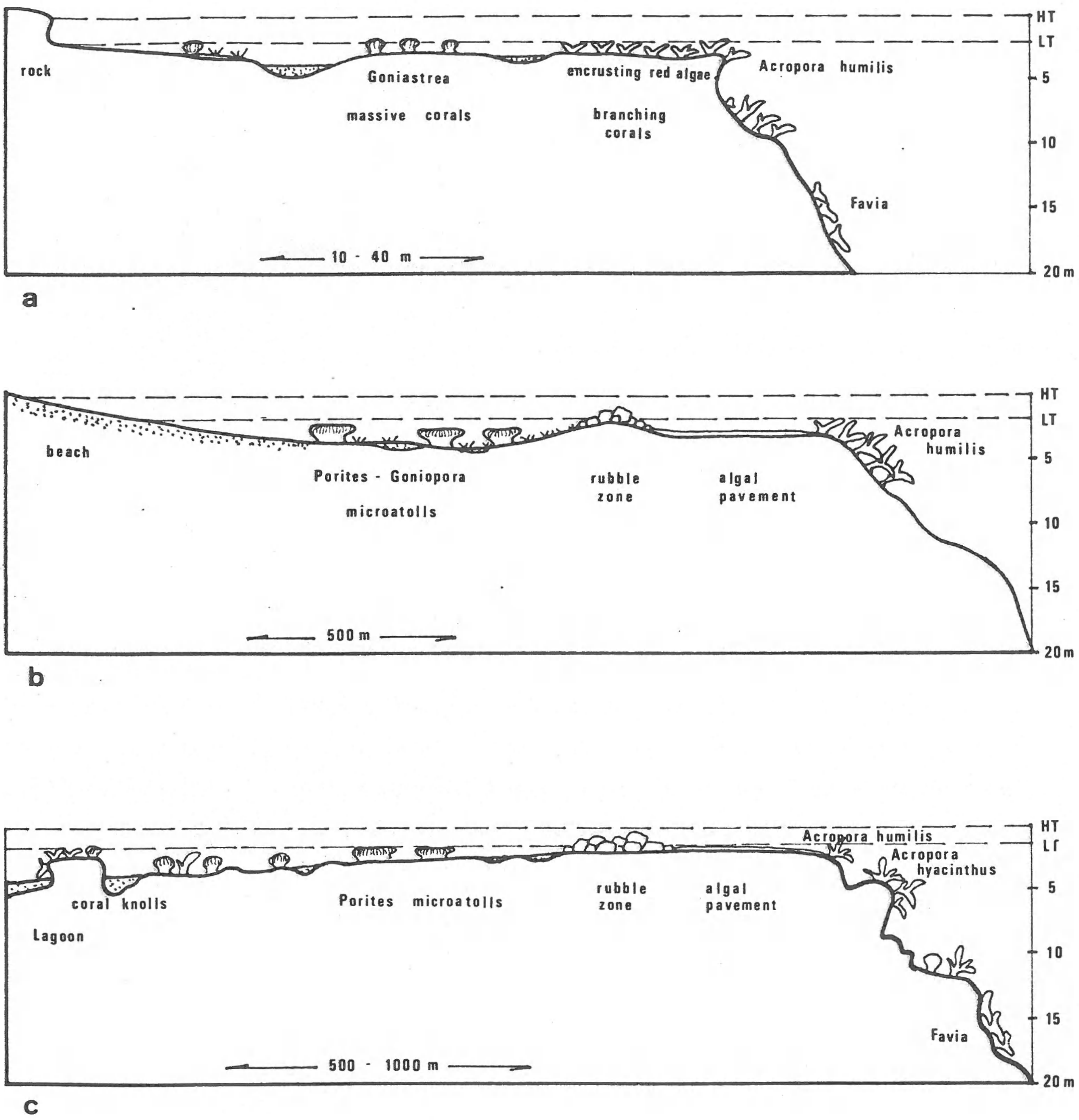


Fig. 16 : Cross-section through fringing- and barrier reef types (schematic, not to scale).

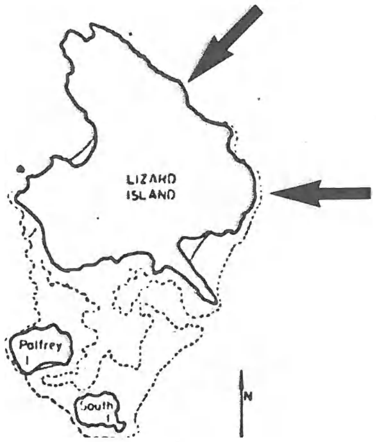
Fig. 16a : narrow fringing reef with reef flat (cf. NE fringing reef).

Fig. 16b : broad fringing reef system with beach formation (cf. Coconut Reef).

Fig. 16c : barrier reef (cf. Windward- and Southern Barrier).

2.3.3. The fringing reefs s.s.

2.3.3.a. The narrow fringing reef along the NE-and E-coast of Lizard Island



Sampling stations : none.

Description : These narrow fringing reefs have essentially developed along the NE- and Eastern coast of Lizard Island; along the NW-coast they are almost inexistant except in the immediate vicinity of North Point. Included in this reef type are the short and narrow reef stretches along the SW-coasts of Palfrey- and South Islands.

These eastern reefs do not form any continuous fringe; they are strongly conditioned by the coastal morphology and become very narrow along the granitic elevations of the E and NE face, whereas they broaden at the level of the granitic depressions (e.g. Crystal Beach & reef, Coconut reef); the best example of the latter type of broadened fringing reef with beach formation, Coconut reef, will be described below (2.3.3.b.).

This type of narrow fringing reef is schematized in fig. 16a. At some places no reef flat exists; only a coralgal colonisation of the foot of the granite cliff is present. Generally however the fringing reef develops a narrow reef flat of about 10 to 20 m wide, which is not exposed during ordinary low tide.

STEPHENSON et al. (1931) provided a short description of a portion of this fringing reef without well-developed reef flat; they see it as "a young reef, with no reef-flat, still narrow, and consisting mainly of living coral, with a predominance of massive Porites".

MONTY (1967) described this fringing reef along the Eastern coast of Lizard Is. as follows (see also fig. 17) : a short reef flat of about 10 - 15 m wide is present and shows poor madrepore growth (some Goniastrea, small Poscillopora, filamentous algae and encrusting red algae. In the immediate neighbourhood of the front, a somewhat denser coral growth appears, intermingled with encrusting red algae. The branching corals Acropora humilis (A. gemmifera) mark the distal end of the reef flat which is immediately followed by a subvertical reef slope, forming an impressive, rather smooth rocky wall locally covered with gigantic encrustations of Favia. This wall is interrupted at some places by crevices, conducts and caves at - 10, - 15 m. The latter apparently are connected with the nearsurface by subvertical chimneys; in the caves and pipes grow mussids, pectinids, <u>Turbinaria</u> as well as an enclave of a fragile coral fauna characteristic of backreef settings. This entire cave- and chimney structure may somehow be compared with a condensed spur- and -groove system where the spurs have joined each other and only vertical grooves and basal crevices remain open.

At depths of - 10, - 15 m this subvertical slope abruptly abuts the silty bottom sands of the Perireefal Area.

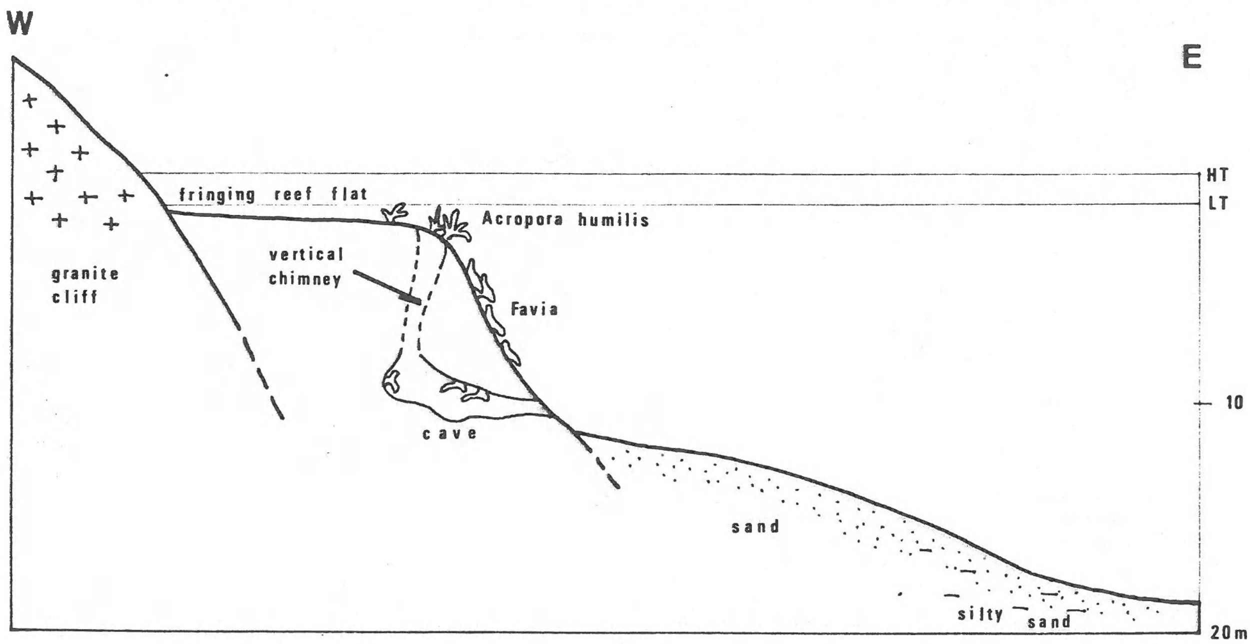


Fig. 17 : Schematic cross-section through a fringing reef along the Eastern coast of Lizard Island (after MONTY, 1967).

2.3.3.b. <u>The leeward fringing reef at North Point</u>

<u>Sampling stations</u> : L 292 (foot of reef slope).

<u>Description</u> : (Fig. 18) : North Point shows another type of fringing reef locally developed around the granitic leeward side of North Point and along the coast of the Kapok Cove embayment; this fringing reef differs from the eastern windward fringing reefs mainly by its broader cross-section admitting a clear ecological zonation,and its gentler slope.

Granitic boulders and blocks are scattered over the proximal part of the reef flat, flanked seawardly by an algal flat (encrusting red Algae) locally covered by a sand veneer. Further seaward follows a zone characterized by faviids and green filamentous Algae.
The outer reef flat constitutes a zone with Acropora humilis and A. digitifera; the porous coral rock is heavily encrusted with red Algae and sparsely colonised by faviids, Astreopora, Symphyllia etc.
The complex frontal zone is incised by channels and shows a poorly differentiated spur-and-groove system; it is colonised by tabular Acropora hyacynthus showing larger diameters with increasing depth, and by Acropora cervicornis. Coral shingle is concentrated in the channel beds. Down from about - 10 m the reef slope (inclination 45°) is covered by "soft corals" like Lobophyton,

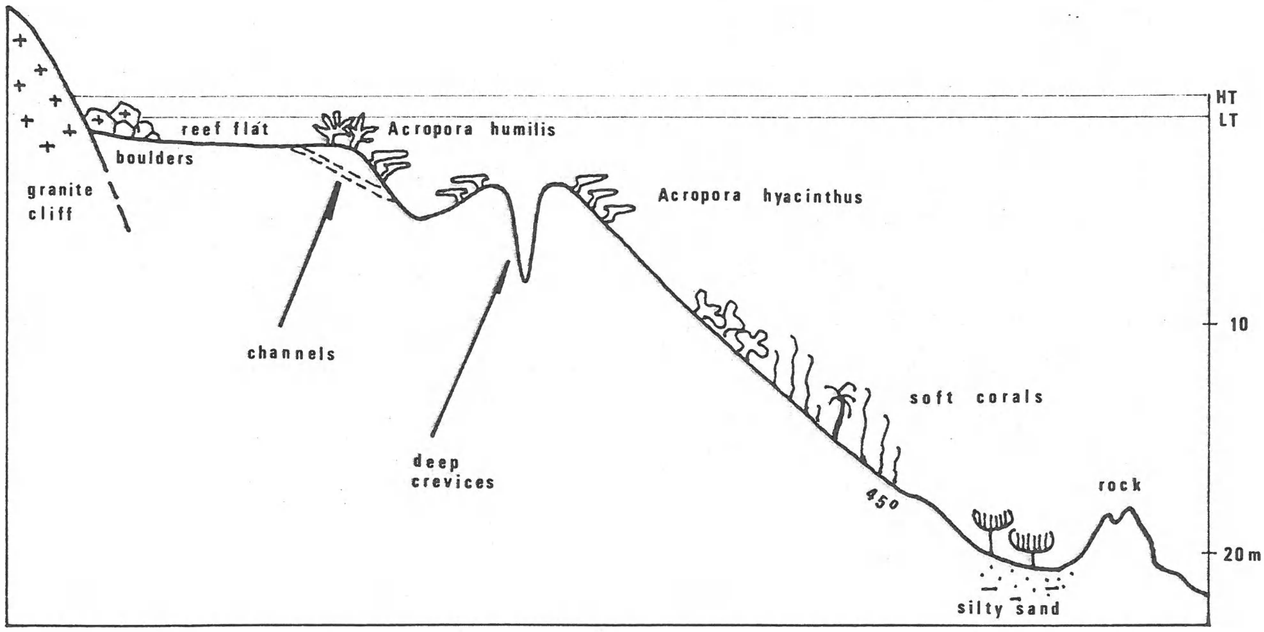
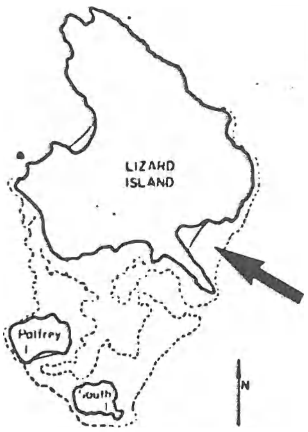


Fig. 18 : Schematic cross-section through a fringing reef at North Point (not to scale). After MONTY (1967).

Sarcophytum and filiform gorgonians covered with comatule crinoids (Comatulae). Below say - 13 m these gorgonians are the only subsisting alcyonarians, anchored on the naked, "dead" reef-rock bottom.

At - 18 m occurs a small ridge below which the slope flattens for a short while. At - 20 m lies a flat sandy bottom upon which some dead coral heads and gorgonians occur.

2.3.3.c. Coconut Fringing Reef



Sampling Stations : From NE to SW (roughly - see Annex 3) L 241, L 242, L 243a-b, L 244a-b, L 245, L 246, L 247a-b, L 248, L 249, L 250, L 251a-b, L 252.

Description : This reef, which follows up the southern end of the narrow NE fringing reef, forms a particular reef unit roughly corresponding to the scheme outlined on fig. 15b (broad fringing reef system with beach formation). It faces the SE and hence receives the full impact of the SE Trade Winds and swells. It lies in the direction of the Windward Barrier and is separated from the latter by the South Point spur and the Lagoon entrance. To the NE this reef narrows considerably and passes into the NE fringing reef. Towards the NW the reef system passes to the siliciclastic sediments of the Lizard Is. central valley which slopes down northwesterly towards Anchor- and Watson's Bays. This sediment-filling has allowed the broad development of the Coconut Reef with beach and dune formation; associated water seepage has apparently originated the reef destruction and/or its seeward preservation on the clastic wedge. Indeed, were it not for the reef front, colonised by staghorn coral, and the microatolls found on the reef flat, coral growth is extremely reduced on this strongly *Lithothamnion*-cemented reef.

As this reef lies slightly higher than the Windward- and Southern Barriers, its reef-flat is regularly exposed at low tide.

The following reef zones may be recognised from shore to reef front (NW-SE, Fig. 19) :

a) Backreef structures :

Dune- and beach formation : The SE-edge of the central plain stretching out between the granites of South Point and east Face, is partly plugged by a system of dunes. Behind a restricted area of recent low dunes, lies a less continuous ancient dune ridge towering over scattered more recent ones and bordering

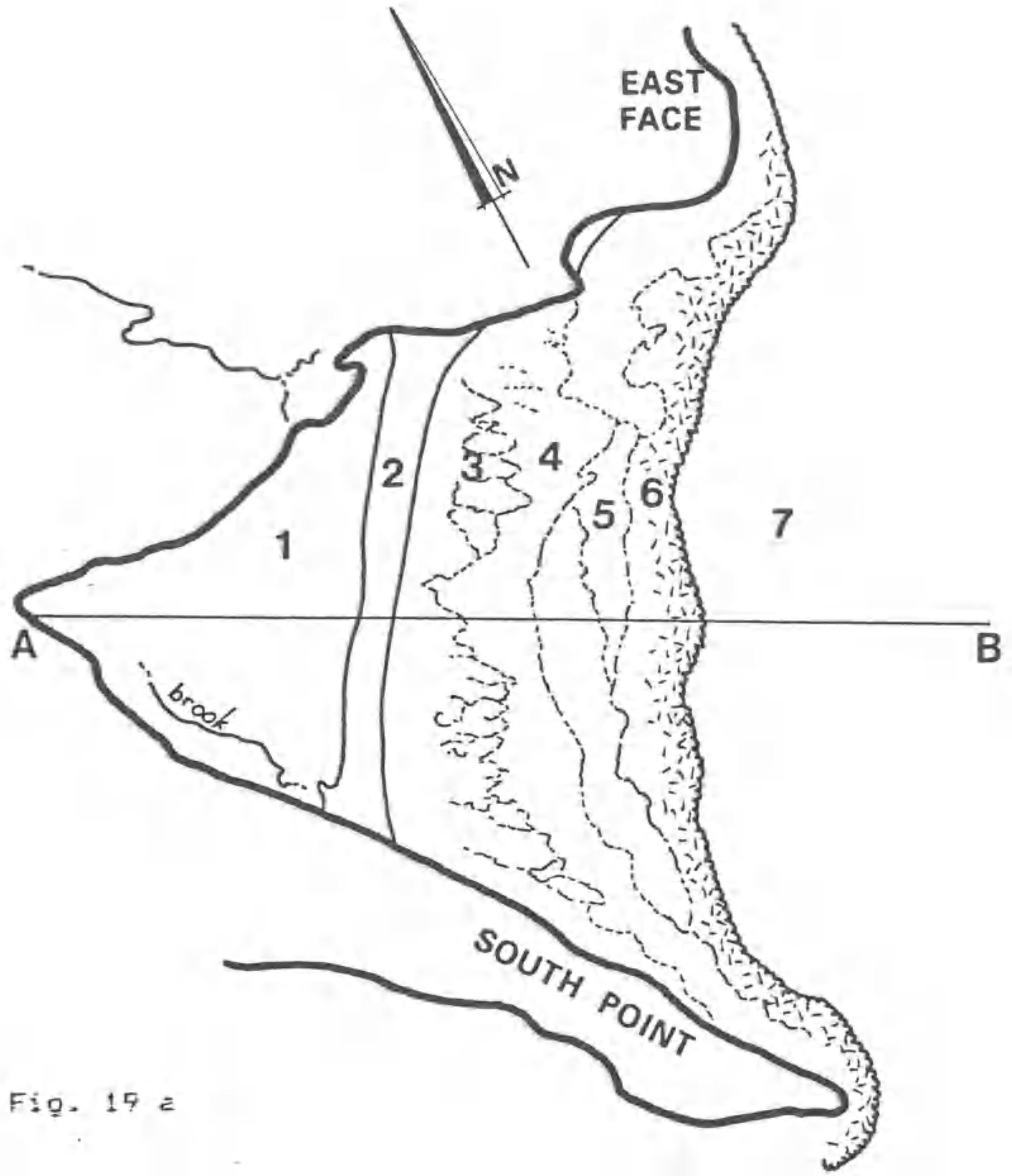


Fig. 19 a

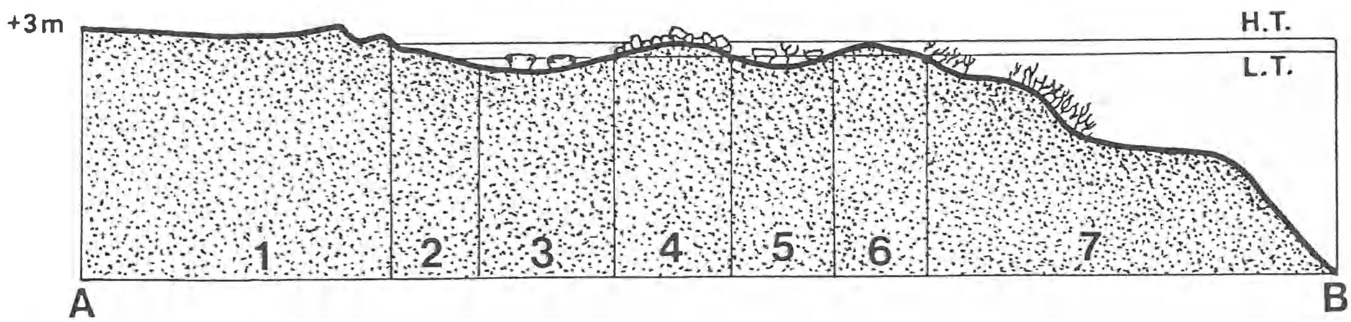


Fig. 19 b

Fig. 19 : a) Zonation of the Coconut Fringing Reef (zone limits are in reality more ill-defined than indicated here).

b) Cross-section A-B, showing main zones and subdivisions described in the text. 1: +3m-plain (terrace) with ridge and dunes; 2: beach; 3: microatoll-zone; 4; rubble-zone; 5: moat; 6: algal pavement; 7:reef front, terraces and slope. (schematical - fig.19b not to scale).

the terrace along almost the entire beach. This ridge is best developed at its SW-extremity (along the South Point granite). In section this ancient ridge shows at least three pumice layers.
The uppermost part of the paleodunes, from the youngest pumice layer up to the recent soil formation, is made of very fine sand, whereas medium-grained sand characterises the lower parts of the section. This ridge is interrupted by a terrace which should correspond to the + 3 m terrace backing Casuarina Beach in the SW-corner of the island.

At both extremities of the Central Valley plain, temporary freshwater-brooks can be observed whereas small freshwater-pools, covered with driftwood and pumice, occur behind the terrace-ridge. The NE-brook is fed by a steep conduct downhill the granite mass of Cook's Mountain, and is associated with a narrow strip of "rain forest" development.
At the time of our stay on the island during the months june-july no discharge could be observed. As no freshwater runoff was observed at the surface, some drainage must take place by percolation whereas the remainder of the freshwater in the pools evaporates. It should be noted that this freshwater percolation might be a factor inhibiting coral growth on the reef.

A long, straight beach separates the dune system from the reef flat. The beach is at its broadest at its NE- and SW-extremities. Beach rocks are absent here. Beach sands are generally medium- to coarse grained, badly sorted with a relatively important fine fraction; the terrigenous component is most obvious in the finer fractions (detrital silt + organic material). Most of this beach material however is derived from the reef flat in front and essentially consists of reef rock fragments and abraded skeletal debris, mainly clasts of foraminiferal tests. Winds and tides cause sorting of these foraminiferal tests into strips of beach where we find alternating concentrations of Marginopora on one hand, and of Calcarina, Baculogypsina and Amphistegina on the other (Figs. 1, 2, pl. 3); the latter fraction generates the reddish colour of the sand. Maximal Marginopora concentrations occur at the SW-extremity of the beach.

The beach surface is pierced by numerous burrows (more than 60 cm deep) produced by the Ghost Crab, Ocypoda ceratophtalma.

Microatoll zone : The foreshore passes into a area characterised by the presence of scattered "microatolls", subcircular metric built ups of Porites and Goniopora. These structures result from the stressed vertical growth of corals due to the limitation by water depth and eventual low tide emersion; they accordingly tend to expand centrifugally, leaving a decaying center invaded by borers. (Fig. 2, pl. 2). The transition from the beach to the microatoll-zone is very gradual and irregular whereas the sediment becomes more and more gravelly seawards. In front of both extremities of the beach (areas of maximum freshwater percolation and/or runoff, the coral colonisation vanishes and the bare sandy areas reach their maximum width. At the seaward edge of the microatoll-zone, intensive algal growth occurs; this algal-algobacterial coat is profusely colonised by Foraminifera (see Chapter 3). Interruptions of this coat denude sandpatches where scattered massive corals (Porites) occur, together with a few Acropora humilis, and alcyonarians. The mollusc associations diversify towards the rubble zone. Often Tridacna fossor and T. crocea associate with the microatolls.

b) Forereef structures :

Rubble zone : The transition from microatoll-to rubble zone is again very gradual; the bottom slightly rises to intertidal level, and the landward edge of the rubble zone shows up as an irregular mass of extremely badly sorted, eroded gravel, coarse sand and cavernous reef-rock which is, in tidal pools, overgrown by an algal coat. Giant Tridacna derasa (e.a.) as well as smaller T. crocea, T. fossor are to be found in these pools, as well as cones, strombidae, Trochus, crawling spider shells (Lambis lambis), seastars (e.g. the blue Linckia laevigata), Holothuria, sea-urchins etc., scattered massive and branching corals, some small microatolls and alcyonarians.

Further seaward, the rubble zone is very chaotic; the sedimentary veneer consists of coarse gravel, coral shingle, huge blocks of reef rock etc., interspersed with sand pockets, gravelly-sandy tidal channels perpendicular to the coastline whereas an algal coat (see Chapter 3) is almost omnipresent and overgrows everything except the sandpockets and drain channels. The vegetation cover houses Marginopora and other epiphytes.

Moat : Between the rubble zone and the algal pavement, an irregularly formed and somewhat discontinuous depression - the moat-stretches out along the reef flat. This moat is covered with water at low tide; the sedimentary veneer consists of gravels (coral shingle) and coarse, mainly foraminiferal sand (showing a reddish colour due to the abundance of Calcarina, Baculogypsina and Amphistegina-tests.) The pools contain some microatolls as well as Acropora humilis, scattered staghorn corals (Acropora spp.), alcyonarians, small sea urchins and starfishes. The floors of the microatolls are often perforated by Tridacna fossor whereas giant Tridacna occur sporadically. A Foraminifera-rich algal-algobacterial coat is present here.

Algal Pavement : The moat passes seawards to a slightly rising, rather smooth, well-cemented floor which is more or less uncovered by the water at low tide. This is the realm of the encrusting red algae, Lithothamnium, Goniolithon. The smooth algal pavement locally shows crevices and smaller depressions (10 to 30 cm deep) filled up with a sandy gravel, almost exclusively consisting of foraminiferal tests (Calcarina, Baculogypsina, Amphistegina) and showing well developed,flat-topped ripple-marks. Towards the edge of the reef flat, this cemented floor becomes gradually smoother. No corals grow here.

Reef front and slope : In contrast to the NE fringing reef, the freef front is strongly broken and slopes irregularly towards sandy terraces at - 3 m and - 12 m. Staghorn coral (Acropora spp.) grow profusely whereas the terrace sediments are of the same gravelly-sandy type as the one found in the rubble zone and the algal pavement. These sediments also consist mainly of foraminiferal tests (Calcarina, Baculogypsina and Amphistegina) and are obviously derived from the reef flat. The reef slope is somewhat more gentle here than in the Windward Barrier, as the terraces, and particularly the - 12 m terraces, are much broader.

2.3.4. The Barrier System

South of the main island (Lizard Island s.s.) there is a barrier reef. It consists of two distinct units :

1) A well-developed barrier extending from South Point to South Island and
2) a shorter, narrower, less developed barrier linking South and Palfrey Islands.

These reefs may be termed "barriers" as they are built up in the same way and show a comparable zonation as the huge, outer barrier protecting Lizard Island from the open ocean. Nevertheless, as there is a wide open strip of marginal shelf between Lizard Island and the Outer Barrier, currents and waves regain sufficient strength to allow luxuriant coral growth mainly upon the SE windward barrier of Lizard Island.

The reef barriers show a definite zonation and a distinction can be made between forereef- and backreef areas and structures. Contrary to the way we described the fringing reefs more to the N (proceeding from landward to seaward), I will give a description of the barrier reef units starting with the Rubble Zone and proceeding seaward to the forereef zone, and afterwards start again from the rubble zone and proceed lagoonwards to cover the backreef structures.

The zonation of this barrier system is illustrated on the maps and cross-sections, figs. 20-21 (see also fig. 16c).

2.3.4.a. The Southeastern or Windward Barrier

Sampling Stations : (From N to S, roughly - see Annex 3) L 253; L 254; L 255a-b; L 256; L 257; L 258; L 259a-b; L 260; L 261.

Description : (See also fig. 20). The SE barrier or "Windward Barrier" stretches out between South Point and South Island, over a length of about 2.5 kms in a NE-SW direction, facing the Trade Winds and the swell. It is built upon a granitic backbone which follows the structural NE-SW trend; this backbone emerges at South Island itself, more to the N as a small granitic islet (Bird Islet) near the Lagoon entrance, and finally as the South Point granitic spur. The reef is interrupted near its NE extremity by the narrow, deep Lagoonal pass.

As a whole, the Windward Barrier lies slightly lower than Coconut Fringing Reef. The reef flat is almost perpetually covered with water, even at low tide, except for the larger boulders of the Rubble Zone. Only at neap tides on calm days the reef flat partially emerges at low tide.

a) Forereef structures : The forereef comprises the following zones, in a seaward direction : rubble zone, moat, algal pavement, reef front and -slope.

The Rubble Zone : This zone is very similar to its homologue on Coconut Reef Flat : a very badly sorted mass consisting of coral shingle (mainly Acropora debris) and intermingled blocks and boulders of all sizes of reef rock and larger coral debris originating from the reef front is redeposited upon the reef flat during cyclones and storms. Some of the larger blocks may originate as well from the breakdown of a former higher flat built up during the Holocene transgression. These blocks and boulders are colonised by a highly diverse encrusting and sessile flora and fauna. Very small, scattered colonies of massive corals (Goniastrea) survive here as well as the hydroid zoophyte Aglaophenia cupressina. In crevices and underneath the blocks and boulders, sea-urchins, and brittle-stars, etc. are found. The rubble zone is the highest part of the reef flat; its elevation is about 1 m above the reef crest towards which the reef flat gently slopes.

Moat : In front of the rubble zone, a narrow moat stretches out longitudinally along the reef flat; depth hardly increases here, but this area is characterised by a sudden increase in massive corals, such as Goniastrea, Plesiastrea, Favia, Favites. Alcyonarians (Lobophytum, Sarcophytum) and a small encrustating colonial anemone, Palythoa caesia. Coral shingle and coarse foraminiferal sand compose the sedimentary cover whereas the algal coats appear to be rather patchyly present.

Algal pavement : Seaward of the moat rises a strongly cemented floor covered by encrusting red algae, Lithothamnium, Goniolithon. This algal pavement is analogous to the one observed on the Coconut Reef flat and shows the same but shallower and less frequent, crevices and gravelly-sandy depressions. The algal coat is almost completely absent here and generally the floor is neatly cemented. The highest part of this pavement, immediately bordering the moat, is virtually devoid of madrepores; only a few scattered faviids and alcyonarians occur. Seaward, this pavement gently dips towards the breaker area whereas a progressive increase in corals and alcyonarians is recorded.

Reef Crest : Immediately beyond the algal pavement, bordering the reef flat s.s. and just below or at the low tide level numerous flat, digitate Acropora humilis associated with other Acropora-species appear (A. digitifera, A. palifera) while alcyonarians decreases in abundance.

In seaward direction the digitate and compact Acropora humilis-colonies are replaced by the tabular, rounded and often large colonies of Acropora hyacinthus, defining another zone where madrepore diversity increases. The presence, absence or progressive transition from these zones to one another depends on substrate morphology. The zones are well defined when gentler sloping spurs are present; when the passage from the reef crest to the reef front is abrupt they may be very poorly visible and have a very short lateral extension. Competition between coral and rhodophytes may result in a very irregular, cemented bottom inhabited by boring bivalves (e.g. Tridacna crocea) and a rich vagile fauna.
The algal-bacterial coat is no longer present in the same form as further landward but narrow-segmented Halimeda are frequent as well as green filamentous algae like Chlorodesmis.

Reef front and -slope :

Reef front : In a seaward direction the reef crest passes to the reef front s.s. characterised by a sudden increase of slope. Two types of transition depending on substrate morphology occur in this area :

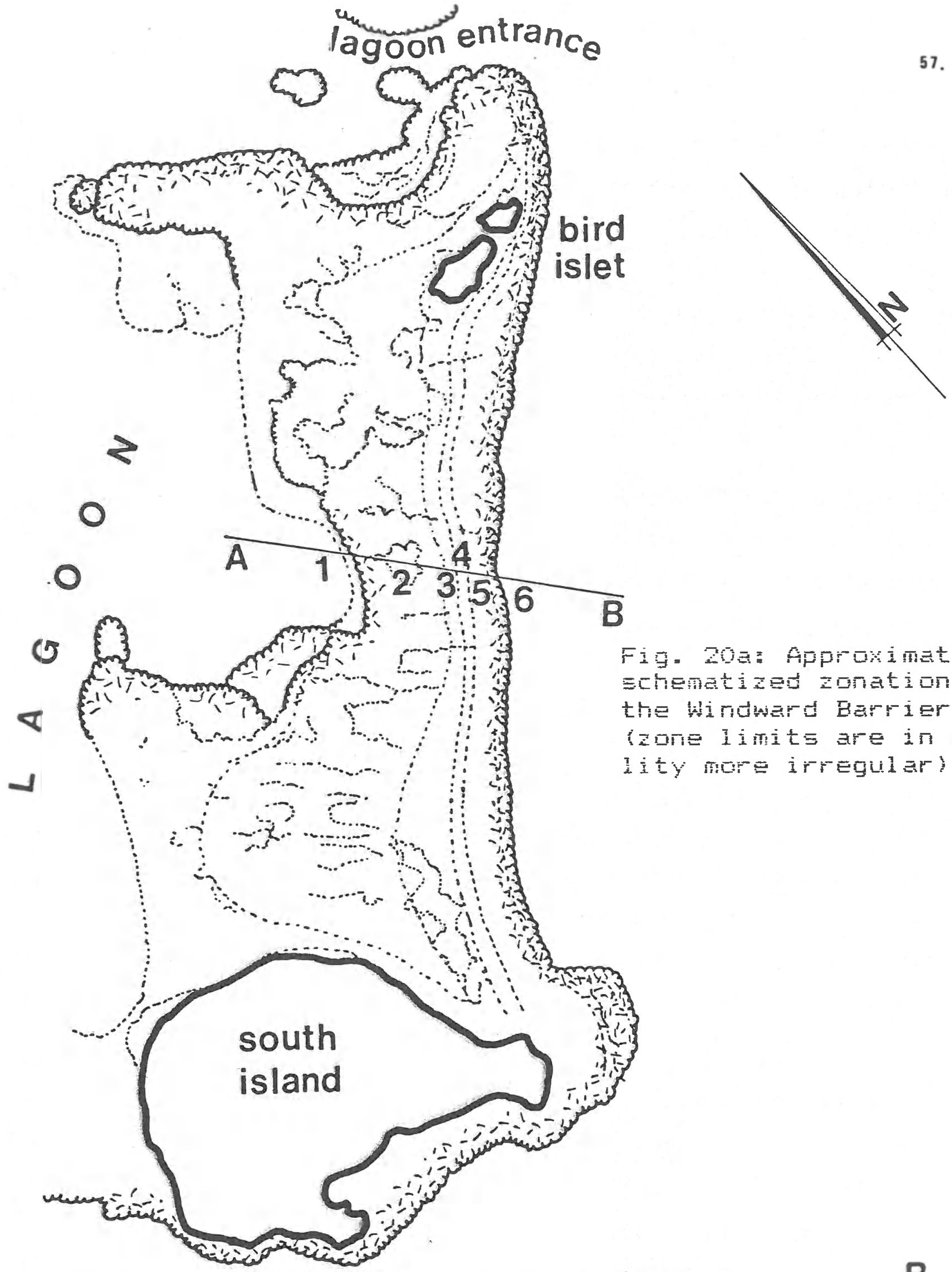


Fig. 20a: Approximative, schematized zonation of the Windward Barrier (zone limits are in reality more irregular).

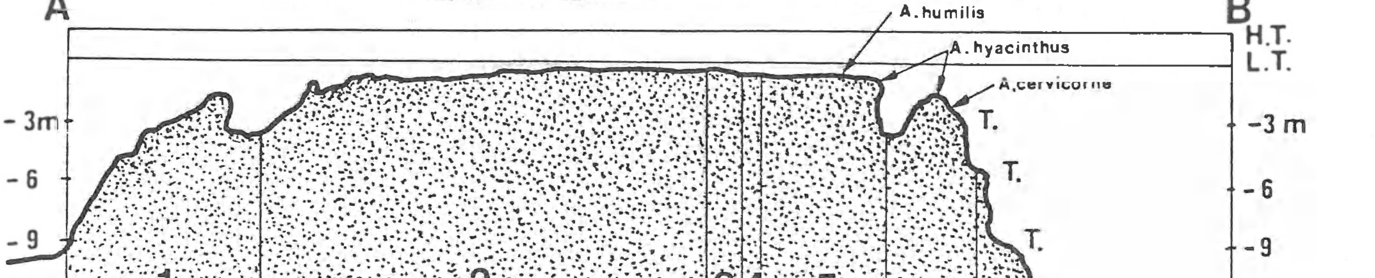


Fig.20b: Cross-section A-B, showing main zones (see text). 1: backreef structures & sand; 2: microatoll-zone; 3: rubble-zone; 4: moat; 5: algal pavement & reef crest; 6: reef front; 7: reef slope & terraces (T.) After echosounding track 1

(1) The upper reef front is abrupt and subvertical down to the - 3 m terrace. This wall may be cut by surge channels of varying depths; some of them do not go deeper than the - 3 or - 6 m terraces, other reach depths of - 10, - 15 m or down to the front.
(2) Less abrupt morphologies allow the development of spur-and-grooves displaying a nice transitional zonation of Acropores. Tidal currents may here be forced into blowholes, chimneys formed by coral growth at the bases of the spurs and opening on top at the reef crest.

The humilis-zone progressively passes below low tide level to the hyacinthus-zone where madrepore diversity increases. These circular and tabular, often large colonies of A. hyacinthus are then gradually replaced deeper down by - often extrelemy luxurious - "forests" of staghorn coral, Acropora pulchra and related species. The transition A. humilis - A. hyacinthus - A.pulchra takes place within a horizontal distance of only 10 - 20 m and a maximal depth variation of 3 - 5 m. The vertical walls of the surge channels are often colonised by lamellar encrusting coral species (Montipora, Porites, Echinopora lamellosa) and by massive Favia. Numerous sea-urchins (Echinometra mathaei, Heterocentrotus mamillatus) live in the cavities between the corals whereas the violet-black, longspined Diadema setosa inhabits the sandpatches and terraces. These terraces, a few m wide, are covered with either coarse organoclastic sand, or gravel composed of staghorn coral fragments. The solitary corals Fungia (spp.) occur here.

Reef slope : The reef slope s.s. sets on from the - 3 m terrace downwards. The slope is interrupted by terrace levels at - 6 m, - 15 m, - 18 m. On the upper part of the slope, massive corals (Porites, Favia), Lobophyllia and meandroid species Symphyllia, Oulophyllia are abundant as well as alcyonarians, sponges, tunicates etc. Deeper downward madrepore growth becomes sparser and the formerly mentioned species are gradually replaced by cup-shaped or vase-shaped species such as Turbinaria, Echinopora, Pachyseris together with mussids, sponges and several gorgonians supporting clusters of black crinoids (feather stars). The lower part of the slope is mainly colonised by alcyonarians such as the black branching Antipathes abies covered by oysters, and the ahermatypic branching coral Dendrophyllia. The reef base is marked by a sudden slope break.

b) Backreef structures :

The backreef flat : The backreef floor is characterised by an organoclastic sandy layer accumulating in the depressions. This backreef flat more or less gently slopes down towards the lagoon while coral diversity increases with increasing water depth. This backreef flat can be subdivided into the following zones lagoonward from the rubble zone :

A transitional zone situated just behind the rubble zone, is characterized by a sandy substrate with small hemispherical corals such as Goniastrea. An algal-algobacterial coat with Halimeda is present.
The microatoll zone shows the same features as its Coconut Reef homologue. Lagoonward, water depth pregressively increases up to - 1 m below low tide level. Coral zonation is more or less confuse; as a rule, massive corals of the Favia-type are abundant; these colonies are spherical when young but flatten when growing larger and approaching the low tide water-level. Furthermore, branching Acropora (A. hebes, A. pulchra) and Seriatopora occur as well as the solitary Fungia, alcyonarians (Lobophytum, Sarcophytum, Aglaeophelia) and a rich epifauna of molluscs among which several Tridacna species, echinoderms (Echinometra, Linckia laevigata), brittle-stars, etc..

The distal, lagoonal border of the backreef flat is characterised by often dense forests (see Figs. 1, 2, pl. 6) of staghorn corals and A. palifera, Pocillopora e.a.. The transition backreef flat - lagoon is locally abrupt; elsewhere the presence of sandy channels linking the two units results in a gentler slope.

2.3.4.b. The Southern Barrier (between Palfrey and South Islands) (Fig. 21)

Sampling Stations : (From E to W, roughly - See Annex 3). L 262; L 263; L 264; L 265a-b; L 266.

Description : Stretching out between Palfrey & South Islands this barrier shows a profile which can be compared to the one of the Windward Barrier to which it is linked, seawardly, by a narrow reef fringe bordering the southern rim of South Island, and lagoonwardly, via the sandy backreef area limiting the Southern lagoon.
This reef follows the NW-SE structures in the granite and considerably narrows in a NW-direction. This may be a further hint at the presence of a granitic backbone supporting South Island and the Windward Barrier and of a structural depression underlined by the main lagoonal trend (NE-SW) between Palfrey and South Islands.

The zonation of the reef is comparable to the one of the Windward Barrier although the zones are more compressed over a shorter horizontal distance while

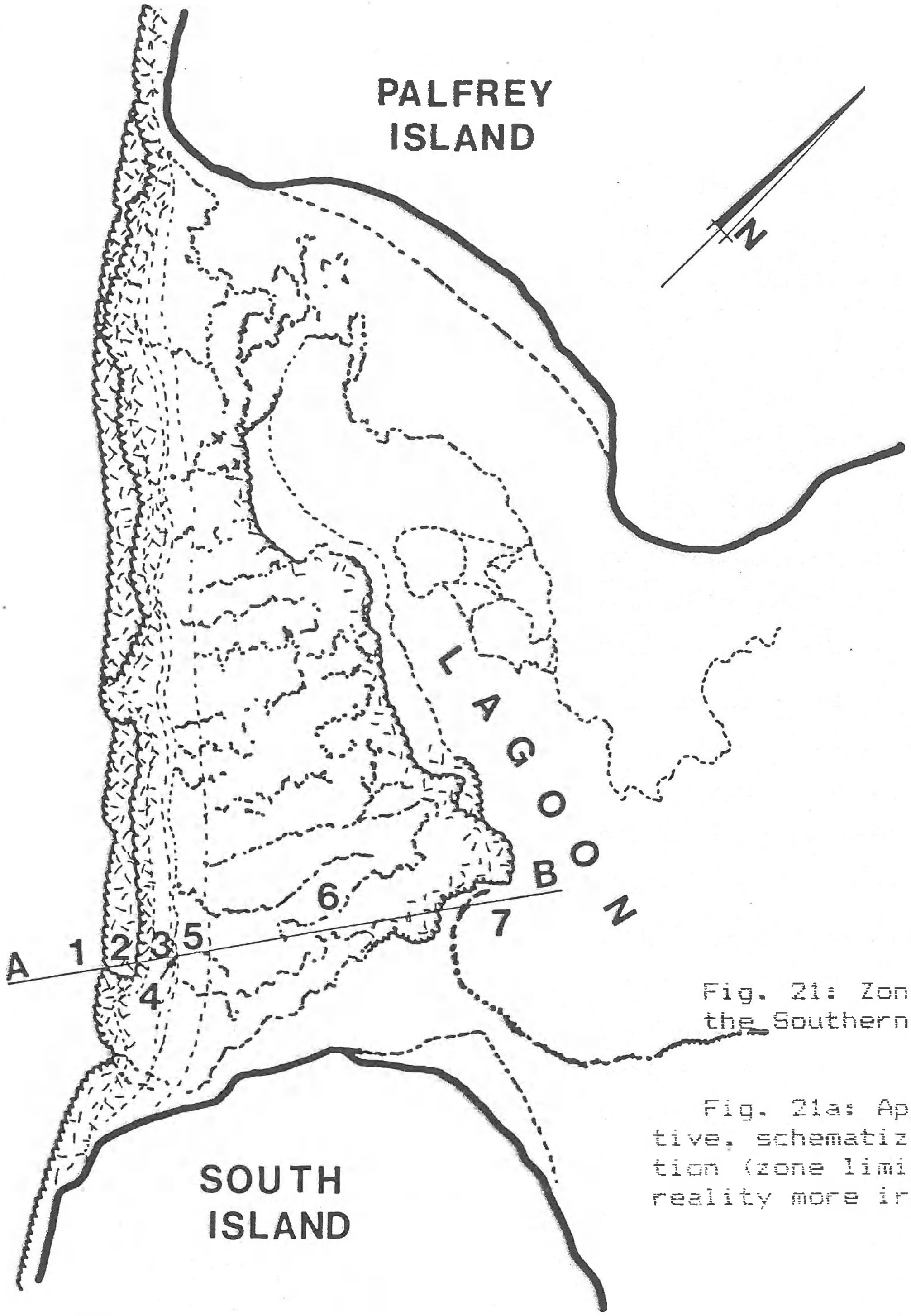


Fig. 21: Zonation of the Southern Barrier.

Fig. 21a: Approximative, schematized zonation (zone limits are in reality more irregular).

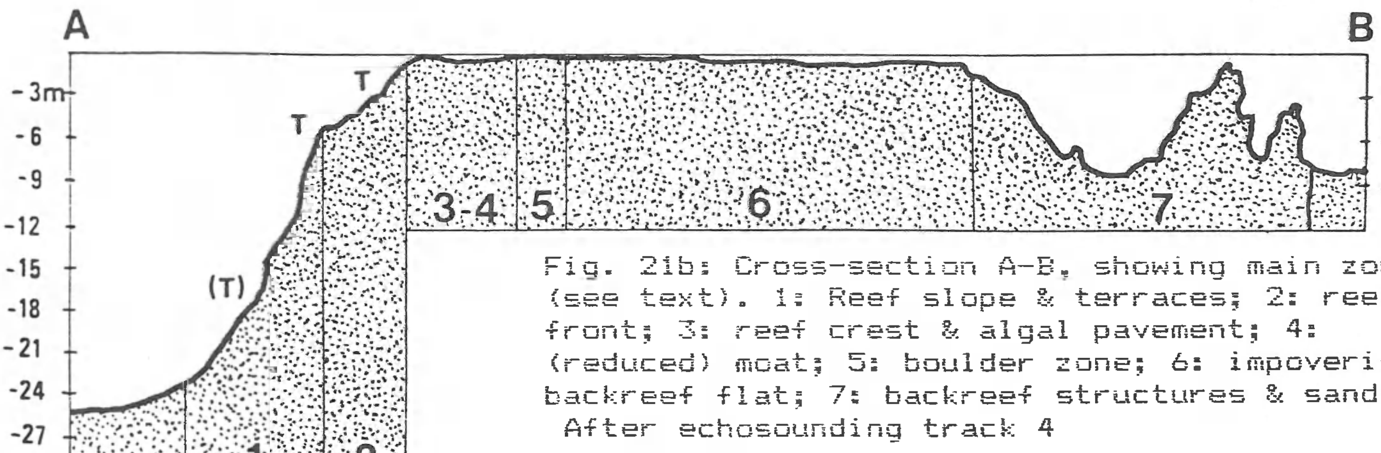


Fig. 21b: Cross-section A-B, showing main zones (see text). 1: Reef slope & terraces; 2: reef front; 3: reef crest & algal pavement; 4: (reduced) moat; 5: boulder zone; 6: impoverished backreef flat; 7: backreef structures & sand
After echosounding track 4

the coral growth is impoverished. The reef flat lies slightly higher than the Windward flat and the boulder zone is largely uncovered at low tide; large boulders and blocks of reef rock are in fact scattered over the entire back-reef area (see Fig. 1, pl. 4).

a) Forereef structures :

Rubble Zone (boulder zone) : This highest zone of the reef flat differs from its homologues on the formerly described reefs by the huge blocks and boulders of weathered reef rock lying much higher;boulders over 1 m long are not rare. As a result this area presents a very chaotic aspect. Some alcyonarians and a well-developed algal coat occur here while coral growth is virtually absent.

The moat is almost absent on this flat; locally however it can be distinguished as a narrow depression between the algal pavement and the boulder zone; coral growth is very scarce here notwithstanding the presence of small, isolated A. humilis colonies. The algal coat thins out in this area whereas boulders are persistent.

The algal pavement is well developed and cemented by rhodophytes. Sand patches are always present. Small A. humilis - colonies are scarce. Alcyonarians are present. Encrusted boulders and blocks occur as far as this zone, which gradually dips towards the reef crest where alcyonarians are predominant. Coral growth regains importance near the edge of the reef platform where the bottom slopes towards the reef front.

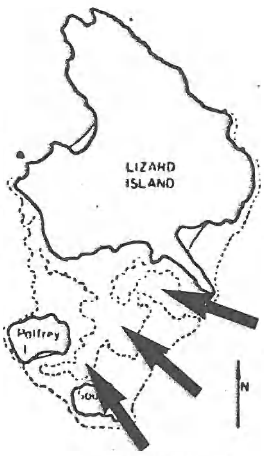
The reef front : Alcyonarians are still well-represented as well as hemispherical colonies of Porites, branched staghorn coral, meandroid coral species, Goniopora and Favia. Terraces are not so well-developed as on the Windward- and Coconut fronts and are often simply marked as slope notches. Large, tabular A. hyacinthus colonies comparable to the ones growing on the Windward front have not been observed here.

The reef slope : At about - 6 m downward a break interrupts the moderate slope from where down the reef steeply slopes towards the perireefal bottom. The slope is interrupted at the terrace levels of - 12 m and - 18 m where old reef rock emerges at the surface and is covered with a coral growth which is sparser than at the Windward Barrier. Staghorn corals are predominant on this slope.

b) Backreef environments :

Backreef flats show a very irregular surface consisting of broken ground covered with boulders, patches of coarse sand and Acropora-shingle, and a very dense algal growth (with Halimeda etc. colonizing most of the area except for some sandy tidal channels). Coral growth is extremely impoverished and only some Favia-colonies survive on this flat.
The backreef flat more or less abruptly passes at its eastward lagoonward edge to a sometimes steep internal reef front developing coral tongues extending into the lagoon. Between them are nude sandy slopes and backreef lagoonal structures like coral knolls. Alcyonarians, staghorn corals (several Acropora-species), Favia, Porites are the predominant coral growths.

2.3.5. The Lagoon



Sampling Stations : L 120; L 121; L 122; L 123; L 124; (L 125); L 126; L 127; L 128; L 129: L 130; L 131; (L 132, L 133); L 134; (L 135); L 136; (L 137a; L 138; L 139; L 140; L 151.

Description : (See e.g. figs. 7, 8). The Lagoon stretches out along a SW-NE axis, thus coinciding with a structural depression of the granitic basement. This Lagoon shows a asymmetrical bathymetric profile (Annex 4); its greatest depths were discovered in its SE part near the backreef of the Windward Barrier, and do not exceed 12 m; the greatest part of the Lagoon bottom is less than 10 m deep.

The Lagoon is delimited, in the SE, by the backreef of the Windward Barrier; the connection with the open sea is secured by a narrow but deep pass (Lagoon entrance) separating the Windward Barrier from the reef fringing South Point. In the SW the Lagoon border is formed by the Southern Barrier whereas a narrow, almost secluded lagoonal "finger" stretches out southwardly of Palfrey Island; the NW lagoonal border is delimited by the Internal Flat and the Sandy Shoal.

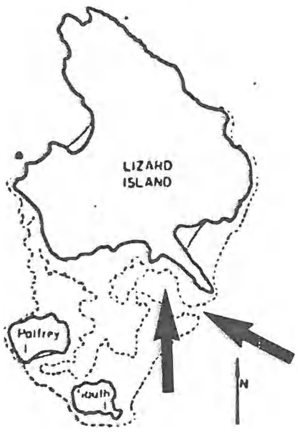
The SE border : From the backreef flat of the windward barrier onward, the bottom often irregularly slopes down leeward to - 4, - 6 m and is steepening rapidly towards - 10, - 12 m. This steep slope is only interrupted at places where sandy gullies drain the reef flat directly into the Lagoon, or where reef patches and knolls occur (echosounding tracks, Annex 4). The larger reef patches are colonised by a multitude of corals (Porites, Acropora), whereas the smaller knolls are mainly monospecific and can be considered as "megacolonies", often constructed by Porites sp. While the knolls are irregular although more or less subspherical accretions, the reef patches generally show rather steep slopes, somewhat flattened roofs (mini reef flats) and rise abruptly from the sandy-silty Lagoon bottom.

The SW border shows essentially the same features as te SE border though the reef patches and knolls are irregularly scattered over a shallower bottom, enclosed in a narrow elongated and barred, almost secluded lagoonal extension. Here again the bottom slopes rather steeply from the southern flat towards the Lagoon.

The NW border : In the entire NW part of the Lagoon the bottom slopes gently and gradually towards the shallow recolonised fronts of the Internal Flat and the Sandy Shoal; coral knolls and patches occur locally at the base of these front ridges. Only in the central area, between the Internal Flat and the Sandy Shoal, that is the prolongation of the leeward channel which separates them, the sandy Lagoon bottom rises continuously up to a depth of a few meters (sample L 151).

The Central Lagoon : Towards the centre of the Lagoon away from the coral knolls, the Lagoon bottom is almost devoid of any coral growth while some alcyonarians occur locally. The bottom is generally sandy and bare; the sediment is a silty to muddy sand and shifts into a muddy silt in the deepest area immediately behind the windward flat; the whole floor is virtually covered by an organic, bacterial coat except where the latter is interrupted by fresh bioturbations which are common. Coated grains are abundant in the sediment. Holothurians and crabs are the main bioturbators while fish (e.g. stingrays, carpet-sharks) are also active in disturbing sediment. Coarser, badly sorted sediments occur in the immediate neighbourhood of the coral knolls and -patches where coral shingle and boulders of dead coral are overgrown by a bacterial coat.

The NE Lagoon and Lagoon entrance (Pass) : Between the recolonized edge of the

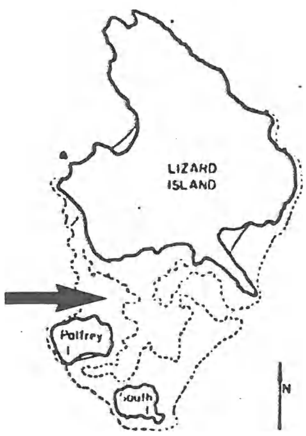


Sandy Shoal and an extention of the windward backreef, the Lagoon narrows considerably and shows a heavily bioturbated bottom flanked by coral knolls with abundant colonies of Millepora. Towards the NE, this Lagoonal extension broadens again and gradually deepens while narrowing again towards the Lagoon entrance with depths up to 15 - 17 m in the passage way. Tidal currents are very strong in this entrance area where the presence of two large reef pinnacles ("bommies"),almost reaching the surface, is to be noted. These steep-walled and flat-topped pinnacles belong to the windward barrier - backreef system but, as they receive the full impact of the strong tidal currents from the open sea through the pass, their seaward (SE) flanks are richly colonised by a luxuriant coral growth (Acropora spp.; Montipora spp., e.a., alcyonarians). Except for a shingle- and boulder area near the base of these pinnacles the bottom is of the same type as the bottom further SW-ward in the Lagoon.

2.3.6. The Leeward Units

All reefal units situated NW of the Lagoon show impoverished backreef characteristics corresponding to their situation in low water energy conditions and more confined settings.

2.3.6.a. The Internal Flat



Sampling stations : L 161; L 162; L 170; L 171; (L 139 - lagoonal - is at base of recolonised front).

Description : (Fig. 22).This sandy and rocky flat stretches out between Palfrey and Lizard Islands. It is separated from the latter by a tidal channel which links the Lagoon to the Leeward Patchreef Area.

This leeward flat might be a remains of a reef which would have formed during higher or at least older eustatic sealevel conditions. It would subsequently have been placed in unfavourable ecological conditions after the growth of the present Windward Barrier. Sediments derived from the present Windward Barrier might well have buried the windward front of this ancient reef.

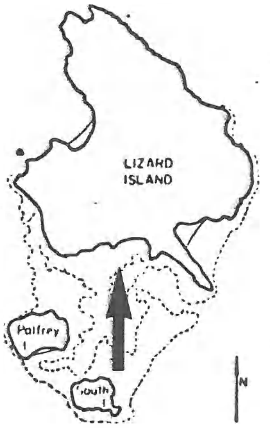
The flat is water-covered at high tide and is covered by sandpatches (coarse, badly sorted sands) between irregularly distributed boulders and blocks of ancient, weathered reef-rock covered by a dense algal growth such as Halimeda. Moreover, debris of several kinds of organisms (molluscs, e.g. large cone shells) form a coarse and irregular shingle (which no longer deserves the name of "coral" shingle, though staghorn coral fragments are well represented). This cover is densely overgrown with algae or at least with a cyanobacterial coat. In the main, central area of the flat, alcyonarians are rare and corals virtually absent, except for some rare small colonies of Porites, Goniopora and Millepora.

The SE border : The transition from this flat towards the Lagoon is characterized by a small, recolonised, windward platform front, 1 to a few meters high, rising from the sloping Lagoon bottom. This front either shows a nude, irregularly incised rocky ridge or is colonised by Porites lutea(as hemispherical colonies or microatolls) and faviids (Symphyllia). Towards the Lagoon bottom, at depths of 2 - 3 m, low bushes of staghorn coral may be present, as well as Millepora-knolls. The upper crest of this "front" is colonized by abundant alcyonarians.

The NE border : The bank flank is limited by a small front sloping rapidly down towards the bottom (3 - 4 m) of the tidal channel between the Internal Flat and the Sandy Shoal. Coral growth is locally luxuriant : Several Acropora - species (humilis, palifera), Pocillopora, hemispherical colonies of faviids (Favia, Plesiastrea, Favites), Symphyllia, Lobophyllia, Goniopora, etc.; as well as giant clams (Tridacna derasa e.o.), solitary corals (Fungia, Polyphyllia) and alcyonarians are present. At the lower part of this small front, rich colonies of Goniopora and Porites occur. In fact this NE front shows the most diversified coral colonisation of the entire backreef area of the Lizard reef complex.

The NW border : The leeward limit of the internal platform is not so well-defined as the NE- and SE borders which showed steep though short recolonised fronts. In the NW the sand-on-rock flat slightly and gradually deepens while, first, the alcyonarian colonisation increases, followed by the appearance of faviid corals. Either immediately, or interruptal by some isolated, low reef patches the bottom slopes towards the sandy - 3 m terrace upon which the leeward patchreefs have developed.

2.3.6.b. The Sandy Shoal



Sampling stations : L 144; L 145; L 146; L 149; L 150; L 271a-b; L 272; (L 147; L 148; L 269; L 270).

Description : (Fig. 22). The "Sandy Shoal" is a roughly triangular, slightly subtidal bank delimited to the N by Lizard Island, to the SE by the Lagoon and to the SW by the tidal channel in front of the Internal Flat. It shows up as an almost denuded sandy area, 2 - 3 m deep.

The main, central area : The main part of the sandy shoal shows a very shallow sandy bottom devoid of coral growth. The sedimentology of this area is complex : sands are bi- or multimodal with varying terrigenous component decreasing in a southward direction; the sorting is generally bad with grain size dominance near 125 microns. Ooids and coated quartz grains are abundant under the Lyngbya-mat which stabilizes most of the shoal (see pl. 15).

The bottom is heavily burrowed and burrowing mounds as high as 30 - 40 cm frequently occur; the whole area shows ripplemarks of varying amplitudes and directions; main rippling direction is NE-SW. This heavily burrowed area does not seem prosperous for the growth of Halimeda which occurs only as isolated small tufts. Scarce Thalassia-thalli grew during the last weeks of our stay on the island. Molluscs are frequent here; gastropods (Conomurex, several conus species as well as Strombidae occur as well as infaunal lamellibranchs (cardiids, Tellina). Small sponges are occasionally encountered.

The SE Marginal area and -border : The sand layer on the bottom thins out and gradually more rocks pierce through the sand. These rocky protrusions are composed of ancient, altered reef-rock (e.g. Acropora-debris cemented to the rock !) and lead to the conclusion that the main area occupied by the sandy shoal constitutes the sandy backreef flat of an ancient reef while the SE marginal area and the small front are the recolonised remnants of its reef crest and - front, buried further SE-wards under the lagoonal sand. The sand veneer covering the Sandy Shoal results from sand deposition during storms and cyclones. The veneer thickens towards the NW; the ripples represent tidal features forming during flood tide. The transition sandy area - marginal area is in places gradual, or may be more abrupt via a low step where the rock appears (see fig. 22).

The sediment is always a mixed terrigenous - organoclastic sand. Locally some coral shingle lies near the bases of the rocky protrusions.
Towards the SE, alcyonarians occur and become more and more numerous. Sea-anemones are present.
In this marginal area, patchy meadows of Halimeda occur. An algal-cyanobacterial coat is mostly present. The rocky boulders are mainly colonised by encrusting and branching red algae while madrepores and allied forms reappear : Porites, Goniopora, faviids, staghorn coral, Seriatopora hystrix, Millepora, and alcyonarians. The colonised rocky protrusions piercing the sandy bottom are up to 0.75 - 1.50 m high. Molluscs are always frequent and isolated, large giant clams (Tridacna derasa, T. gigas) rest on the sand. Fungia specimens occur occasionally.

The SE border of the Shoal is composed of a rim of patchreefs forming a recolonised front towards the sloping lagoonal bottom. These patches are eroded, encrusted, cemented and irregularly outlined blocks of reefrock, colonised by the same corals as mentioned above for the rocky protrusions in the marginal zone. Towards the N these patches are gradually shaped as coral knolls (Millepora knolls) and reef patches resembling those of the backreef area of the Windward Barrier though on a more modestscale.

Towards the S on the contrary, reef rock, patches and coral growth disappear almost completely in front of the extension of the northern part of the Internal Flat. To the west, the border of the Sandy Shoal is formed by the tidal channel separating Sandy Shoal and Internal Flat. This channel probably originated in the erosive action of tide flushing through a narrow passage.

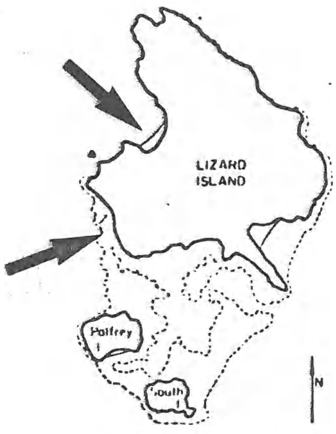
The northern limit is formed by the southern beach of Lizard Island s.s. and consists of a series of crescentic beaches, separated by granitic spurs composed of huge wind-and microbially eroded granitic boulders lying chaotically together upon their eroded basements. These beaches enlarge considerably towards the E and culminate in the very broad Windy Beach facing the central valley.

The beach sands consist predominantly of coarse, terrigenous sands; no large foraminiferal concentrations have been encountered here as opposed to these found on Coconut Beach or Casuarina Beach; the foraminiferal (and other bioclastic) remains resulting from the production of the Sandy Shoal are apparently washed away, being carried (fragmented) through the tidal channel into the leeward patchreef area and down in the lagoonal sink by wind and current.

On the eastern part of Windy Beach, protected from wind and strong tidal currents by a granitic promontory and where fresh-water percolation and runoff from the granitic mass of South Point occurs, a poorly developed mangrove (Rhizopora mucronata) grows in the intertidal zone. Beachrock is present in the immediate neighbourhood of this mangrove.

From the beaches the bottom gently slopes towards the Sandy Shoal-depths of - 2, - 3 m; the algal coating and intensive burrowing starts already in the lower intertidal area, leaving the tops of the hugest burrowing mounds almost uncovered at low tide.

2.3.6.c. The leeward patchreefs



The patchreefs decribed under this heading are mainly concentrated in the area between Palfrey Island and West Point (facing Casuarina Beach) on one hand, and in the shallow zone of the Anchor - Watson Bay on the other.

Sampling stations : L 273; L 274; L 275; L 276a-b; L 277; L 278 a-b-c-d-e-f-g; L 282 a-b; L 289 a-b; L 290; L 291; L 100; L 102; L 105; L 153; L 154; L 155; L 157; L 160; (L 279; L 280; L 281; L 283; L 284 a-b-c-d-e-f-g; L 285; L 286; L 287).

Description (Figs. 7-8) :

Central area and southern border : Most of these shallow patchreefs are situated on the - 3 m terrace stretching out between Palfrey Island and Casuarina Beach. They look like small or medium-sized recolonised reef-rock protrusions piercing the sand cover of the - 3 m terrace; presumably ancient reef-rock underlies the often thin sand veneer over the greatest part of the surface of this terrace. This supposition has been confirmed on and around some shallow patches in front of Casuarina Beach (fide SEGERS, 1975). (We could be dealing here with a natural submarine lithification process as exposed by HOTTINGER, 1982). The shape of these patches is often irregular but a certain tendency for elongation in a NW-SE direction (tidal currents) is present. These patches are covered by a more or less luxuriant growth of alcyonarians (Lobophytum, Sarcophytum, Sinularia), anemones, and madrepores such as staghorn coral (several Acropora-species), Montipora, Porites (often forming complete or half microatolls) and hemispherical faviids. A patchy algal-algobacterial cover (Halimeda predominant) is present, mainly on and near the shallower patches in front of Casuarina Beach and leeward of the Internal Platform. A rich fauna of echinoderms (sea-stars like Linckia

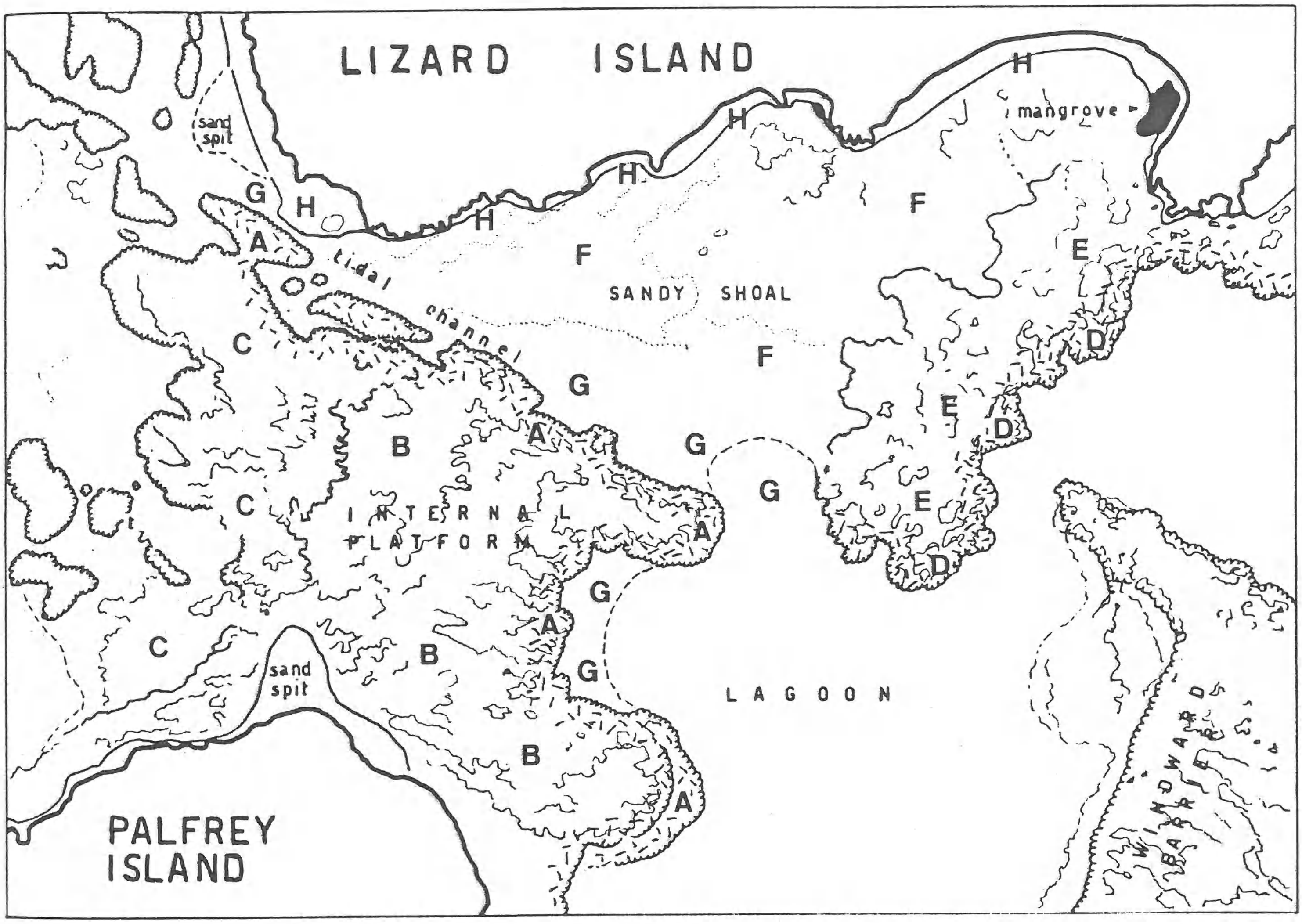


Fig. 22 : Internal Flat & Sandy Shoal.

Legend of map :

Internal Flat : A : recolonised fronts; B : impoverished platform; C : transitional area (slope towards - 3 m terrace).

Sandy Shoal : D : recolonised front; E : SE marginal area with reefrock; F : central, sandy area.

Other : G : tidal channel & subtidal sandy slope; H : sandy beaches & sand spits (inter - supratidal).

laevigata, Culcita novaeguineae (the pin-cushion star), brittle-stars etc.), Crustacea (shrimps, prawns, hermit crabs of all sizes) and molluscs (e.g. several Conus species, Strombidae, giant- and other clams, Cypraeidae, spider shells - Lambis lambis - etc.etc.) colonises these patches.

The interpatch areas consist of rippled coarse- to medium grained, badly sorted sand which is often bioturbated by burrowing crabs; a cyanobacterial coat most often covers the sandy surface. Around the larger patches, concentrations of coral shingle (mostly staghorn coral debris) generally occur.

At the approaches of the almost straight Casuarina Beach the bottom gently slopes but deepens again in front of the beach; irregularly elongate sandy pools (depth up to - 1,5 m) are aligned parallel to the coastline and form the prolongation of the narrow tidal channel between Casuarina Beach, the internal platform and the SW sandy shoal. The beach shows an extensive development of beachrock, disappearing under the sand at high tide level. The beach sand is of the same coarse, terrigenous type as on the southern beaches whereas wave-sorted accumulations of larger foraminiferal tests (Marginopora) occur mainly in the northern part of the beach.

The Western border : Beyond the edge of the - 3 m-terrace the bottom gently slopes down towards the perireefal depths of - 20 to - 25 m. This sandy slope is only interrupted by a few though large reef patches rising abruptly from the sand-shingle bottom. These reef patches are probably remains of ancient reefs; up to depths of - 5, - 10 m they are colonised by e.g. staghorn coral forests whereas at greater depths, alcyonarians are almost the only colonising organisms. The patches show a leeward, rather steep slope ending abruptly at the perireefal bottom (- 24, - 25 m).

The Northern part : Towards the northern edge of Casuarina beach the - 3 m terrace gradually narrows and the reef patches are irregularly scattered over a restricted area, only interrupted by a few (sandy) tidal channels. At the seaward slope of this area often dense staghorn coral forests occur. Terrace and reef growth disappear almost completely in front of West Point, whereas between West Point and Rocky Point some impoverished patches occur again on the shallow parts of the more regularly sloping bottom. Over the entire area of the leeward double bay (Anchor - Watson bays) the sandy bottom gradually slopes down from the beach towards perireefal depths; large but low patches occur here from immediate subtidal depths onwards. Porites (micro-atolls), staghorn coral and alcyonarians are the predominant colonising organisms; the colonisation of the reef patches impoverishes gradually towards greater depths and beyond - 7 to - 10 m no living coral-colonised reef patches are encountered. The beach portion between Watson Beach and North Point is almost devoid of coral growth and shows no features comparable to reef patches of -fringes.

2.3.7. The Perireefal Area

Sampling stations : L 50; L 54; L 56; L 59; L 60; L 62; L 63; L 65; L 67; L 69; L 71; L 72; L 75; L 77; L 81; L 82; L 84; L 86; L 90; L 91; L 92; L 93; L 94; L 98; L 106; L 107; L 108; L 109; L 110; L 112; L 292.

Description : As has been shown before, the transition reef slope - perireefal seabed is rather abrupt at the foot of the fringing - and barrier reef systems (i.e. in the entire NE, SE and SW parts of the Lizard Island reef complex). This transition is situated at slightly variable depths between 24 - 27 m. The simplified undersea topography of this shelf area immediately surrounding the Lizard archipelago is shown on fig. 11 whereas the echosounding tracks (Annex 4) provide detailed profiles of the area.

In the NE Perireefal Area between the fringing reef and the (non-explored) Sandbank Reef which is a bare sandcay surrounded by a reef fringe, the seabed is very irregular and shows numerous mounds and ridges of what ORME and FLOOD (1977) call "Halimeda banks"; North of Sandbank Reef these banks are apparently flat-topped (see ORME and FLOOD, 1977; ORME, FLOOD and SARGENT, 1978) but in the "channel" between Lizard Island and Sandbank Reef these mounds show quite sharp crests and might, perhaps, behave as a kind of megaripples considering the strong tidal currents sweeping through the relatively narrow "bottleneck" between the two reefal units. (See fig. 3 and echosounding tracks, Annex 4). Sediments of these banks are largely composed of loose thalli segments of the codiacean Halimeda which grows profusely here. These Halimeda-ridges rise from the seabed at an average depth of - 25 m or less whereas their tops rise to - 13, - 15 m, resulting in a strongly accidented landscape with depth variances up to 10 m over relatively short distances (50 - 100 m).

- In the SE, facing Coconut Fringing Reef and the Windward Barrier, the seabed is less disturbed and gently slopes from depths of - 23, - 24 m towards the - 32 m platform. At the foot of the reef slope a narrow band of reef-derived sediments is found (mainly organoclastic medium- to fine sands) but this sediment is quickly replaced further seaward by the kind of muddy-sandy, badly sorted bimodal) Halimeda-rich sediments typifying this entire S-SE Perireefal Area (see pls. 13-14).

In the S and SW, facing the Southern Barrier and South Island the same kind of sediment is found on a bottom which slopes down from the reef foot at about

- 24 m towards a large subhorizontal area representing the - 27 m terrace. Between the reef foot and this terrace some rocky ridges, a few meters high, are present and consist of ancient reef rock. Here again a narrow band of mainly organoclastic sand separates the reef slope from the typical perireefal sediments. In the South, several rocky protrusions produce a rather accidented seabed, particularly in the transitional area between the - 27 m terrace and the - 32 m floor in het S-SE.

The entire perireefal area in the NW of the Lizard Island reef complex is a calm area cut off from the prevailing SE Trade Winds and accompanying swell. Except for a few dead reef patches in the vicinity of Lizard Island the seabed shows only minor disturbances and slopes evenly and gently from intertidal depths towards - 20, - 25 m at a considerable distance from the islands. This feature is caused by a leeward sediment-infilling due to decreased wave- and current energy in this leeward area accompanied by deflection and convergence of the wave fronts broken by the windward reefal barrier (the same phenomenon which is responsible for the formation of sandcays in the lee of several types of reefs - e.g. the nearby Sandbank Reef - see MAXWELL, 1968). The sediment here is a medium- to fine grained, generally badly sorted sand with an important terrigenous and muddy component. Away from the island, in a W and NW direction, this infilling thins out and the seabed gradually regains the characteristic perireefal aspect as described for the windward areas.

The perireefal benthonic macro-fauna and -flora is dominated by : alcyonarians colonising the rocky protrusions and dead reef patches; gorgonids, "black coral" (Antipathes abies); solitary corals (Cycloseris cyclolithes, Cycloseris sinensis, Trachyphyllia), sponges, seastars, brittle-stars; and particularly vast extensions of green algae where Halimeda predominates; an algal-cyanobacterial coat covers most of the muddy-sandy areas.

CHAPTER 3

THE FORAMINIFERA OF THE LIZARD ISLAND REEF COMPLEX AND SURROUNDING PERIREEFAL AREA.

3.1. Preliminary remarks

The distribution of living Foraminifera as reflected in our samples shows only an incomplete time- and season-bound image of the foraminiferal populations continuously living within the reef complex; it is a "frozen time cut", a snapshot renting its incompleteness from the patchiness of occurrences of living specimens which in turn is influenced by the variable length of reproduction cycles as well as by a number of ecological factors (e.g. seasonal blooming of certain Algae).
The semi-quantitative biocoenose evaluations in terms of rare, common, abundant have been obtained by examination of quantities of sample material which were generally (much) larger than those used for the thanatocoenose counts. This discrepancy explains how it became possible that in certain samples some species were recorded as being e.g. common or abundant in the biocoenose whereas the thanatocoenose count of the same sample yielded only moderate percentages of the same species.

It should be born in mind that the biocoenose data yield only restricted distributional information; their interest lie on a biological level. The comparison of biocoenoses with thanatocoenoses does not provide enough clues to clear up the transport pattern in the reef complex.

A better image of the faunal composition is reflected by the thanatocoenose data : seasonal effects such as foraminiferal blooming and patchiness are largely neutralised when we consider the total fauna present in the upper slice of the sediment. Moreover, living Foraminifera from different habitats corresponding to shallow or deep infaunal, epifaunal or epiphytic life get mixed in the thanatocoenoses by burrowing (HOTTINGER referring to KITAZATO, written communication, 1987). However, in some particular areas, the recently produced tests may be intermingled to some degree with subfossil (Holocene) material. In particular, this might be the case for a number of grab samples taken in the Perireefal Area.

3.2. Substrates

It is necessary to define some terms as they are used here, to avoid confusion with shifting meanings of terms used in litterature :

3.2.1. Algal pavement :

This is a term used here in its general sense, defining the seaward forereef zone mainly characterised by encrusting Rhodophyta. At Lizard Island no living Foraminifera have been observed on the algal pavement except for sporadic occurences in the sand pockets.

3.2.2. Algal coat :

This term is used here to define the thick and dense (thickness often several cms) algal growth covering a variety of mostly hard surfaces (gravels, shell fragments, reefrock, etc.. The term "algal mat" would be more appropriate to circumscribe this phenomenon; but this term has already been used to define a variety of algal-bacterial forms including laminated structures (stromatolites) - see e.g. GOLUBIC & PARK, 1973).
This algal coat is present in most intertidal - to slightly subtidal environments in the Lizard Island reef complex and in particular covers vast extensions of the reef flats where it serves as a substrate for most, if not all living Foraminifera.

On the reef flats (Coconut Reef, Windward Barrier, Southern Barrier) the coat consists of often densely interwoven and intergrown species of calcareous algae showing themselves a kind of zonation parallel to the coastline.

On the forereef the algal coat thins out, becomes discontinuous and disappears on the algal pavement near the lowtide surfzone. Here, mainly encrustation by Lithothamnium, Goniolithon and related forms persist, as well as cyanobacterial species like Lyngbya and Phormidium. Palythoa seems to be rare on the reef flats; in this respect it is not appropriate to indicate a Laurencia-Palythoa band here(as observed in the Southern Province of the Great Barrier Reef around Wilson Island (CRIBB, 1965) and Heron Island (CRIBB, 1966)).

Further leeward the algal coat is composed of a whole array of algae; thin, flexible and filamentous species are interwoven with thicker, vesicular ones or more rigid, articulate, calcareous ones. Several species of the codiacean

Halimeda appear in the moat and become more numerous and even dominant towards the microatoll zone and near the beach. The most common of these is H. cylindracea with narrow, rounded thallus segments while in the microatoll zone other, broad-segmented Halimeda-species (H. opuntia ?) occur sporadically.

Further components of the algal coat among the Chlorophyta are (main nomenclatural sources : YALE DAWSON (1962 a, b); WRAY (1977)) : Codium spongiosum, Chlorodesmis, Caulerpa, Boodlea & Boodleopsis spp., rare Struvea and others; Phaeophyta seem to be less important, whereas a considerable number of species belong to the non-encrusting Rhodophyta with several species of Laurencia, Hypnea, Amphiroa, Gelidiella, Liagora, Herposiphonia and others in minor relative abundances. Cyanobacteria like Phormidium are present whereas phanerogames are virtually absent.

This algal coat forms a spongy, elastic surface layer covering all hard and even sandy surfaces and serves as a perfect protecting substrate for Foraminifera which find here humidity during low-tide exposures, a flexible but tough anchorage in higher-energy conditions (wave-impact) and plenty of nourishment in the microhabitats of relatively quiet interstitial seawater.

The fixation of this coat upon sedimentary surfaces is often quite solid, by the deep root systems of e.g. Halimeda. The interface algal coat - sediment is seldom abrupt; largest Algae generally have the deepest fixation in sediment whereas smaller Algae are often mixed with sand grains in variable quantities (fig. 23). In the uppermost layer the largest thalli are found (e.g. Halimeda), with the largest and more robust Foraminifera attached to them by means of their pseudopodia (Amphistegina, Calcarina, Baculogypsina, Marginopora). In the middle layer, these larger thalli are mixed with finer Algae, cyanobacteria and sediment grains. The latter are often empty foraminiferal tests. Here most of the medium-sized and smaller living Foraminifera are to be found, their pseudopodia interwoven with the thalli. In the lowermost layer, Algae become scarcer and only sediment persists, consisting of the larger and medium-sized shells in the thanatocoenose. There is a gradual transition algal coat - sediment, which results in a great mutual fixation potential.

The fixation of this algal coat upon hard surfaces (fig. 24) is secured in a slightly different way. Where the algal coat grows over boulders, shingle, shells etc. the larger Algae do not dispose of sufficient "sedimentary space" to fix themselves by means of deep root systems (although it is often amazing to see how Halimeda - thalli, several cm high, are solidly fixed into small crevices and irregularities of reefrock). Here we find a gradual passage from

very small Algae (+ cyanobacteria) solidly anchored in the substratum irregularities, hollows spaces and crevices, towards larger thalli on top, the whole intermingled and intergrown into an extremely resistant and dense layer. Microscopical observation confirmed that these hard surfaces (eroded reefrock and skeletal calcareous debris) in most cases are densely perforated, or show a labyrinthic inner structure, or both, or show dissolution hollows, thus allowing the microscopical Algae to grow from the inner microhabitats of the substratum in outward direction and link with the main part of the coarser algal coat (fig. 25).
Thus, the algal coat unifies and links tiny organisms into a larger-scale structure capable of resisting equally larger-scale physical and physicochemical stresses such as powerful wave-, surf-, and tidal current impact on the reef flats, salinity fluctuations, insolation etc; in turn the algal coat creates the necessary life-space and protecting habitat for a whole array of other tiny living organisms among which the Foraminifera are the most numerous and prominent.

According to HOTTINGER (1987, written communication) the epiphytal Foraminifera move up and down the thalli of the algal coat in a diurnal cycle, which, at Lizard Island, could not be confirmed as no nocturnal observations were made. Moreover HOTTINGER states that this algal coat, according to his observations in the Maledivas, is also a seasonal phenomenon and that it appears and disappears in a few months.

Nevertheless, observations by MONTY during the "De Moor" expedition made it clear that the algal coat at Lizard Island was present in June (Fall) as well as in January (Summer). Not on single testimony of an eventual temporal disappearing of the Halimeda-dominated algal coat at Lizard Island has been reported by any of the regular visitors of the field station, nor by Mr. DOMM, the Resident Director.

In intertidal- and slightly subtidal environments other than the reef-flats, this type of algal coat is also present, viz. on some parts of the Sandy Shoal, the Internal Flat and the Patchreef Area. The lowermost limit of occurrence of the coat corresponds to the - 3 m terrace. Below this depth the higher algae are thinning out and a number of algal species disappear; the "algal coat" is generally replaced by a "cyanobacterial coat".

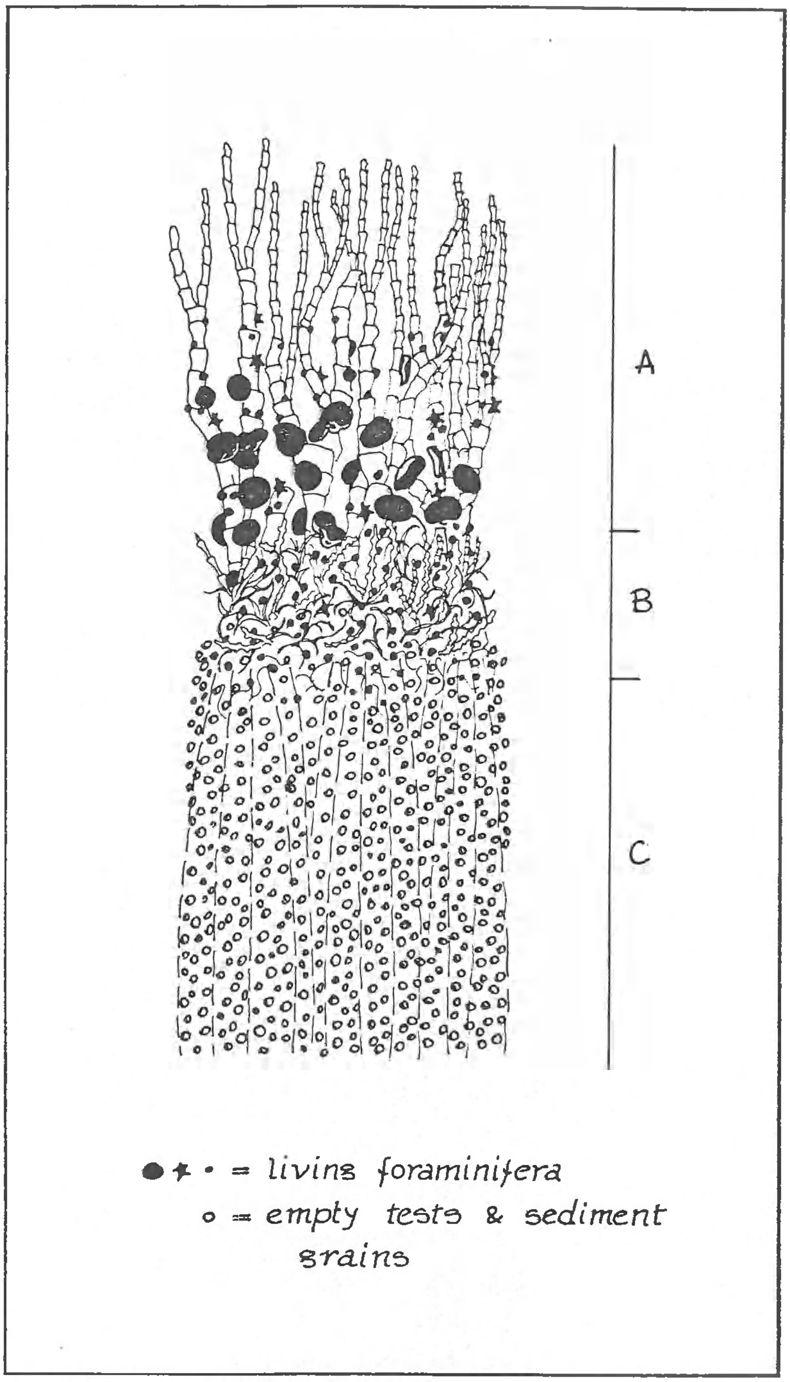


Fig. 23 : Schematical vertical section through an algal coat with underlying sediment on the reef flats.

A = Zone where larger thalli and larger epiphytic Foraminifera predominate; the latter move up and down the thalli diurnally.

B = Transitional zone at the base level of larger thalli, where smaller algal thalli are densely interwoven and where the majority of intermediate - and smaller epiphytic and infannal Foraminifera occur together with empty foraminiferal tests and occasional sediment grains of nonforaminiferal origin.

C = Upper centimeters of sediment fixed by root systems of larger algal thalli; a few living,often infaunal foraminiferal specimens occur in the uppermost cm of this layer but are rapidly replaced by mostly large empty tests below. This sediment is generally a very coarse sand to sandy gravel.

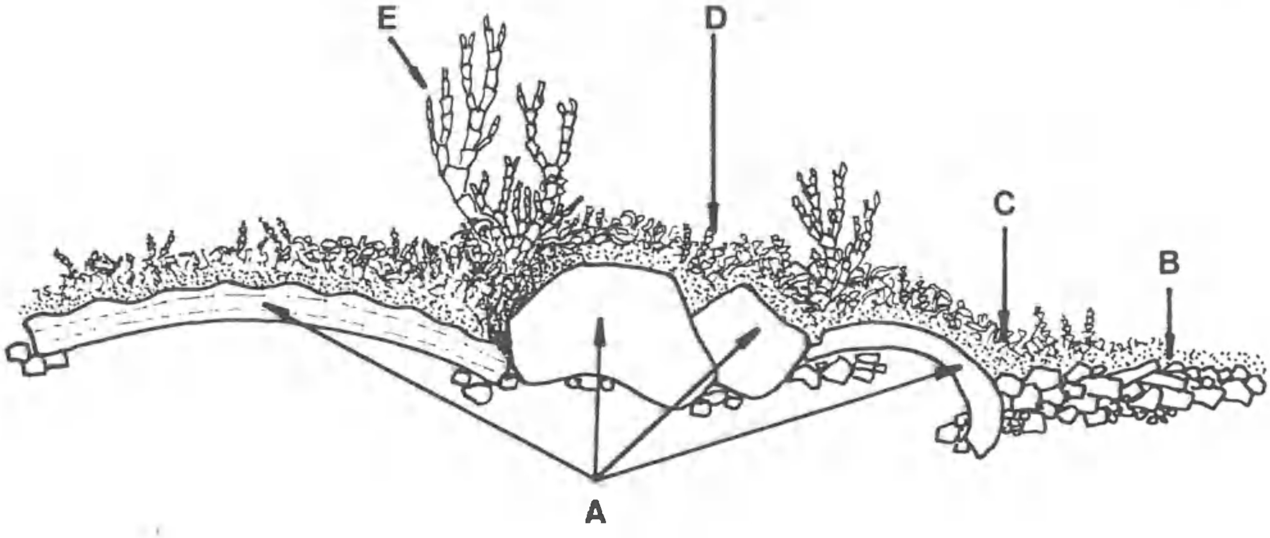


Fig. 24 : Development of an algal coat upon a hard substrate.
A = hard substrate (shell fragments, reefrock ...);
B = small Algae (algobacteria) growing in substrate irregularities;
C = slightly larger thalli fixed in B;
D = larger thalli fixed in C;
E = largest thalli (e.g. Halimeda) rooted in crevices upon and between substratum fragments (schematical).

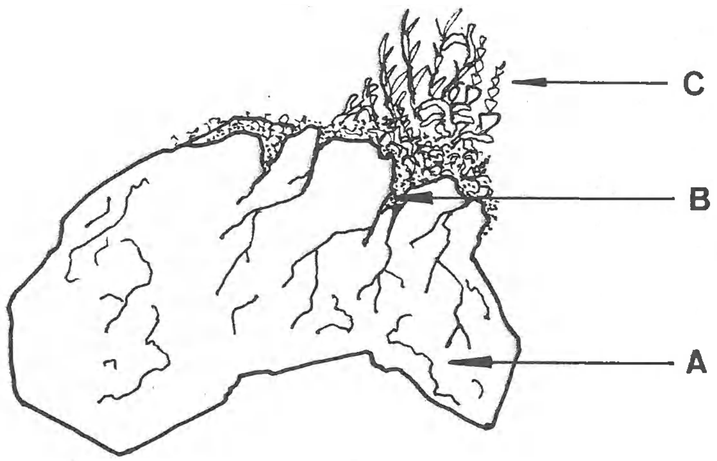


Fig. 25 : Development of an algal coat upon an eroded, perforated organoclastic grain.
A = Skeletal carbonate grain with perforations, hollow spaces and fissures (B) which are coated inside with organic matter and cyanobacteria, and which are externally linked with the small Algae layer C (cf. fig. 24 B) (schematical).

3.2.3. Cyanobacterial coat

This type of coat covers, at Lizard Island, almost all bottom surfaces which are not occupied by the algal coat (which also contains cyanobacteria !). It consists of a thin to very thin (some millimeters or less), often continuous veneer consisting mainly of cyanobacteria and overlying mostly fine sandy - to silty sediments (e.g. the Lagoon). It also occurs on coarser sand (e.g. the Sandy Shoal) and on badly sorted or bimodal sediments (Perireefal Area). Generally the cyanobacterial coat is interrupted only where fresh burrowing mounds occur.

Main components of this cyanobacterial coat are Lyngbya and Phormidium. The cyanobacterial coat serves as the most important substrate for epiphytal smaller Foraminifera in deeper waters (e.g. the Perireefal Area) whereas a possible interaction between the cyanobacterial coat and infaunal Foraminifera living just below the coat (e.g. Bolivina - Brizalina) still has to be investigated. In the same way as explained for the algal coat, although on a smaller scale, the cyanobacterial coat offers pseudopodial support, a protective microhabitat and food to the epiphytal Foraminifera whereas the specific biochemical processes and exchanges taking place in the coat very likely play a crucial role in the distribution pattern of given foraminiferal taxa and - assemblages.

3.2.4. Intermediate substrates

Locally, impoverished fringes of algal coat may be considered as substrates transitional between algal- and cyanobacterial coats. They occur in the marginal areas of distribution of the algal coat whereas Halimeda - meadows in the Perireefal Area may be considered as a particular case of such intermediate substrates.

3.2.5. Distribution of algal- and cyanobacterial substrates

See map, Fig. 26.

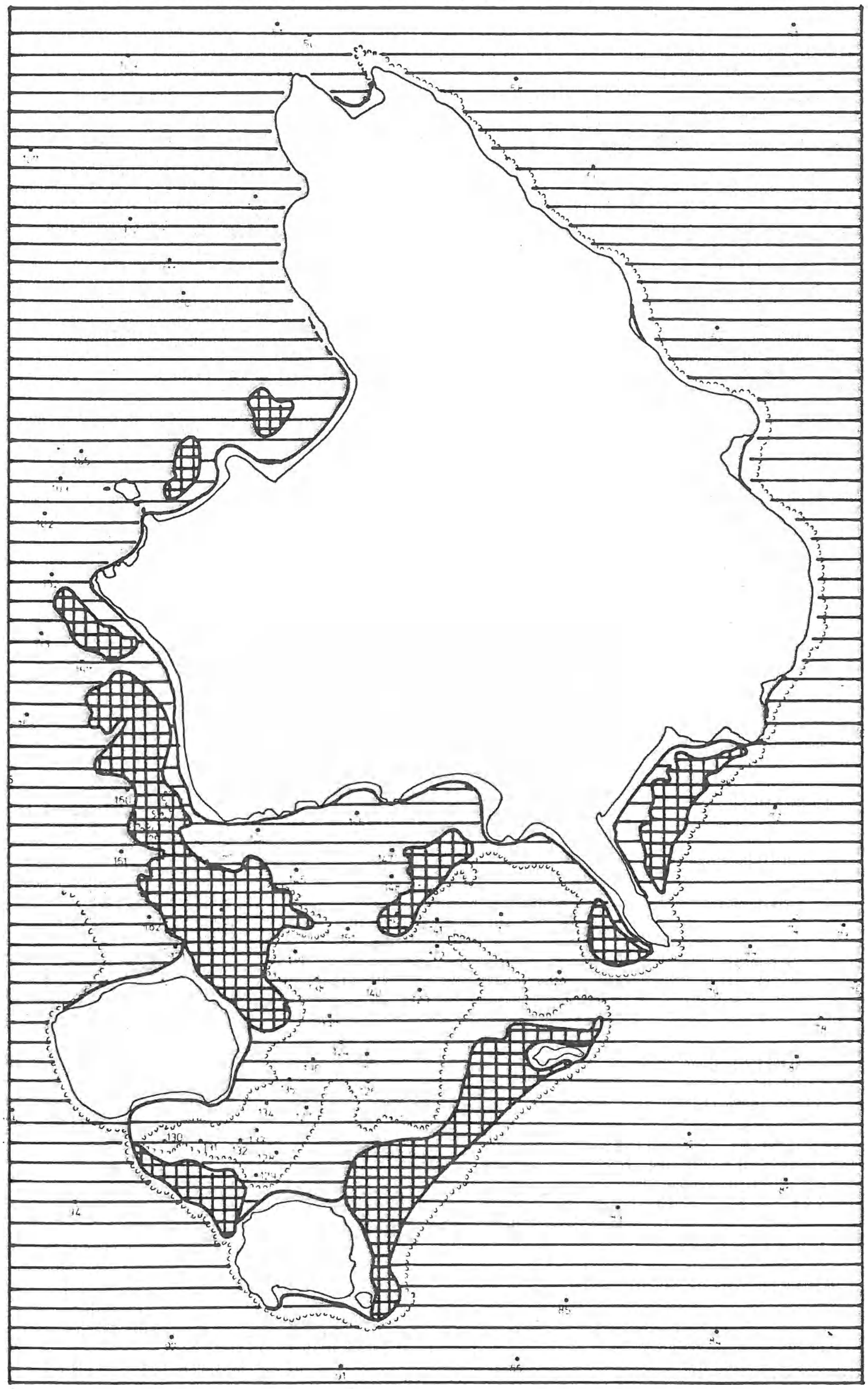


Fig. 26 : Distribution of algal- and cyanobacterial coats.

Legend :

= algal coats predominant

= cyanobacterial coats predominant

3.3. Coconut Fringing Reef

The sampling stations are all located in the intertidal-supratidal zone, with the exception of one sample (L 72) which has been taken on one of the lowest terraces of the reef front, and whose faunal content is further dealt with in the comments on perireefal samples for convencience.

Living Foraminifera : 25 (sub) species (see Annex 5)

- Textulariina : -
- Miliolina:6 living species of which 4 are common to frequent; these 4 are soritids (Peneroplis pertusus s.s., P. pertusus planatus, Sorites orbiculus and Marginopora vertebralis (crenulated form)).
- Rotaliina : 19 Living species of which the most frequent ones are Amphistegina lobifera, Calcarina spengleri s.s., Baculogypsina sphaerulata and Elphidium crispum.

These most frequent living species are all larger taxa dwelling mainly upon the larger algal thalli of the algal coat; they belong to the families Soritidae, Amphisteginidae and Calcarinidae. The only smaller species encountered alive in a more or less regular way are all of them rotaliids : Discorbis mira, to some extent Glabratella patelliformis, Cymbaloporetta gr. bradyi, C. squammosa, and small Heterostegina depressa.

- Forereef : - The Algal Pavement is almost devoid of living Foraminifera. Only few living Foraminifera survive, these being derived from the algal coat. These are mostly larger Calcarina, Baculogypsina, Elphidium crispum and Peneroplis - specimens. Where the first patches of algal coat appear, these are heavily colonised by the species mentioned before, with a predominance of Calcarina, Baculogypsina and Amphistegina; Marginopora is less frequent here and whenever present, tests are generally small. Sorites orbiculus is present however in considerable numbers, solidly fixed upon the algal thalli.
- Moat and Rubble Zone show two types of colonisation : the same type of algal coat-fauna on one hand, and on the other hand a few larger tests (Calcarina, Baculogypsina, Amphistegina) occurring in the almost barren tidal channels and being washed off the weeds.
- Backreef : - Microatoll zone : A dense algal coat is present, showing the same living fauna as mentioned above, with a variation : the further one proceeds in a landward direction, the more a dense colonisation of large

Marginopora becomes predominant over the other species. Calcarina - Baculogypsina - Peneroplis are maintained on almost the same frequency level as on the forereef whereas Amphistegina frequency decreases. Other species occur sporadically. Where the algal coat is interrupted and the coarse underlying sand appears at the surface, only a limited number of washed-off specimens of several species occur (mainly Marginopora, Calcarina, Baculogypsina).

Towards the beach the algal coat thins out, leaving only narrow algal "spurs" between the gradually broadening sandy drain channels.
The transition algal coat - barren sand is often formed by a thin coat consisting of only a fine, hairy weed veneer inhibiting sand transport and allowing smaller species (e.g. juvenile miliolids) to live here (e.g. L 249). In the barren, sandy landward area (convergence of tidal channels) between microatoll-zone and beach, considerable numbers of algal coat-derived living Foraminifera spread over the surface. Here predominate Marginopora, Calcarina, Baculogypsina and smaller species (Bolivina compacta, B. rhomboidalis, Discorbis mira, Cymbaloporetta).

Upon the beach, in the intertidal area, now and then a living washed-off specimen is found.

Thanatocoenose : 70 (sub) species

(see Annexes 1-5); this is almost three times the number of living species (25).

Comparison bio- thanatocoenose : A first glance at the synoptic table (Annex 5) confirms that there is little presence- and frequency shifting between bio- and thanatocoenoses and that the thanatocoenose corresponds fairly well to the biocoenose; as a rule, species that are regularly present alive, are also encountered in often large numbers in the total fauna counts of the same samples. The following anomalies are noteworthy :
- Arenaceous Foraminifera have not been met alive on Coconut Reef (except for a single problematic juvenile).
- Miliolids, except for soritids, were extremely rare in the biocoenose (living juveniles were present).
- Several rotaliid species show high relative frequencies in the thanatocoenose, in contrast with their scarcity in the biocoenose : e.g. Bolivina rhomboidalis, Discorbis mira, Glabratella patelliformis, Planorbulina acervalis, the Cymbaloporetta - species, Sigmavirgulina tortuosa. This is very likely not due to transport effects but is caused by seasonality of many species.

Thanatocoenose distribution : shows a more or less zonal pattern which is characteristic for all reef flats at Lizard Island. For Coconut reef this pattern is visualised on the cumulative percentage curves, traverses 1 and 2 (see Annex 2).

From the diagrams the evidence emerges that a close interrelationship exists between sediment type (grain size), substrate of Foraminifera (algal coat) and distance to shore, factors influencing the qualitative and quantitative distribution of tests in the reefal sediments. From fore- to backreef we notice the following phenomena :
- At the seaward edge of the reef flat (algal pavement, sand pockets of moat and tidal channels), coarse badly sorted gravelly sands predominate; the curves show that the foraminiferal content of these sediments consists mainly of the rotaliids Calcarina - Baculogypsina - Amphistegina (L 245 - L 244 in trav. 1, L 247 - L 246 in trav. 2); foraminiferal diversity is extremely low as well as relative frequency of Textulariina - Miliolina, and smaller rotaliid taxa.
- Further landwards, samples have mainly been taken in sandpockets left uncovered by the algal coat, or consist of generally coarse, badly sorted sand underlying the algal coat in the rubble- and microatoll zones (L 241 in trav. 1, L 249 - L 251 in trav. 2). Here the predominance of Calcarina - Baculogypsina - Amphistegina as a rule somewhat recedes, favouring a relative higher percentage of porcellaneous forms (mainly soritids with Peneroplis and Marginopora). Smaller Rotaliina gain importance here (e.g. Elphidium, with E. Crispum).
Diversity is higher.
- In the sandy backreef area between microatoll zone s.s. and beach, an area of badly sorted but generally finer sand with coarser intercalations, faunas are mixed and whereas Calcarina - Baculogypsina remain important, soritids (Marginopora !) and miliolids are more frequent than on the forereef; the same is valid for smaller Rotaliina (relative importance of Cymbaloporetta ("Tretomphalus"), Cympaloporella). Here diversity is higher than on the forereef. A moderate accumulation effect can be seen from the leeward side of the microatoll zone onward towards the beach (samples L 243 in trav. 1, L 252 in trav. 2). Noteworthy here is the low frequency of Amphistegina and the influx of a whole array of smaller Miliolina and Rotaliina.
- The beach itself (samples L 248 in trav. 1, L 250 in trav. 2) is clearly an accumulation area. Low diversity is produced by sorting the Foraminifera as to their degree of robustness; very fragile tests are absent. Wave-sorting is visible to the naked eye. Indeed, in the intertidal beach zone, as far as the high-tide marking line, alternating bands consisting of either Marginopora-tests or eroded Calcarina-Baculogypsina tests can be seen, colouring

the beach in successive whitish or reddish strips (see pl. 3). Smaller (mainly miliolid and rotaliid) tests are to be found in the finer sand fraction (e.g. Peneroplis, Cymbaloporetta, Elphidium, Glabratella, ...).

- This thanatocoenose "zonation" is also reflected in the fragmentation curves (trav. 1 & 2) (lower curves).

3.4. The Windward Barrier

Sampling stations are almost all situated in the intertidal area (reef flat) and the slightly subtidal backreef zones (staghorn coral forests, e.g. sample L 253). Deeper backreef samples (e.g. L 126) have been included in the lagoonal samples whereas samples from the reef front terraces are not available.

Living Foraminifera : 31 (sub) species (see Annex 5).

- Textulariina : 4 living species, only isolated specimens (mostly juveniles), belonging to the species Psammosphaera fusca, Textularia candeiana, T. pseudogramen, Rotaliammina chitinosa. Of P. fusca only living specimens have been observed, these tests rapidly desintegrate postmortem.
- Miliolina : 9 living species. The same 4 sortitids as on Coconut Reef are frequent to abundant : Peneroplis pertusus s.s., P. pertusus planatus, Sorites orbiculus and Marginopora vertebralis (crenulated form). For the remainder of living taxa only sporadic specimens occur, with one single exception : Miliolinella australis circularis being commonly alive at station L 255b.
- Rotaliina : 18 living species of which the most frequent species are again the same as on Coconut Reef : Amphistegina lobifera, Calcarina spengleri s.s., Baculogypsina sphaerulata and Elphidium crispum. Well-represented are also Glabratella patelliformis, Cymbaloporetta gr. bradyi, C. squammosa. In general there is a good correspondence between Coconut Reef and the Windward Barrier. An exception is the virtual absence of Discorbis mira on the Windward Barrier.

Substrates : The situation here is virtually the same as on Coconut Reef flat.

- Forereef : the forereef, paved by lithothamnioid encrustations, supports only isolated thalli of soft algae in crevices or small depressions. Where the Algae are present they bear the typical Calcarina - Baculogypsina - Amphistegina - Marginopora - Sorites orbiculus fauna. In the sandpockets only a few larger Foraminifera survive in the coarse organoclastic sand.

In the moat we find Palythoa-encrustations together with abundant Laurencia; this may be considered as a development of the Laurencia-Palythoa band (CRIBB, 1965, 1966) though Laurencia spp. are not limited to this band alone. Larger algal thalli are common in the algal coat and the broad-segmented Halimeda opuntia is here and on the entire Windward Barrier more common than on corresponding areas of Coconut Reef.

In the rubble zone a further development of the algal coat is to be found :
- Backreef : This algal coat - development continues in the microatoll zone, and so far as this zone the situation is perfectly comparable to the one on Coconut Reef; living Foraminifera occur in the algal coat whereas in the sandpatches and drain channels where no algal coat is present, only few, generally large washed-off specimens occur alive. Even less distinction between forereef- and backreef foraminiferal fauna can be made here when compared to Coconut Reef; Amphistegina and Marginopora are present on the forereef as well as on the backreef though their distribution is somewhat irregular; the relative frequency of Amphistegina is higher on the forereef, of Marginopora on the backreef.

At the lagoonward edge of the microatoll zone the algal coat thins out, becomes disparate and disappears as such; only a coat consisting of e.g. Gelidiella (?) and cyanobacteria (Lyngbia) forms a thin, discontinuous veneer over the generally finer, badly sorted organoclastic sand which further lagoonwards becomes heavily bioturbated (Calianassa-type of bioturbation). Here the sandy bottom becomes gradually more and more of the lagoonal type; living Foraminifera, linked to the presence of the fine algal coat and the finer sediment occur : e.g. Rotaliammina chitinosa, Quinqueloculina gr. oblonga, Fissurina, Bolivina compacta - rhomboidalis, Neoconorbina terquemi, Cymbaloporetta gr. bradyi, Elphidium poeyanum.

Thanatocoenose : 67 (sub) species (see Annex 5).

This is more than the double of the number of living species and is highly comparable to the number counted in the thanatocoenose on Coconut Reef (70).

Comparison bio-thanatocoenose :

- The arenaceous Foraminifera encountered alive generally do not belong to the same species as those from the thanatocoenose, and vice versa : Psammosphaera fusca has exclusively been encountered alive, as well as (young) Textularia candeiana and Rotaliammina chitinosa. On the contrary, Haddonia minor and Clavulina multicamerata occur regularly in the thanatocoenose but have not been encountered alive.
- This is also valid for the miliolids : species that have been found alive exclusively are Quinqueloculina pittensis and Miliolinella australis circularis whereas many species occuring more or less sporadically in the thanatocoenose

have not been met alive.

- In the Rotaliina the following taxa occur exclusively in the biocoenose : Fissurina marginato-perforata, Buliminoides williamsonianus, Bolivina compacta, B. rhomboidalis, Elphidium poeyanum. On the contrary, Poroeponides lateralis cribrorepandus is not unimportant in the thanatocoenose but has not been encountered alive.

Distribution : The zonal pattern described for Coconut Reef is also found on the Windward Barrier, with the exception of the beach samples on Coconut Reef being replaced here by backreef samples showing the transition towards a lagoonal situation (see cumulative percentage curves, traverses 4 and 5 pro parte, in Annex 2). Traverse 4 cuts through the Windward Barrier between the Lagoon entrance and Bird Islet (samples L 253 to L 256) whereas trav. 5 is situated south of Bird Islet (samples L 253 to L 261). The fragmentation curves show the same general pattern as on Coconut Reef (traverses4 and 5, middle curves). The lowermost curve on trav. 5 shows the granulometry of some samples taken at more or less the same localities by SEGERS; there is a relationship between granulometry, fragmentation rates and cumulative percentages of foraminiferal tests in the sediment.

3.5. The Southern Barrier

Deeper backreef samples (e.g. L 129) have been included in the lagoonal samples. Material from the reef front terraces is not available.

Living Foraminifera : 21 (sub) species (see Annex 5).

- Textulariina : 1 living species (only a few rather juvenile specimens of Textularia candeiana). Arenaceous Foraminifera are extremely rare on the Southern Barrier.
- Miliolina : 6 Living species. Except for 3 out of the 4 typical reef-flat soritids (Peneroplis pertuso-planatus, Marginopora vertebralis - crenulated form) which are common to abundant, only isolated living specimens of Quinqueloculina granulocostata, Q. pittensis and Sorites orbiculus have been encountered.
- Rotaliina : 14 species of which the most frequent are again the typical reef-flat species Amphistegina lobifera, Calcarina spengleri s.s. and Baculogypsina sphaerulata. Well-represented are Elphidium crispum, Cymbaloporetta gr. bradyi, C. squammosa.

- The general impoverishment of this reef with respect to the two earlier-described reefs as far as coral development is concerned (see p. 59) is also reflected in the foraminiferal faunas.

Substrates : The same situation as on the Coconut Reef and the Windward Barrier is to be found here; the algal coat is quasi omnipresent except for the seaward rim of the algal pavement, the forereef sandpatches and tidal channels, and sandy backreef pools; everything else, even larger boulders and coarse Acropora-shingle is overgrown by an algal coat of several cm thickness in which Laurencia is abundant on the forereef (no Palythoa has been observed here), whereas many other algal species together with abundant Halimeda cylindracea and Amphiroa dominate the backreef. All living species occur everywhere in and around the algal coat. In the sandpockets of the algal pavement again only a few washed-off specimens of larger species occur; Amphistegina, Baculogypsina, Calcarina, Peneroplis, Elphidium crispum dominate over Marginopora in the forereef whereas the latter species dominates in the entire backreef algal coat. Towards the Lagoon, in the neighbourhood of the recolonised backreef front and the (finer) sandy slopes, smaller species appear (e.g. Brizalina pacifica), linked to the presence of a cyanobacterial coat and/or infaunal taxa.

Thanatocoenose : 48 (sub) species (see Annex 5).

Comparison bio - thanatocoenose : It is obvious that, except for the few typical reef-flat dwellers (soritids, larger rotaliids) this Southern Barrier reef flat is strongly impoverished as to the living foraminiferal fauna. As the thanatocoenose however yields a species diversity which is comparable to the one of the two other formerly described reef flats, there must be a seasonal cause for this phenomenon. The only species which have been met alive but which are not present in the thanatocoenose are Quinqueloculina granulocostata, Sorites orbiculus, Bolivina rhomboidalis, Brizalina pacifica, Glabratella patelliformis, Angulodiscorbis quadrangularis and Ammonia tepida. With regard to the scarcity of these species in the biocoenoses, not too much importance should be attached to their absence in the sediment.

Distribution : The zonal distribution of Foraminifera in the thanatocoenose again follows the same general trend as described for Coconut Reef and the Windward Barrier. This trend is visualised on Traverse 6 (see Annex 2) right part, stations L 262 tot L 266.

3.6. The Lagoon

Living Foraminifera : 53 (sub) species (see Annex 5).

- Textulariina (5 species) : One species Psammosphaera fusca, is present at several stations and often reaches noticeable frequencies, particularly in the central Lagoon. This species has exclusively been encountered alive. Other living species with perireefal deeper water affinity are restricted to the northern part of the Lagoon and show a patchy occurrence, at least in the living state : Textularia candeiana (frequent in L 121), T. foliacea (frequent in L 120). Other occurrences are doubtful.
- Miliolina (23 species) : Species frequently found alive are the characteristic "backreef" taxa which are equally typical for the (shallow) backreef units such as the Patchreef Area, the Internal Platform and the Sandy Shoal. They comprise Quinqueloculina neostriatula, Q. oblonga s.s., Q. poeyana carinata, Q. montyi and Triloculina trigonula tricarinata. Other species showing occasional high frequencies without occurring regularly are Quinqueloculina bidentata s.s., the Q. oblonga variants segersi and transversestriata, Triloculina earlandi and Schlumbergerina alveoliniformis (both latter species with perireefal affinity). Soritids, even peneroplids, are extremely rare to absent and the few encounterd living Marginopora - specimens are obviously derived from the adjoining reef flats.
- Rotaliina (25 species) : Regular occurrences are registrated for those taxa characteristic for the thanatocoenose too, viz. Ammonia gr. tepida, Cymbaloporetta gr. bradyi and to a lesser extent Parrellina hispidula. Occasional living representants of Spirillina gr. vivipara, Brizalina convallaria, Rosalina orientalis, Haynesina depressula and a few other species are to be met. In some samples from the slope towards the Internal Flat some living specimens apparently derived from this flat occur (e.g. Bolivina compacta).

In the deeper parts of the Northern Lagoon, towards the Lagoon Entrance, some living taxa with perireefal affinity appear, such as Amphistegina lessonii (pass - L 120 depth : - 17 m).

Substrates : As has been described on p. 75 etc. the Lagoon bottom is mainly sandy except for narrow gravelly zones in the immediate neighbourhood of coral patches and -knolls; in the deeper backreef zones of the Barrier System s.l., accumulations of reef-flat derived material occur. A coarser- to finer gradient in the lagoonal sands is observed from the flanks towards the deeper center (see granulometric curve, traverse 5 where a peak of fine-grained sediment is to been seen at the level of L 124 (= L 7)). This entire sandy area is heavily burrowed almost everywhere and shows bottom irregularities due to due to numerous burrowing mounds of the Calianassa - type. Where burrows are fresh, the sand is bare; otherwise the bottom shows an apparently rapid development of a thin to very thin cyanobacterial coat(a few mm thick maximum) of which the complete content has not been determined but which is certainly to a great extent composed of Lyngbya and Phormidium. This coat equally covers boulders and shingle in the vicinity of coral patches.

Developments of coarser algal coats of the reef-flats type have not been observed in the Lagoon s.s., neither have larger algal thalli been observed with the exception of sporadic occurrence on the rims of some coral patches, of the green Chlorodesmis, devoid of epiphytic foraminifera anyhow.

Thanatocoenoses : 121 (sub) species (see Annex 5).

- Textulariina : highest frequencies and more or less regular occurrences are reached by the same species which dominate the arenaceous component in the other shallow backreef areas like patchreefs, Internal Flat and Sandy Shoal. They are : Textularia candeiana (2% in L 123 and L 130), T. pseudogramen s.s. with less T. pseudogramen kerimbaensis, and particularly T. foliacea oceanica which reaches its highest relative percentages in the entire Lizard reef complex (16%) in the Lagoon Entrance (L 120); an accumulation effect of this inflated, solidly built subspecies is obvious in this northern part of the Lagoon, most tests apparently being derived from the Internal Flat and the Sandy Shoal and transported downwards by the tidal currents which are particularly strong in this area, sweeping through the Lagoon Entrance and following a SE-NW trend or vice versa. It is noteworthy that in the same sample (L 120) the (flattened) subspecies T. foliacea s.s. (characteristic for the Perireefal Area) has been found alive in considerable quantities.

Miliolina : Most frequent species are those which have already been recorded as common in the biocoenose. Noteworthy is the presence of the P. pertusus acicularis - form in several lagoonal samples (e.g. 3% in L 139); here we exclusively find the stouter form with rounded cross-section of the uniserial chamber series (see Part 2). Species reaching occasional high frequencies but which are otherwise absent or rare, are obviously derived from the Southern Barrier reef flat. Alveolinella quoyi, present in the Lagoon Entrance (L 120) once more hints at the perireefal affinity of this depositional environment.

- Rotaliina : Frequent species are again the typical shallow backreef taxa. One species, Ammonia gr. tepida, though present in other shallow environments such as the Patchreef Area etc., occurs in such high numbers in the lagoonal thanatocoenoses that it can be put forward to characterise these fine-grained sediments.

Comparison bio-thanatocoenose :

Species which are very characteristic for the lagoonal samples occur in both bio- and thanatocoenose. Nevertheless, living specimens are far less frequent than empty test-accumulations and often show a patchy occurrence.

Distribution : The distribution of Foraminifera in the lagoonal thanatocoenose is shown in the traverses 3, 4, 5 (NW-SE) and 6, 7 (SW-NE) (Annex 2, see also circular diagrams Annex 1). In general the lagoonal thanatocoenoses show less variation in the faunal composition than in the relative amounts of the faunal components. Furthermore the relative percentages of taxa seem to be closely linked to the granulometry of the sediment.

- In the deeper, central part of the Lagoon, fine-grained sediments predominate (see trav. 5 - granulometry) (e.g. sample L 124). These fine sediments are characterised by a predominance of rotaliids over miliolids (arenaceous Foraminifera are virtually absent to very rare). Diversity is rather high, particularly of rotaliids, and the characteristic Ammonia tepida reaches its relative frequency peak here, whereas among the miliolids the characteristic trio Quinqueloculina neostriatula - oblonga - montyi persists.

Towards its flanks, the Lagoon shows a gradually increasing influence of the surrounding shallow environments in its thanatocoenoses.

- In the northern part of the Lagoon (between the Lagoon entrance and the northwesterly extending coral tongue connected with the Windward Barrier (level of sample L 122), the thanatocoenoses still show the characteristic lagoonal components but are influenced by the vicinity of the Pass and the Windward Barrier in the SE, and of the Sandy Shoal in the NW. Quinqueloculina - Ammonia persists here but towards the Sandy Shoal the diversity drops whereas the relative percentage of miliolids increase; Hauerina pacifica appears; Reussella as well as the Cymbaloporetta bradyi-group increase.

Proceeding along the pathway from the central to the northern Lagoon (L 124 - L 123 - L 122 - L 121) a gradual increase of miliolids is to be noted, as well as a small peak of arenaceous taxa at the level of L 123. Ammonia gr. tepida is important in the central - as well as the southern Lagoon but its frequency decreases considerably at the level of the narrow passage between Sandy Shoal and the Windward Barrier coral tongue (L 122) whereas e.g. Elphidium crispum, Reussella and Cymbaloporetta might be washed off the reefflat.

- The Lagoon entrance itself is characterised by a sudden peak of arenaceous Foraminifera (24% in L 120) as well as by the presence of a number of taxa (e.g. Alveolinella, Amphistegina lessonii) with perireefal affinity in this deeper water (between - 15 and - 20 m) (see before). Moreover a considerable apport of reef-flat - derived material is reflected by the increased amounts of soritids, Amphistegina, Calcarina and a few other taxa whereas the characteristic lagoonal Ammonia tepida - population has almost completely disappeared. The sample L 120 shows a picture perfectly intermediate between the lagoonal and the eastern perireefal situation and a peak of arenaceous Foraminifera.

- The lateral flanks of the central Lagoon and the entire southern part of the Lagoon show a rather steady, "lagoonal" composition of the fauna with signs of increased admixture of reeflat-derived material (Amphistegina, Calcarina, Elphidium crispum). Glabratella patelliformis and Reussella simplex are always present in these backreef environments. An increase of the frequency of Cymbaloporetta gr. bradyi is balanced by a decrease, or even the complete disappearing of Ammonia tepida. The NW-flank of the Lagoon is moreover characterized by the consistent presence of small numbers of Hauerina pacifica derived from the Internal Flat and the Sandy Shoal.

The relative frequencies of the three typical lagoonal quinqueloculinids change with depth : Q. neostriatula and Q. montyi are dominant in the shallow parts and flanks of the Lagoon whereas Q. oblonga takes over this role in the deeper, finer-graded central Lagoon.

The extreme south-western extremity of the Lagoon (lagoonal "finger" enclosed by Southern Barrier and Coral knolls in front of Palfrey Island) is characterised by a strong shallow backreef influence determining the dominance of the smaller rotaliids and the relative abundance (10%) of the arenaceous foraminifera. Here the situation is inverse in respect to what is found in the more northwardly situated areas transitional towards shallow environments; the faunal composition is somewhat comparable to the one of the recolonised fronts of Internal Flat and Sandy Shoal (increased Textulariina, calcarinids, Amphistegina - Baculogypsina, drop of miliolids in general and of soritids in particular, increased rotaliid diversity, many Cymbaloporetta gr. bradyi)(see trav. 7 - compare to L 150 - L 131).

3.7. The Internal Flat

Living Foraminifera : 16 (sub) species (see Annex 5).

This low number may reflect a primary impoverishment of this particularly exposed, shallow environment. The effect may be enhanced by the low number of samples doubtlessly eliminating some rare living species.

- Textulariina : Only 1 living species, Reophax fusiformis, at Stn. 162.

- Miliolina (10 species) : Quinqueloculina granulocostata and Massilina inaequalis are alive in more than one sample; the typical shallow backreef species Q. neostriatula and Q. oblonga s.s. have been encounterd alive too. Other occurrences are occasional.
- Rotaliina : 5 Living species, of which only one has been encountered alive in more than one sample : Cymbaloporetta gr. bradyi.

Substrates : The main, shallow part of this platform is covered by a, locally dense, algal coat with Halimeda cylindracea comparable to the one present on the backreef flat of the Southern Barrier and is similarly impoverished as to its foraminiferal fauna. The characteristic foraminiferal species (Marginopora and larger soritids, Amphistegina ...) of such an algal coat have however not been encountered here. This may be due to seasonal factors, as the thanatocoenose witnesses the temporary presence of some of these species upon the Internal Flat (see below).

Laterally to the main algal coat on sandpatches between the algal-covered boulders, a thin cyanobacterial coat such as has been met on the backreef slopes of the Windward Barrier, the Sandy Shoal and locally in the Lagoon, is present. This cyanobacterial coat seemed to be largely devoid of living Foraminifera during our stay on the island.

Thanatocoenose : 50 (sub) species (see Annex 5).

Number comparable to the one registered on the Southern Barrier (48).

Quinqueloculina curta is characteristic for the Internal Flat and reaches here its highest relative percentages in the thanatocoenoses of the Lizard Archipelago.

Virtually no Calcarina - Baculogypsina tests have been found in the Internal Flat samples.

Comparison bio-thanatocoenose :

A few species have been encountered alive which are otherwise absent from the thanatocoenose; they are Reophax fusiformis, Quinqueloculina granulocostata, Q. oblonga transversestriiata and Spirillina vivipara revertens. Q. granulocostata is often more frequent in the bio- than in the thanatocoenose (e.g. Southern Barrier, Lagoon).

Distribution : See traverses 5, 8, 9 (Annex 2) and circular diagrams (Annex 1).

The traverses show the local abundance of Textularia agglutinans and T. foliacea oceanica in the central part of the Internal Flat.

Miliolina dominate over Rotaliina. Miliolina diversity is rather low and the most frequent species are Soritidae (mainly Peneroplis). The characteristic miliolids Q. gr. oblonga - Q. neostriatula - Q. montyi, typical for Patchreefs, Narrow Pass, Sandy Shoal and Lagoon, are less important or even absent here. As to the rotaliid assemblage, its principal components are Cymbaloporetta and Ammonia. The frequences of these two genera are lower than in the Patchreef Area.

The Internal Flat is separated from the Sandy Shoal and from the beach of Lizard Island by a narrow pass; Traverse 9 shows that diversity increases towards this pass. Arenaceous Foraminifera disappear almost completely, and among the Miliolina the soritids (Peneroplis) decrease in importance whereas the characteristic Sandy Shoal - Patchreef Area Foraminifera Q. montyi - Q. tropicalis - Q. poeyana carinata are added to the already present Q. neostriatula - Q. oblonga. Among the Rotaliina, Reussella simplex, Amphistegina lobifera and Glabratella appear, paralleled by a general increase in diversity.

The same pattern can be observed in the gradual transition Internal Platform - Patchreef Area. Amphistegina gains gradually more importance as well as Cymbaloporetta and smaller rotaliids.

The bad sorting of the medium- to coarse sediment of the Internal Flat (see granulometry, lowermost graph, Trav. 5) is reflected by the foraminiferal fragmentation curves on travs. 5, 8, 9 (Annex 2). Towards both the Patchreef Area and the Lagoon, the percentages of unidentified foraminiferal fragments (correlated with fine sediment) increase. Very likely the Internal Flat, notwithstanding its poor biocoenose at the investigation period, is an area where foraminiferal production dominates over accumulation; the thanatocoenose is primarily composed of tests produced on the spot.

3.8. The Sandy Shoal

Living Foraminifera : 37 (sub) species (see Annex 5).

- Textulariina : 4 living species, in low numbers. The Internal Flat - Patchreef Area species T. foliacea oceanica is not present.
- Miliolina : 13 living species. Occurrences are very patchy; as on the Internal Platform, characteristic shallow backreef species frequent in the sediment are rarely found alive. Only living Quinqueloculina poeyana carinata is common

in the biocoenose of Stn. L 150 (SE marginal area); also Q. oblonga s.s. has been encounterd alive at several stations though never in important quantities. Other miliolids occurring in more than one sample are Q. oblonga transverse-striata and Triloculina linneiana s.s.. Soritids are very rare in the biocoenose : only Peneroplis pertusus planatus occurs in sample L 149 (close to recolonised front).

- Rotaliina : 20 species. Regularly occurring taxa are Cymbaloporetta gr. bradyi and Ammonia gr. tepida. All other records concern rare, isolated specimens except for Haynesina depressula which is common in L 145, and Ozawaia (?) tongaensis being common in L 150.

Substrates : As has been described on p. 66 etc. the bottom here is predominantly sandy except for the SE marginal area showing some reefrock points. Bioturbations, mainly burrowing mounds of the Calianassa - type are omnipresent. As in the Lagoon, most of this sandy surface is covered by a thin cyanobacterial(Lyngbya)coat which seems to grow rather rapidly as it covers even the burrowing mounds except for the fresh ones. At the time of sampling this cyanobacterial coat seemed to support only very few, isolated living Foraminifera.

In the SE marginal area scattered algal patches develop upon the sand veneer covering the underlying reefrock; they are mainly composed of Halimeda cylindracea. At the time of sampling these algal patches were extremely impoverished as to their foraminiferal epifauna though the thanatocoenose bears the evidence that a richer fauna is supported by this algal substrate at other periods of the year. SEGERS observed not far away from stations L 271 - L 147, an Halimeda patch covered with living Marginopora (in July) (fig. 1, pl. 8).

At the end of the investigation period(July), an algal bloom started to develop upon a large surface of the Sandy Shoal; this bloom mainly consisted of Thalassia and did not support any foraminiferal epifauna (see pl. 7).

Thanatocoenose : 67 (sub) species (see Annex 5).

Comparison bio - thanatocoenose : The Sandy Shoal is an example of an area where the bio - thanatocoenose do not match well. Several species common or abundant in the thanatocoenose do not occur alive. Quinqueloculina neostriatula, characterising the thanatocoenose, has been found alive only at one Stn (L 150), Q. montyi, Hauerina pacifica and Peneroplis pertusus have not been found alive at all. Several species encountered alive are rare or absent in the thanatocoenose, e.g. Ammobaculites sp.; Textularia foliacea; variants of the Buliminoides madagascariensis - group; Bolivina rhomboidalis; Brizalina striatula;

Neoconorbina sp. aff. N. pacifica; Rosalina orientalis; Elphidium limbatum; Nonion (?) gr. scaphum.

Distribution : see traverses 3, 7, 8 (Annex 2).

The most striking phenomenon is the increase of diversity from beach and central area towards the SE marginal area and recolonised front where Amphistegina-Calcarina gr. are an important faunal component apparently linked to the extensions of the algal coat in SE direction. This marginal area is at the same time characterised by a sudden increase in Cymbaloporetta. Otherwise the Sandy Shoal remains rather steady in its faunal composition dominated by Miliolina and particularly by the quartet Quinqueloculina neostriatula - Q. gr. oblonga - Q. montyi - Hauerina pacifica.

3.9. The Leeward Patchreefs

Living Foraminifera : 72 (sub) species (see Annex 5).

This is, in all the non-perireefal areas, the highest number registrated though many occurrences are occasional and/or patchy, or even doubtful.

- Textulariina : 7 species. Here again Psammosphaera fusca is present in the biocoenose without leaving a trace in the thanatocoenose. Other species commenly present are Textularia candeiana and T. foliacea.
- Miliolina : 25 species. Occurrences are rather patchy. Regularly present species are the characteristic shallow water- backreef taxa Quinqueloculina neostriatula and Q. oblonga s.s.. The other oblonga - variants, segersi and transversestriata are equally present in moderate numbers. Hauerina pacifica, though absent from the biocoenose in remaining patchreef samples, is common in the very shallow L 153. Among the soritids, Peneroplis pertusus s.s. is most common in general; P. pertusus planatus is common in L 155 whereas P. pertusus acicularis is common in L 289 - L 291 (Watson's Bay). For the first time living Sorites marginalis appear in the deepest samples L 100 - L 155 (transition to perireefal conditions; - 10 m), whereas Sorites orbiculus is common in L 278, as well as Marginopora vertebralis (shallow-water form). Large living Marginopora are commonly alive on the algal and algobacterial substrates of the shallow reef patches facing Casuarina Beach. Alveolinella quoyi has been met alive in the deeper-water sample L 100.
- Rotaliina : 40 species. Here again occurrences are rather patchy. The best represented species are Cymbaloporetta gr. bradyi (present, alive, in almost all samples, as on the Sandy Shoal and the Internal Flat; common in the deeper-

water samples L 153 - L 155 - L 100 and in Watson's Bay - L 291). Ammonia convexa has been found alive in many samples and may be considered as a species characterising the shallow Patchreef Area; it is common in L 277 and L 153. Ammonia tepida is less frequent in the bio- than in the thanatocoenose. Amphistegina lobifera occurs alive in some shallow-water samples whereas in deeper water (e.g. L 100) this species is replaced by the more flattened species A. lessonii; in the sample L 155 both species abound in the bio- as well as in the thanatocoenose; this sample is, incidentally, the only one in our Lizard Island Reef Complex material where this phenomenon can be witnessed.

A few other Rotaliina showing more of less regular occurences in the biocoenose are Neoconorbina terquemi, Elphidium advenum, E. limbatum and Nonion (?) gr. scaphum. A patchy presence is to be noted for Buliminoides madagascariensis parallela (common in L 155, - 10 m), Cibicides aravaensis (equally common in L 155), Ozawaia (?) tongaensis (common in L 277).

Substrates : The main area of well-developed algal and algobacterial growth was found in the shallow parts of the central area and its southern border. The very shallow patches in front of Casuarina Beach, at or just below lowtide level show a dense algal coat reminiscent of the one present on the reef flats. The algal composition is the same (dominance of Halimeda cylindracea).

Compared with the eastern reef flats, the typical Calcarina - Baculogypsina colonisation of these latter units has disappeared upon the leeward reef patches. Amphistegina lobifera is considerably less numerous; Marginopora vertebralis (crenulated form) on the contrary abounds here; its empty, eroded tests concentrate on the northern part of Casuarina Beach.

The interpatch area which is mainly sandy (see p. 83) locally shows a development of the same kind of cyanobacterial coat which has been described for the Sandy Shoal, the Lagoon and other areas. Only few living Foraminifera have been collected here, the maximum abundance and diversity of living Foraminifera lying in the algal reef-patch sediments themselves. The elongate pools between the beach and the reef patches are almost devoid of any cyanobacterial or algal coat and their bottom does not support a significant amount of living foraminifera.

In the SSE, the Patchreef Area gradually slopes up towards the Internal Flat; alcyonarian and coral growth gain importance here but the algal substrate does not change significantly; Halimeda cylindracea remains an important component of the algal coat.

In the SE the sandy Patchreef bottom grades into the sands of the Sandy Shoal and the heavily bioturbated bottom of the tidal channel separating Sandy Shoal and Internal Platform.

In a westerly direction the seabed gradually slopes down from the - 3 m platform towards greater depths; here the typical shallow-water algal coat disappears; only isolated tufts of larger thalli remain, together with Alcyonaria, staghorn coral and patches of thin cyanobacterial coat between the bioturbations.

In the patches of the northern part (Anchor - Watson's Bay), the algal coat is considerably restricted; the reef patches mainly consist of microatoll-like Porites - elevations covered with abundant alcyonarian growth, staghorn coral and isolated tufts of Halimeda "opuntia", and Chlorodesmis. A thin cyanobacterial coat, resembling the one occurring in the Lagoon, covers sand, shingle and boulders and supports little or no living Foraminifera except in deeper water.

Thanatocoenose (126 species - see Annex 5).

Comparison bio - thanatoecoenose : The Patchreef Area being apparently an area of important accumulation (particularly the sandy areas of the leeward slope), there is a considerably greater diversity in the thanato - than in the biocoenose. Most of the characteristic species are present in bio- and thanatocoenoses whereas some species occur alive but are not present as empty tests in the thanatocoenose; these are Psammosphaera fusca, Fissurina laevigata, Alliatina translucens, Bolivina compacta, Brizalina striatula, Rectobolivina raphana, Cancris auriculus and Elphidium galeraensis.

Distribution : The distribution of Foraminifera in the thanatocoenoses of the Leeward Patchreef Area can be followed in the traverses 4, 5, 10 and 14 (see Annex 2).

Traverse 10 is almost perpendicular to the elongation of Casuarina Beach and illustrates the smooth, gradual transition from beach to Western Perireefal Area. L 278 (left limit of the traverse) shows a poorly diversified beach assemblage with high numbers of soritids. On the - 3 m terrace (L 160) the typical shallow patchreef assemblage occurs (higher diversification - dominance of the characteristic Cymbaloporetta - group). Further seaward, beyond the edge of the - 3 m terrace (the "edge" being in fact only a smooth transition towards increasing inclination of the seabed) Miliolina reach their maximum abundance peak (over 50% of total population) (L 154). From here onward the image of the faunal composition changes gradually and progressively; in sample 155 (- 10 m) all relative percentage values are in a position intermediate between mean shallow and mean deeper perireefal environment values (comp. L 154, - 6 m and L 98, - 25 m). Rotaliid diversity increases considerably towards deeper water and the very high amphisteginid component (over 25% already in L 155) is a constant feature in samples of the Leeward Slope and Western Perireefal area; it demonstrates the importance of postmortem displacement in a NW (leeward) direction, often over great distances, of these larger and stouter tests resisting destruction for a considerable time before being fragmented. The high amount of amphisteginids is caused by the superposition of the displaced fauna upon the already important amhisteginid faunal component being produced in situ.

Simultaneously, the fragmentation curve roughly demonstrates, from E to W (shallow to deep), an increase in fragments and unidentified fragments and a decrease in identified forams; this again stands for an increase in the apport of foraminiferal detritus and eroded material in a leeward direction, upon the leeward slope which can be considered as a huge debris-cone, upon which sedimentation plays a more important role than colonisation. It is only a few km NW out of the coast of Lizard Island that the "normal" perireefal conditions again prevail.

Traverses 5 and 4, at least their NW extremities, cut through the - 3 m terrace and the leeward slope more obliquely. Traverse 5 shows an image comparable to trav. 10; here too the Amphistegina increase is obvious whereas a slight increase of arenaceous foraminifers can be seen towards L 100. Traverse 4 demonstrates the same phenomena more to the N and remains closer to the coast (Casuarina Beach - West Point). In the shallow area between L 277 and L 153 the characteristic Patchreef fauna shows high numbers of miliolid components; note that here, close to the coast, the Cymbaloporetta - dominance which was characteristic more to the S (e.g. L 160) (and upon the Internal Flat) is partly replaced by relatively high Ammonia - Elphidium contributions. Towards the NW (Leeward Slope) the previously described image again appears : increase of rotaliid diversity with considerable amphisteginid component and increase of arenaceous Foraminifera, clearly an accumulation effect of stouter and robuster tests (e.g. Textularia foliacea oceanica). Traverse 4 again shows the already described fragments - unidentified forams increase towards deeper water whereas trav. 5 on the contrary shows the inverse phenomenon. This is probably due to the particular sedimentological characteristics of sample L 100 showing an important granulometric fraction between 500 and 1000 microns in which foraminiferal tests generally are more easily recognisable even if broken or eroded.

The left-hand part of trav. 14 (from L 154 to L 50, SW-NE) completes the picture shown by travs. 4 and 5 and shows once more the smooth transition from shallow-water faunas to deeper perireefal ones.

3.10. The Perireefal Area

Living Foraminifera : 108 (sub) species (see Annex 5).

Textulariina : 16 species. None of these taxa is abundant throughout. Reophax fusiformis occurs mainly in the Eastern Perireefal Area. Nouria polymorphinoides is abundant in L 56. Textularia barkeri and T. candeiana occur exclusively in the Western Perireefal Area. T. foliacea and representatives of the T. pseudogramen - group (s.s. and kerimbaensis) are much more common in the thanatocoenoses.

- Miliolina : 38 species. Among these, the following taxa occur regularly alive in several samples : Quinqueloculina crassicarinata (particularly in the SE and Southern Perireefal Area), Q. granulocostata, (scattered occurrences), Q. neostriatula (living specimens always belonging to the deeper-water variant with compressed chambers), Q. oblonga s.s. (the other oblonga-variants rarely occur alive), Q. pseudoreticulata (mainly in the SE, S and SW areas, very common in L 86, off the Windward Barrier), Triloculina trigonula tricarinata (T. trigonula s.s. has not been encountered alive in the Perireefal Area and it is supposed that specimens present in the thanatocoenose are derived from the reef complex), Pseudohauerina occidentalis involuta (alive, mainly in the NE and E areas; eventually comprising some P. howelli).

Soritids : Peneroplis pertusus s.s. has been encountered alive in almost all perireefal samples, often in considerable quantities; the few living specimens belonging to P. pertusus planatus might partially be derived from the reef complex. Sorites marginalis, Amphisorus hemprichii and Marginopora vertebralis (flat form) yield living specimens at almost all perireefal stations. Alveolinella quoyi is particularly common in the S and SW areas.

- Rotaliina : 54 species. Nodosariids and lagenids are very rarely encountered alive. Brizalina striatula and Reussella simplex are present in the majority

of perireefal samples. Neoconorbina terquemi and Cancris auriculus are absent from the N and NE areas but are consistently present in the SE, S and SW. Poroeponides lateralis cribrorepandus is present in the eastern Halimeda area. Amphistegina lessonii is common to abundant throughout. A. cf. papillosa is present in almost all perireefal samples. Cibicides lobatulus is present in the eastern area (Halimeda - substrate); Cibicides pseudolobatulus is present in the NE area where smaller skeletal debris are more frequently intermingled with Halimeda - flakes than in the E and SE, and other areas. Planorbulina acervalis and Gypsina globulus have equally been encountered alive in the E and NE Halimeda - areas. Cymbaloporetta gr. bradyi is present in several samples in the N, NE and NW; in the northwestern samples this group has commonly been met alive, as well as Ammonia tepida.
Calcarina spengleri mayori is common in almost every sample in the N, NE, E to S but disappears almost completely (at least living specimens) from the western, leeward samples with their more finely graded sediments and smaller Halimeda - component. Operculina ammonoides is common to abundant in almost all perireefal samples except for a few shallower stations in the NE) (Nummulites cumingii as O. ammonoides but less abundant). Heterostegina depressa occurs as mostly large, flaring specimens contrary to those present in the reef complex itself. Nonion (?) gr. scaphum is regularly present alive except in the Eastern, Halimeda-rich area. Large living Heterolepa praecincta are apparently linked to the presence of the Halimeda - substrate, together with Cibicides and allied taxa.

Substrates : The Perireefal Area has to be divided roughly into three main areas :
1) A N-NE area rapidly sloping down from the coast to a - 25, - 27 m terrace covered with Halimeda - ridges.
2) A S-SE area more gradually descending towards a - 32 m terrace mainly covered with Halimeda - rich, sandy - muddy (bimodal) sediments; and
3) The entire western, leeward area consisting of a gradually descending slope covered with fine- to medium-grained, badly sorted sand.

- The Eastern Perireefal Area (windward side) shows only a very narrow transitional strip (less than 100 m) of organoclastic coarse sand mainly derived from the reefs of the "Barrier System". Many living Foraminifera derived from the reef flats and -terraces (e.g. Calcarina, Baculogypsina ...) have been found here. As their characteristic substrate - the intertidal algal coats - are absent from these depths, it is believed that they are periodically and often transported downwards in massive quantities to the foot of the reef. Except for finer cyanobacterial coats and some isolated tufts of Halimeda, larger thalli do not grow in significant quantities in this area.

Further seaward, this particular "reef-foot sand strip" is gradually replaced by the characteristic deeper perireefal bottoms. In the SE area this transition is somewhat less abrupt than in the NE, and perireefal samples close to the coast reveal an increased fine-sandy component (e.g. L 60, L 62, L 65, L 91...). All windward samples contain a more or less important muddy component of a bluish-grey colour. They contain an important to very important Halimeda - component; often large, unbroken flakes in the E and SE, broken and worn, intermingled with the other skeletal debris in the NE and SN. The NE and N area, as a result, offers an ideal substrate to allow maximum development of arenaceous Foraminifera whereas the abundance of Halimeda - flakes in the E and SE seems to offer suitable substrate conditions for the development of a predominantly sessile foraminiferal fauna in which Cibicides and allied forms are common. These Foraminifera permanently attach themselves to the broad thallus-flakes of Halimeda.

Submarine observations during the Belgian "DE MOOR" - expedition confirmed that large areas of the perireefal seafloor in this area are completely uncovered by Algae, or are covered by isolated tufts of Halimeda, Udotea, Rhipocephalus, Penicillus e.a.; a thin cyanobacterial coat seems to be almost omnipresent, even upon the muds. No development of an algal coat comparable to the one growing on the reef flats and in shallow intertidal backreef areas has been observed here (MONTY, 1969).

- The Western Perireefal Area (leeward side) shows, at a considerable distance from the island, a gradual transition of the finer sand with important terrigenous components of the Leeward Slope, into the same type of perireefal bottom as described for the NE area : accumulation of skeletal debris with less important mud component (mud increases towards the SW) and moderate amounts of Halimeda particles; most Halimeda debris are worn and broken. Typical shallow-water algal coats seem to be absent though the same Algae as mentioned for the Eastern Perireefal Area occur : Halimeda (spp., mainly "monile"-type with larger, flattened segments), Udotea, Rhipocephalus, Penicillus, Caulerpa, Acetabularia (and probably several other species as well). Here too, underwater observations during the "DE MOOR"-expedition (MONTY, 1969) as well as sample evidence confirm that larger areas are covered by a thin cyanobacterial coat (a number of perireefal samples indeed contained numerous quantities of

Phormidium and Lyngbya in the fraction below 75 nm - determination MONTY, 1976, oral communication).

Thanatocoenose : 209 (sub) species (see Annex 5).

- Textulariina : 22 species. Most of the taxa occurring in all Lizard Island Reef Complex environments occur in the perireefal samples, plus several additional ones. The most frequent taxa occur in almost every perireefal sample; they are : Textularia agglutinans, T. barkeri, T. candeiana, T. foliacea, T. pseudogramen s.s. and its subspecies kerimbaensis.

- Miliolina : 83 species. Highest frequencies and regular occurrence among the non-soritids are to be noted in the first place for Quinqueloculina neostriatula, here almost exclusively represented by the deeper-water form with compressed chambers; a few empty, eroded tests derived from the reefs and possessing inflated chambers are to be found even far away from any reef, in this way demonstrating their high "transportability"; Q. oblonga s.s. is the only quinqueloculinid occurring often in large numbers in all perireefal samples; all kinds of apertural architectures are displayed by this species in the thanatocoenose (see also Part 2). Except for the incisa - subspecies the other oblonga - variants are less frequent here. Among the soritids, Peneroplis pertusus s.s. is numerous in almost every sample; high frequencies and regular occurrence are reached by Sorites marginalis, Amphisorus hemprichii, Marginopora vertebralis (flat form), all of these represented by often very large, discoidal, flattened specimens, of both generations. Sorites orbiculus is somewhat less frequent but occurs regularly in perireefal samples though many tests are broken and eroded which could be an indication, together with their being virtually absent in the perireefal biocoenoses, of these tests being transported towards deeper water from the reef complex. Finally the constant presence of Alveolinella quoyi is to be noted, except in some shallower - water samples of the Leeward Slope.

- Rotaliina : With its 104 species this group displays an amazing diversity in the thanatocoenose. Dominating, often very abundant species are Reussella simplex (up to 12% in L 71), Amphistegina lessonii (up to 28% in L 62), A. cf. papillosa (up to 21% in L 98), Cymbaloporetta gr. bradyi which is one of the few species or species groups consistently present in all Lizard Island environments, including the Perireefal Area; Ammonia tepida (up to 11% in L 108); Calcarina spengleri mayori, best represented in the NE perireefal area.

Operculina ammonoides and Heterostegina depressa (the large, flat, flaring form). Planctonic species are present in almost all perireefal samples but highest frequencies are registrated in the SE perireefal area (windward side).

Comparison bio - thanatocoenose : In the entire Perireefal Area, thanatocoenose diversity is much higher than biocoenose diversity. It is obvious from the often strongly eroded aspect of many tests observed in the entire Perireefal Area that a great deal of these tests has been depositioned a more or less long time ago and that the accumulation of empty tests largely exceeded the production of living specimens. Many species occurring more or less regularly in the thanatocoenose have not been met alive; a great deal of species show regular occurrences of empty tests but have rarely been encountered alive. Only a few living species on the contrary have not been met as empty tests. They are : Psammosphaera fusca (see comments in description of reef complex faunas); Nouria harrisii (a species possessing a test wall composed of sponge spicules; this wall desintegrates easily and rapidly after death), and Triloculina earlandi.

Living specimens of some species may occur in other samples than their dead counterparts. This is the case for e.g. Quinqueloculina distorquaeata which has been found alive in the Halimeda - banks area whereas empty tests predominate more to the N and S. Other examples of the same phenomenon are Massilina corrugata, Gypsina globulus to a certain extent, Monspeliensina dubuissoni, Sigmavirgulina tortuosa and Heterolepa praecincta.

These phenomena are due to a superposition of processes : on one hand the seasonality in the production of Foraminifera causes the often irregular distribution of living specimens; on the other hand, varying bioturbation intensity lies at the origin of varying turnover rates among newly produced and old shells whereas destruction of tests is more or less selective.

Distribution : The distribution of Foraminifera in the thanatocoenoses of the Perireefal Area is made explicit in the traverses 1, 2, 3, 4, 5, 10, 11, 12, 13 (more or less normal to the rim of the reef complex) and 14, 15 forming concentric belts around the reef complex; 14 is close to the coast, 15 about 1 km (more or less) further seaward (see Annex 2).

- On the windward (SE and E) side of the reef complex, the traverses (1, 2, 3, 4, 5) show a more or less abrupt transition from reef environment conditions (with e.g. high to very high Calcarina - Baculogypsina - Amphistegina component) to more stable, hardly disturbed perireefal conditions characterised by a procentual distribution of about 10% arenaceous tests, about 20 to 30% Miliolina and about 50 to 60% Rotaliina. Towards the N, arenaceous tests increase towards 15%, Miliolina up to almost 40% and Rotaliina decrease towards less than 50% (traverse 13). Fragmentation curves, from landward to seaward, are all characterised by a progressive increase of unidentified fragments and decrease of fragments and identified tests, thus reflecting progressive increase of importance of fine component in the sediment (e.g. bimodal muddy sediment with important Halimeda component E of the reef complex).

- On the leeward (NW and W) side of the reef complex, the traverses (4, 5, 10, 11, 12) show a smoother, progressive transition from reefal or close- to reef conditions to fullperireefal conditions. Here the influence of the accumulation zone delimited by the Leeward Slope is reflected in the Textulariina to Miliolina plus Rotaliina balance : higher arenaceous component (up to 20%), whereas the ratio Miliolina (up to 35-40%) to Rotaliina (about 40-50%) remains more or less unchanged. Further to the West (L 98) full perireefal conditions prevail, characterised by a decrease of arenaceous tests (to less than 10%) and Miliolina (to less than 20%) and a corresponding increase of Rotaliina (over 70%), and by an enormous increase of the number of amphisteginids (over 35% of the total thanatocoenosis). The accumulation effect is reflected in the fragmentation curves which generally show the inverse phenomenon of what was to be seen on the windward side : from landward to seaward, the number of identified tests remains more or less constant on a higher level than on the windward side (around 40%),fragments increase up to 30-35% and unidentified fragments remain constant around 15-20% or decrease slightly.

A clear picture of the local perireefal thanatocoenose variations is obtained by the concentric traverses 14 and 15. Traverse 14 remains close to the limits of the reef complex and the shores of Lizard Island, and cuts through the Leeward Slope in the NW whereas the outer belt formed by traverse 15 remains further offshore (about 1 km more or less). A first glance at both traverses already reveals that trav. 14 is much more strongly accidented than trav. 15, thus reflecting the marked influence of the reef complex vicinity in the perireefal thanatocoenoses close to the coast, and this not only on the leeward side of the reef complex.

Trav. 14 starts, in the S, at the foot of the Southern Barrier and remains close to the reef fronts of the Barrier- and Fringing Reef systems. From L 94 to L 91 a decrease of the influence of leeward accumulation can be observed in the decrease of arenaceous tests and of Miliolina. From L 91 to L 82 typical perireefal windward conditions prevail : presence of the muddy Halimeda -

sediments is reflected by gradual increase of soritids, Bolivina gr., Cibicides and allied sessile Foraminifera remaining more or less in situ, and many smaller rotaliids together with a maximum of planctonic Foraminifera.

From L 82 to L 72 the traverse crosses the Lagoon Entrance; influence of the latter is mainly to been seen in the variations within the Rotaliina-component; Rotaliina diversity decreases and this group becomes dominated by the Cymbaloporetta - group, Eponididae, Discorbidae, Amphistegina and even small Spirillina. Typical Halimeda - sediment taxa like Cibicides, Operculina etc. decrease here. In L 72 the global picture is somewhat disturbed as this is not a perireefal sample s.s.; it has been collected upon the - 12 m terrace upon the Coconut Reef front (importance of Calcarina - Baculogypsina - Amphistegina). From L 72 to L 50 the picture remains more or less constant; the only notable variations are a considerable increase of arenaceous Foraminifera towards almost 30% in the N; Miliolina remain fairly constant around 30-35% and only drop down in the N till 20% between L 56 en L 50, rounding North Point or falling into leeward conditions; the Rotaliina level remains constant around 52-53% and important variations in the Amphistegina - percentages are due to slight fluctuations in the distance from the reef front. The NW part of the traverse passes through Watson's Bay in the Leeward Slope area; in these shallower depths the thanatocoenoses suddenly change; from L 50 onwards towards L 154 a characteristic shallow-water backreef fauna is observed; depth gradually decreases towards the South (L 153 is upon the - 3 m terrace). The faunal trends are characterised by a drop of arenaceous Foraminifera from almost 30% to 3%; miliolid importance increases from almost 20% to about 60% with the sudden appearance in considerable numbers of Q. neostriatula (inflated form), Q. gr. oblonga, Q. montyi e.a.. The soritid frequency does not change in a significant way; a slight decrease is followed in southward direction by a new increase. Among the Rotaliids, the sudden increase of Ammonia is remarkable as well as, again, the variability in the presence of Amphistegina and Calcarina, these groups being unimportant in Watson's Bay but reaching almost 20% further South. The fragmentation curve shows a relation to the cumulative procentual faunal diagram and is directly related to the different sedimentological environments which are passed by the traverse. In the S and SE (area of muddy Halimeda - sediments) the numbers of identified tests and fragments are generally low; in L 77 the influence of the Lagoon Entrance with its predominantly fine sand - mud is marked by a further drop in the percentages of identified tests and fragments, whereas the coarser skeletal debris - environment in the NE is characterised by a marked increase in these values, paralleling the rise of the Textulariina - curve. The fine sands of the Leeward Slope in the NW are typified, from L 50 onwards, by an increase of unidentified tests and corresponding drop of identified tests - fragments. Again it is to be seen that the fragmentation curve is a tool faithfully reflecting the sedimentology of the area and as such being a useful link between the sedimentology - granulometry and foraminiferal thanatocoenose found in the concerned area.

Traverse 15 shows a strongly smoothened image when compared to trav. 14. From L 90 to L 75 the diagram shows the windward full-perireefal picture characterised by very high rotaliid diversity, medium- to low miliolid and low Textulariid diversity. Arenaceous Foraminifera very gradually and steadily increase towards the North, as well as soritids. Quinqueloculina quinquecarinata, characterising the deeper, open shelf, reaches about 10% in L 75. Among the Rotaliina, Bolivina gr. and Reussella are important together with Cibicides (and allies) and Operculina characterising the muddy Halimeda - sediments. The sudden increase of Cymbaloporetta gr. may be the only significant indicator of the neighbourhood of the Lagoon Entrance (cf. L 77, trav. 14).

From L 75 onward towards the N, the traverse is more and more influenced by the accumulation effect upon the shelf bottom between Lizard Island and Sandbank Reef. Arenaceous Foraminifera further increase steadily, reaching a maximum of about 20% at L 54 (cf. the L 50 peak, trav. 14). Miliolina remain almost steady, with a slightly increasing importance of soritidae and Quinqueloculina neostriatula (the form with compressed chambers). Importance of rotaliids remains almost unchanged; L 71 is characterised by a sudden increase of Reussella and discorbidae, decreasing again towards the N (this may eventually be a Lagoon Entrance - related phenomenon). Cibicides and sessile allies remain constant in the muddy Halimeda - environment but decrease towards the N. Operculina remains more or less constant and shows a peak in the N. (L 54). From L 71 onward towards the N, Amphistegina gradually dominates Rotaliina with frequencies up to 20% and more (effect of superposition of in situ produced tests with material derived from Lizard and Sandbank Reef Complexes).

The leeward part of the traverse being at considerably greater distance from the main island than traverse 14, the leeward accumulation effect is shown to act inversely upon the thanatocoenoses as was the case in trav. 14 which passed through much shallower water. Arenaceous Foraminifera slightly decrease from L 54 to L 98; Miliolina decrease considerably, from more than 45% in L 106 to 20% in L 98; the corresponding increase in rotaliid importance is largely due to the striking increase in amphisteginids, from 10-15% in L 109 - L 54 to more than 35% in L 98.

The fragmentation curve of trav. 15 shows essentially the same trends as the corresponding curve of trav. 14. From L 90 to L 54 in the N the curve shows almost the same dominances as the corresponding section of trav. 14, though extended over a greater distance. It is to be noted that, due to tidal current drift and bottom currents in a leeward direction, a leeward displacement of corresponding features can be seen in the fragmentation curves as well as the cumulative diagrams, at least in the E and NE areas. As an example of this phenomenon the extension of the influence of the Lagoon Entrance can be traced in the fragmentation curves of travs. 14 and 15; in trav. 14 this influence is expressed in a drop of identified tests and fragments between L 82 and L 77, i.e. in front of the Lagoon Entrance; in trav. 15 a corresponding drop is to be found between L 75 and L 71 - L 67, i.e. more to the N.

As a rule, relative importance of unidentified tests is greater in trav. 15 than in trav. 14, which can be interpreted as a progressive decrease of the influence of the reef complex paralleling increasing distance.

The only notable divergence between the fragmentation curves of travs. 14 and 15 is to be found in the NW section; as trav. 15 is located considerably more to seaward, in an area where the leeward accumulation is less than closer to the coast, the curve remains more or less on the level of L 54, hardly drops down towards L 109 - L 106 towards L 98 where full-perireefal conditions prevail.

CHAPTER 4

INTERPRETATIONS AND CONCLUSIONS

While chapter 3 pursuits in the first place the raw data about the distribution of Foraminifera, chapter 4 deals with the generalised distributional trends which can be distilled out of these data. Causes and effects will be discussed, and some particular topics will be lifted out of the general context, and commented. Finally a summary of data and interpretations leads towards a general conclusion of this work.

4.1. Diversity

"Diversity is the relationship of the number of species to the number of individuals in an assemblage. If all assemblages comprised the same number of individuals, the numbers of species could be compared directly." (MURRAY, 1973). Diversity thus could be said to be an expression of the abundance or scarcity of species in a given sample, and by comparison of samples, in a given biotope or thanatotope.

Fig. 27 shows that both bio- and thanatocoenoses fall apart into three classes :

- A low-diversity class ($T < 50$ resp. 100) comprising mainly intertidal to slightly subtidal, windward reef surface and backreef systems (fringing reef, Windward and Southern Barrier systems, Internal Platform, Sandy Shoal).
- A medium-diversity class (biocoenose $50 < T < 100$, thanatocoenose $100 < T < 150$) comprising deeper subtidal units up to -10, -15 m (Lagoon, Patchreef Area comprising Leeward Slope samples up to - 10 m).
- A high-diversity class formed by the Perireefal Area with biocoenose $T > 100$ and Thanatocoenose $T > 200$.

The numbers of species belonging respectively to the three suborders Te, Mi, Ro obviously follow grosso modo the same trend as the total T numbers. These suborder fluctuations are visualised in the triangular diagrams (see below).

- Fisher- α index : Following MURRAY (1973, 1976) the Fisher- α index has been chosen here (excluding other indices, e.g. the Yule-Simpson index) as a measure of diversity (FISHER, CORBETT and WILLIAMS, 1943) :

$$\alpha = \frac{n_1}{x}$$

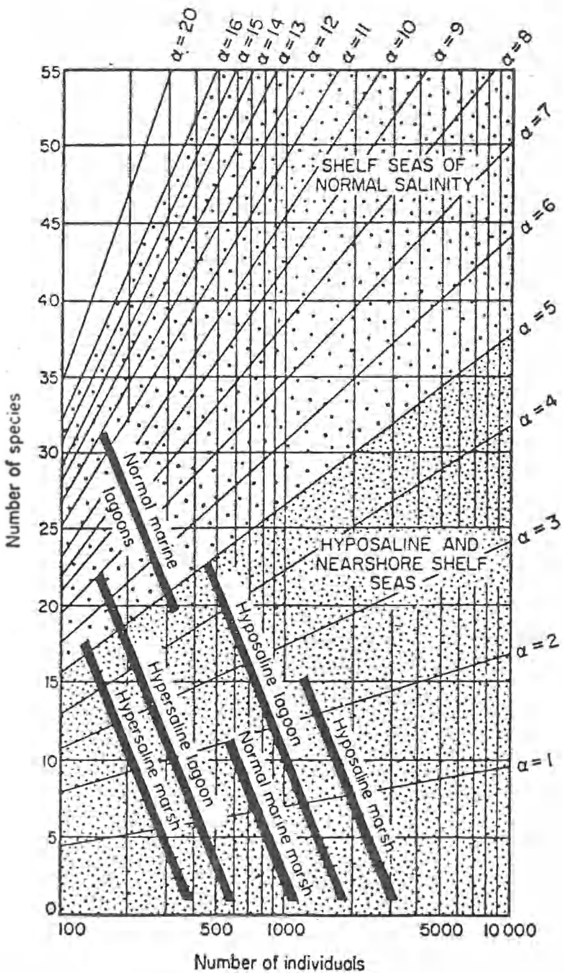
	Coconut Reef		Windward Barrier		Southern Barrier	
	B	Th	B	Th	B	Th
T	25	70	31	67	21	48
Te	-	4	4	5	1	5
Mi	6	23	9	32	6	22
Ro	19	43	18	30	14	21
	Lagoon		Internal Flat		Sandy Shoal	
	B	Th	B	Th	B	Th
T	53	121	16	50	37	67
Te	5	11	1	4	4	6
Mi	23	52	10	25	13	34
Ro	25	58	5	21	20	27
	Patchreefs		Perireefal Area			
	B	Th	B	Th		
T	72	128	108	209		
Te	7	11	16	22		
Mi	25	63	38	83		
Ro	40	54	54	104		

Fig. 27 : Numbers of foraminiferal species in bio- and thanatocoenoses from the respective reef units and the Perireefal Area at Lizard Island.

Legend : B = Biocoenose,
Th = Thanatocoenose,
T = Total number of species,
Te, Mi, Ro = Numbers of Textulariina, Miliolina, Rotaliina.

where x is a constant having a value less than 1 and n_1 can be calculated from N (1-x), N being the size of the population."

The index does not need to be calculated for each sample, as the α-value can be determined by plotting the number of species against the number of individuals upon the logarithmic base graph.
There exists a minor tendency for α to increase with sample size. Nevertheless, this diversity index is very easy to use and produces useful results.



Summary of the range of diversity in different environments.

Fig. 28 :
Generalised ranges of foraminiferal diversity expressed as values of the Fisher Index (from MURRAY, 1973).

Fisher- α indices for the Lizard Island samples :

Figs. 29 to 32 show the Fisher- α indices for the examined samples, arranged into four groups reflecting the physiographic situation of the sampling stations. A first graph shows the samples from the Fringing - and Barrier Reef

System, a second groups the mainly shallow backreef samples, a third graph shows the Lagoon sample indices and a fourth graph groups all perireefal samples.

Notice : The logarithmic base-graph provided by MURRAY (1973) (slightly modified in fig. 32) has been used to plot the Fisher- α diversities. As the quantity of material used for thanatocoenose counts is variable (see chapter 1), the numbers of individuals have been standardized to 1 gr dry sediment $>$ 74 µm grain size standard. The advantage of this procedure is that samples are plotted on an equal base and that, apart from diversities, sample richness can directly be read from the graphs.

Samples containing less than 100 specimens/gram have been omitted as these do not fit into MURRAY's graph. All of these (few) omitted samples have very low diversities.

1) The Fringing- and Barrier Reef System (Fig. 29)

There is a diversity gradient from forereef to backreef. Samples from the Algal Pavement and sandy - gravelly tidal channels and sandpockets show lowest values (e.g. L 261, L 266, L 263) and are generally poor (placed at the left of the graph). As a rule, α -diversities increase towards the backreef where the first leeward accumulation phenomena can be witnessed, superimposed upon the comparatively high production of the algal coats with α values between 3 and 5. Some beach samples show high abundance - low α values (e.g. L 241, L 252) whereas a few subtidal samples from the backreef area of the Windward Barrier show much higher α values (L 353, L 254) up to 12-15.

2) The Shallow Backreef system (Fig. 30)

Sandy Shoal samples show relatively high α values between 5 and 12. Samples from the vicinity of the Narrow Pass (tidal channel) show highest values, samples near the beach (e.g. L 146) lowest.

Internal Flat samples show α-values between 4 and 11. The lowest values were found in samples from marginal, leeward areas (e.g. L 161), the highest values in samples from the central area with an algal coat (e.g. L 170).

Almost all patchreef samples show α -diversities higher than 5, with the exception of L 161 and L 157 (near-beach of tidal current-swept sandy areas). Samples located far leeward, in deeper water (L 100) show highest α-values

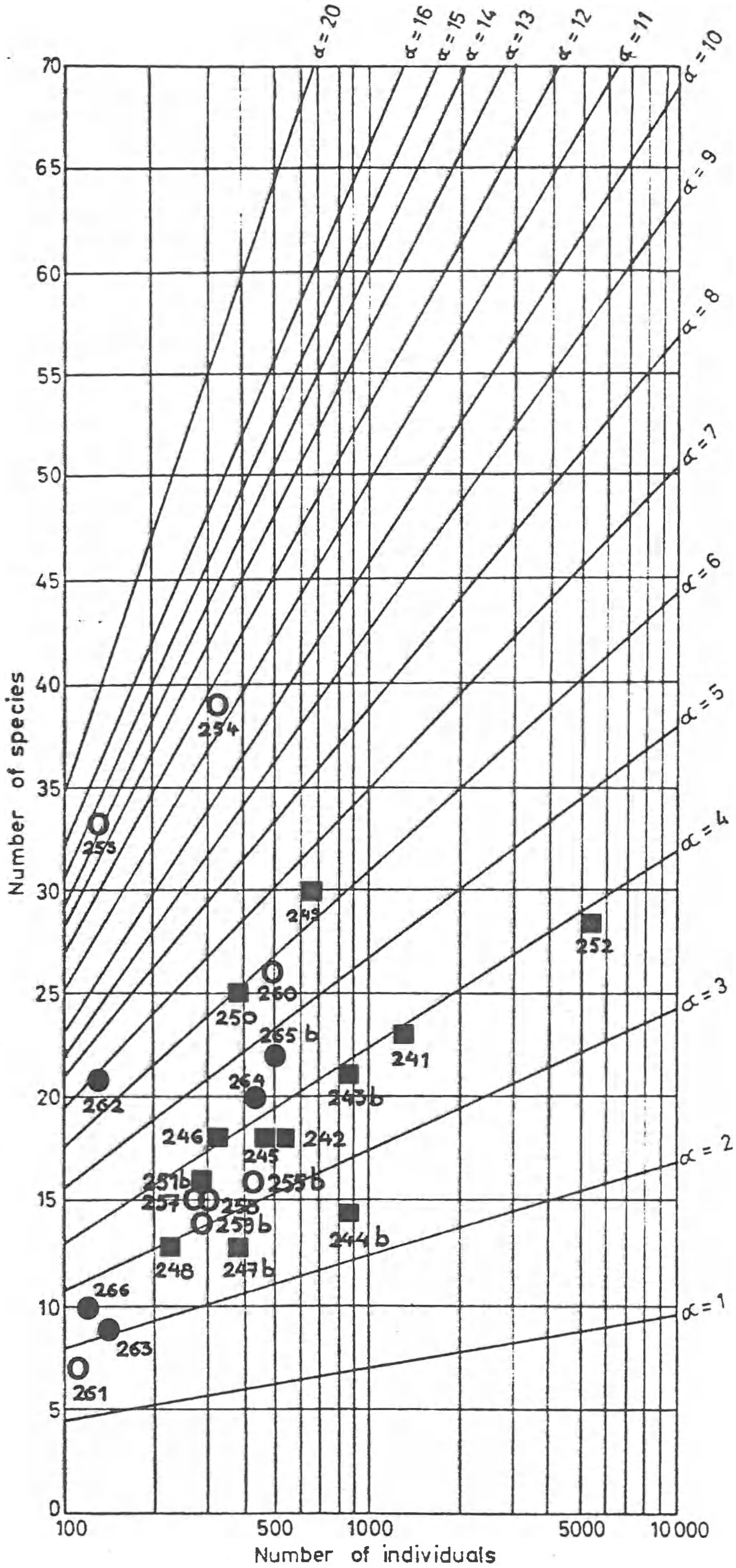


Fig. 29 : Fisher- α diversity indices for samples from the Fringing- and Barrier Reef System.

Legend : Black squares = Coconut Fringing Reef samples; open circles = Windward Barrier samples; black circles = Southern Barrier samples.

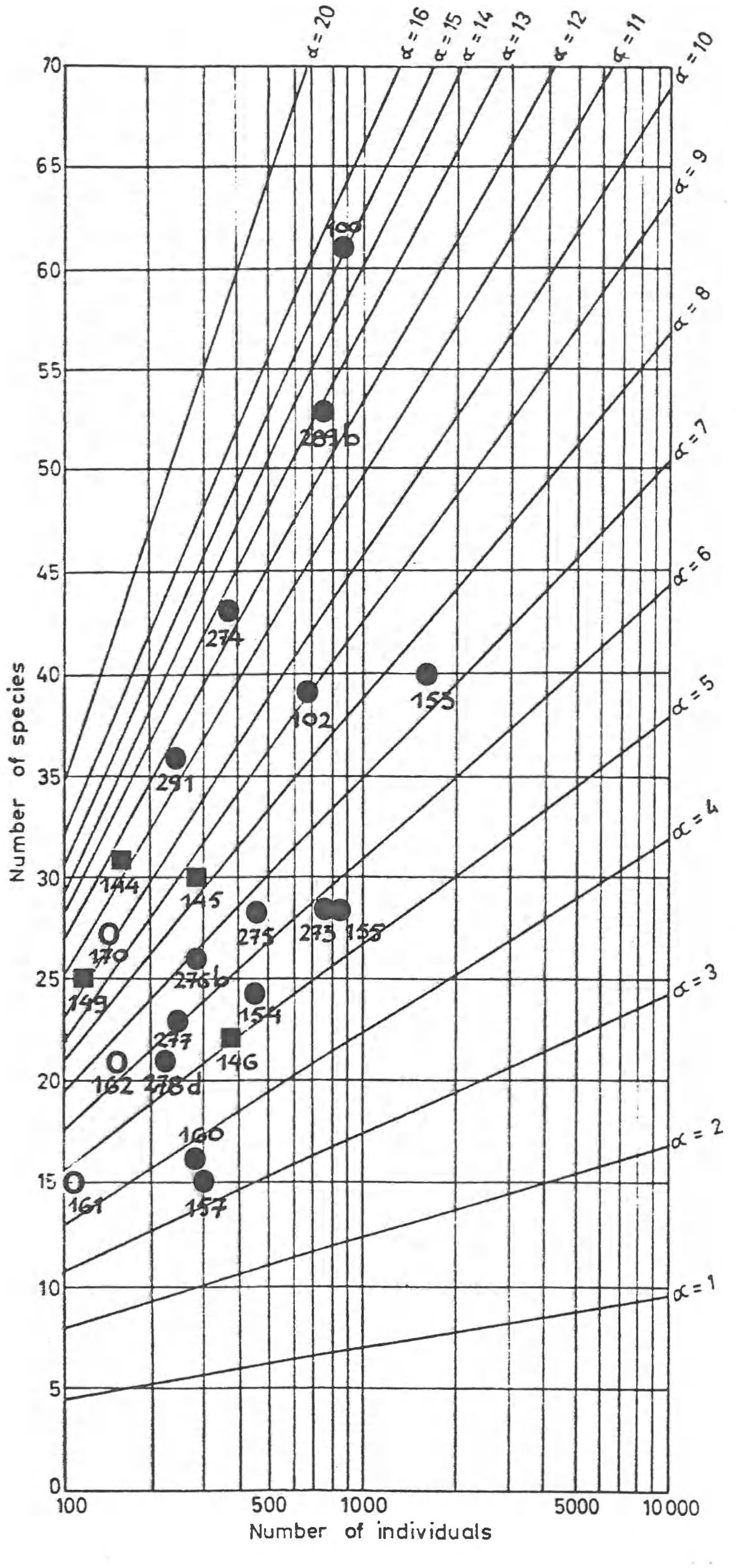


Fig. 30 : Fisher- α diversity indices for samples from mainly shallow backreef environments.

Legend : Black squares = Sandy Shoal samples; open circles = Internal Flat samples; black circles = samples from Patchreef Area.

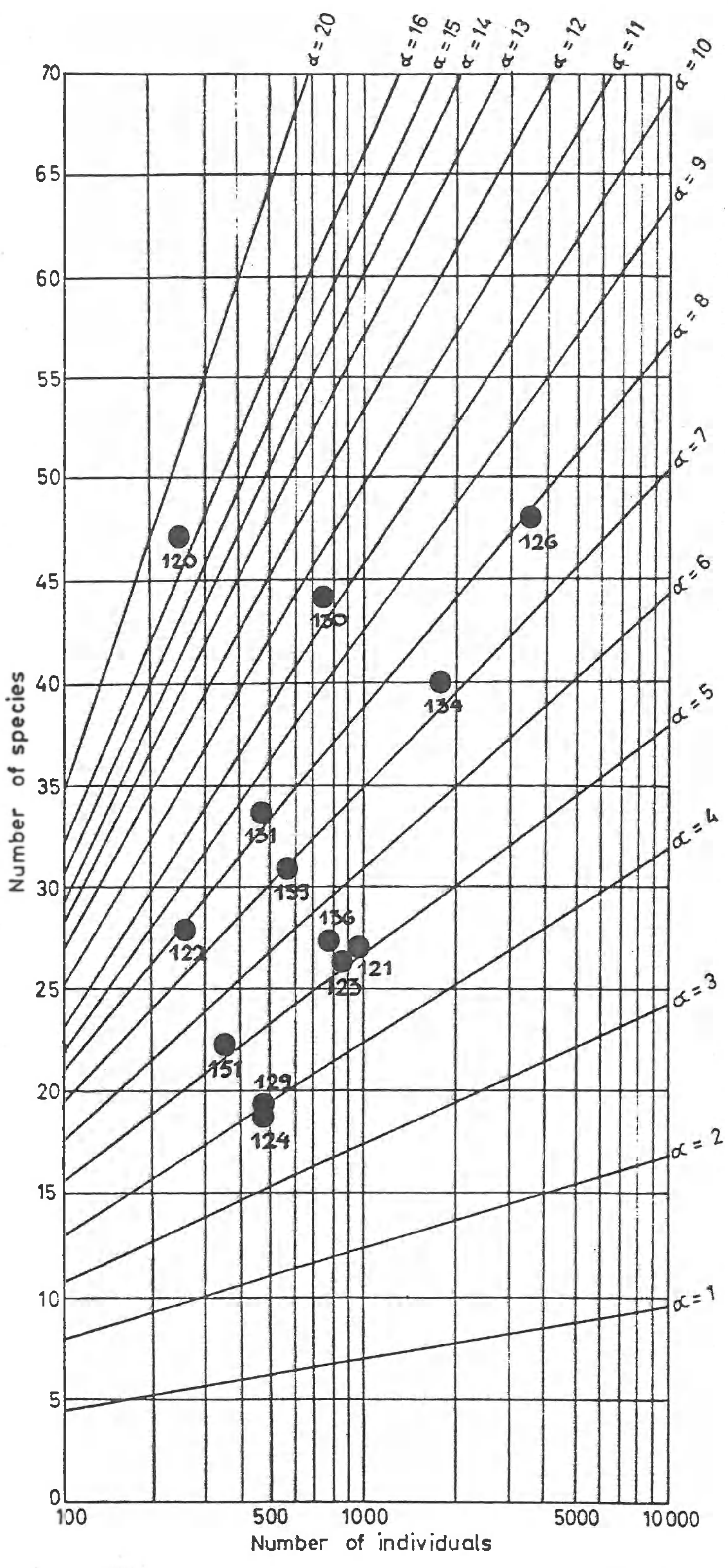


Fig. 31 : Fisher- α diversity indices for samples from the Lagoon.

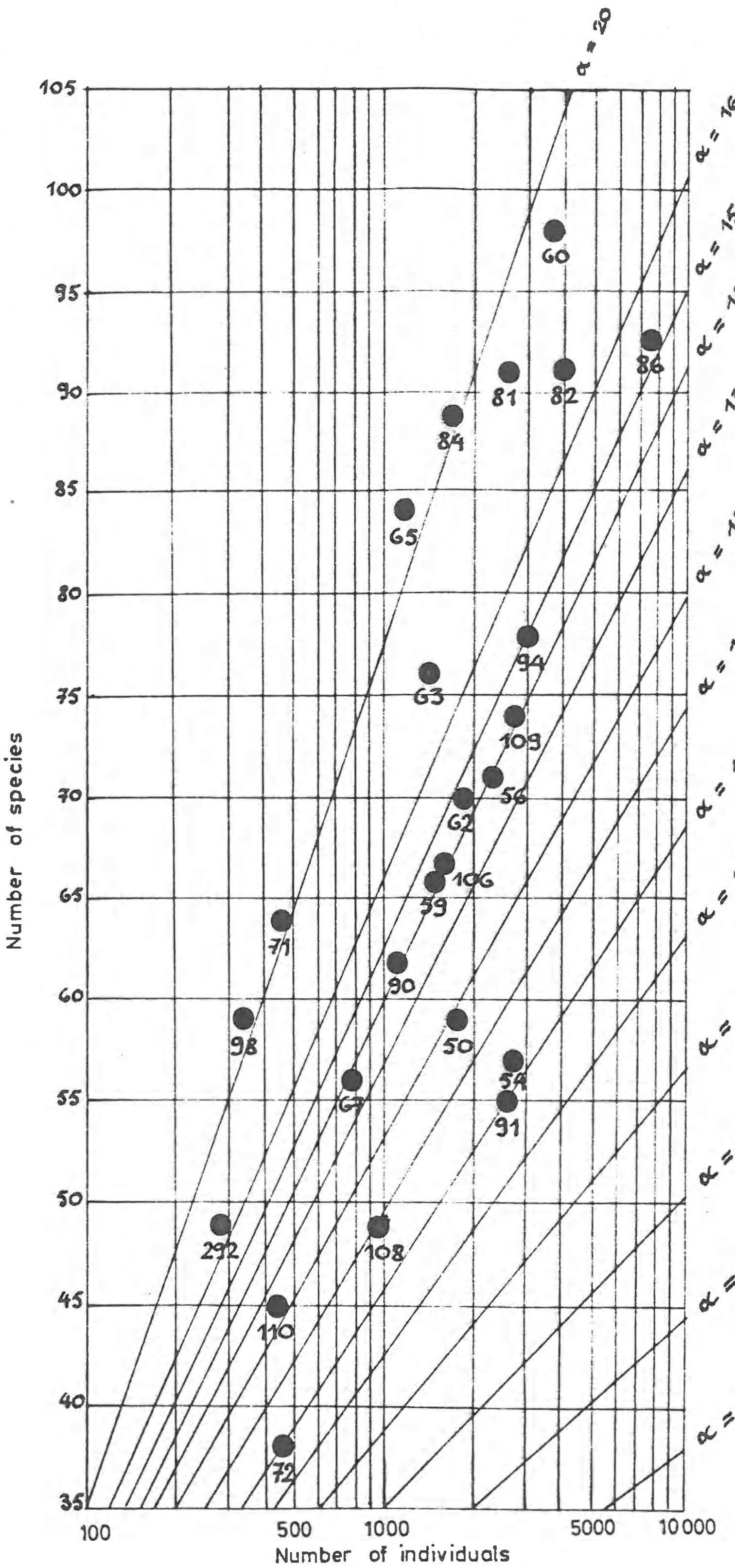


Fig. 32 : Fisher- α diversity indices for perireefal samples.

of perireefal affinity. Obviously, the most important factors influencing diversity are, again, depth and on the Western Slope:leeward accumulation effects.

3) The Lagoon (Fig. 31)

Diversity is apparently influenced by position of the sampling stations facing either recolonised fronts at leeward lagoon edges, or sandy slopes and drain channels in backreef areas. Highest α -values are to be noted for the samples at both NW and SW extremities of the Lagoon; L 120 (α = more than 16) is at the Lagoon Entrance and shows strong perireefal influence superposed upon an accumulation effect by reef flat-derived material (high Amphistegina-content). L 130 and L 131 on the contrary (α = 10 resp. 8) are from the SW lagoonal extension in the backreef area of the Southern Barrier and at the same time facing the recolonised front in the N, near Palfrey Island (superposition of accumulation effects). Lagoonal diversities are, as a whole, fairly well comparable with those of the Patchreef Area s.l. (+ Internal Platform and Sandy Shoal).

The depth range of both areas is comparable, limited to 10 m (more or less). Both areas are situated in a leeward backreef position and the accumulation effects are comparable : in the Lagoon, material derived from the windward reefs accumulates whereas in the deeper parts of the Patchreef Area accumulates material from the Internal Flat, the Sandy Shoal and the shallow reef patches.

4) The Perireefal Area (Fig. 32)

The higher diversities encountered in the SE (values over 16) are due to a combination of the factors depth, direct exposure to SE-NW trade wind drift and superposition of reef-complex-derived material. The last factor equally plays an important role in the NW (leeward slope) but as the seabed is shallower there, and at the same time cut off from the SE open marine influence, diversities are lower. Note that L 98 in the W, sufficiently distant from the main island, has again an α -value over 20.

5) Conclusion

α -Distributions in the respective main environments have been visualised in histograms (Fig. 33). For convenience, 5 α -classes have been distinguished, with boundaries at α = 5, 10, 15 and 20. The samples from the Lizard Island environments fall apart into three major diversity groups :

- A low-diversity group consisting of samples from shallow (intertidal) high- to medium energy, forereef to immediate backreef environments; reef flats and immediately adjacent areas of fringing - and Barrier reef systems. -Diversities show a distinct peak at values lower than 5.

- A medium-diversity group consisting of samples from all shallow, leeward backreef environments (depths from intertidal to about - 10 m), comprising Patchreef Area, Internal Flat Sandy Shoal and Lagoon. α -Diversities show a distinct peak between values 5 and 10.

- A high-diversity group consisting of samples from the Perireefal Area. α -Diversities show a distinct peak between values 10 and 15. Diversities lower than 10 do not occur whereas the presence of diversities higher than 15 or even 20 accentuate the shift towards high diversities in this environment.

4.2. Triangular plot

The relative percentages of the three foraminiferal suborders (Textulariina, Miliolina, Rotaliina) in the Lizard Island samples are plotted in fig. 35 according to the method of MURRAY (1973). For comparison, the summary triangular plot compiled by MURRAY (1973) showing generalised areas for major marine environments is reproduced in fig. 34.

The triangular plot, fig. 35 is based on 93 samples taken together in variously shaded areas according to their respective provenience from different environments. Most samples are concentrated along the Miliolina-Rotaliina side of the diagram; percentages of Textulariina are low except for some samples from the Perireefal Area (e.g. L 50 near North Point) and from the Lagoon entrance (L 120).

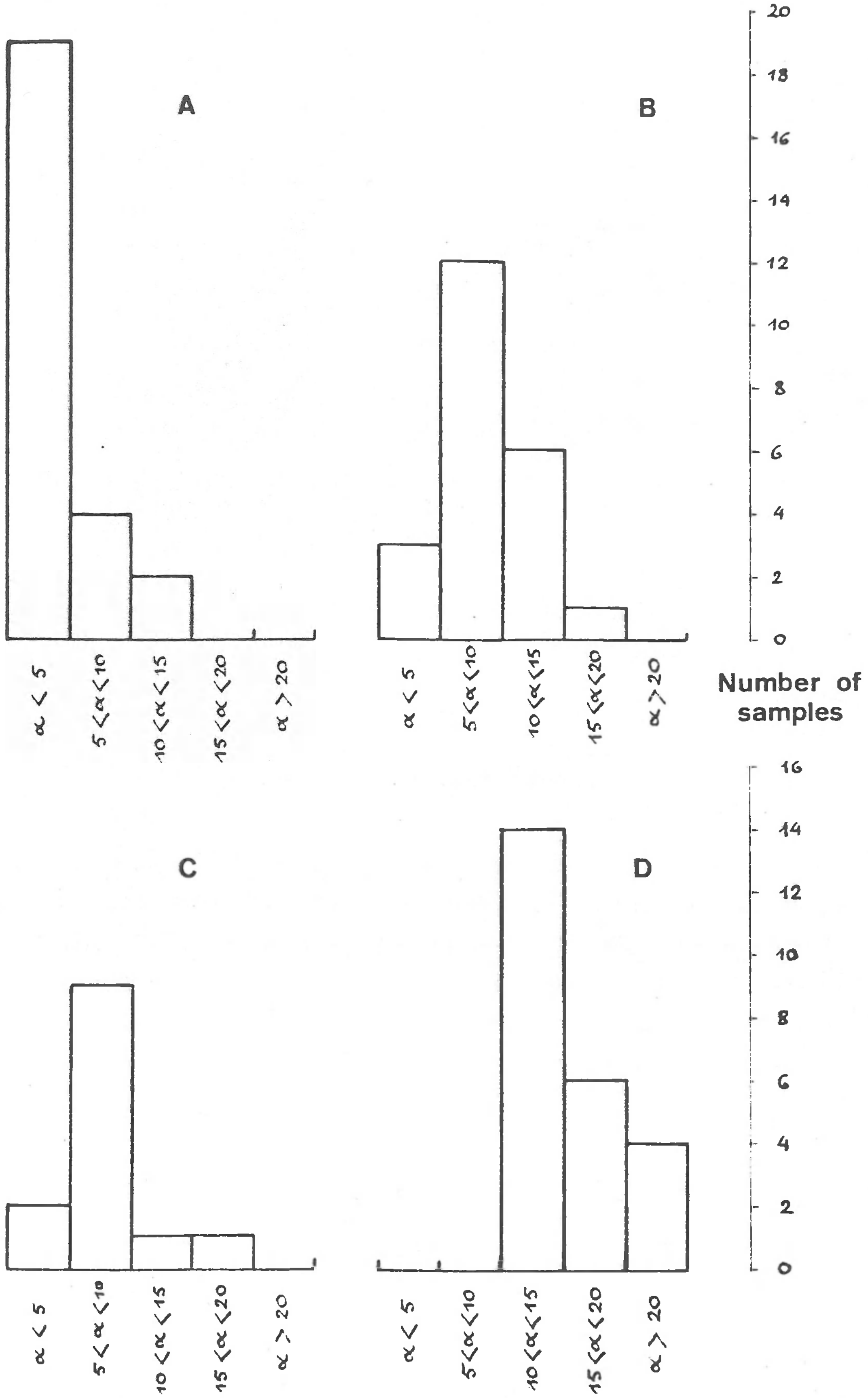


Fig. 33 : Distribution of α -diversities in histograms.
A = Fringing - and Barrier Reef System; B = mainly shallow backreef environments; C = Lagoon; D = Perireefal Area.

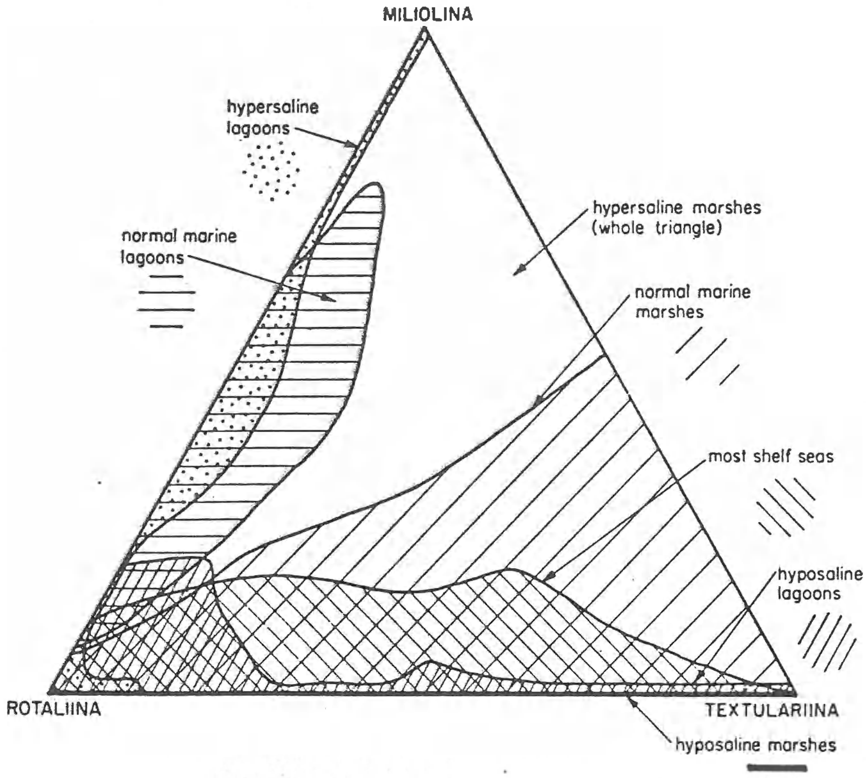


Fig. 34 : Summary triangular plot (from MURRAY, 1973)

- Samples from the fringing - and barrier reef system : Textulariina are less than 10%, Rotaliina vary from 50-55 % to almost 100 % and Miliolina are dominant with percentages from 80 to 100 %. The concentration of many samples in the Rotaliina-corner of the triangular plot might eventually be considered as a possible indication of (at least temporary) salinity fluctuations by evaporation upon the reef flats and near the beaches (compare to MURRAY, 1973).

- Samples from the Lagoon : Textulariina are below 10 % except for one sample at the Lagoon entrance (L 120).

- The samples from the shallow backreef environments (Sandy Shoal, Internal Flat, Patchreef Area) occupy almost the same area as the samples from the Lagoon. Nevertheless, two differences are to be noted : on one hand, samples from the Sandy Shoal extend far towards the Miliolina-corner along the Miliolina-Rotaliina side of the triangular plot, which may be an indication of (at least temporary) salinity fluctuations in the Sandy Shoal and along the southern beaches of Lizard Island. As the boundary of the Patchreef Area

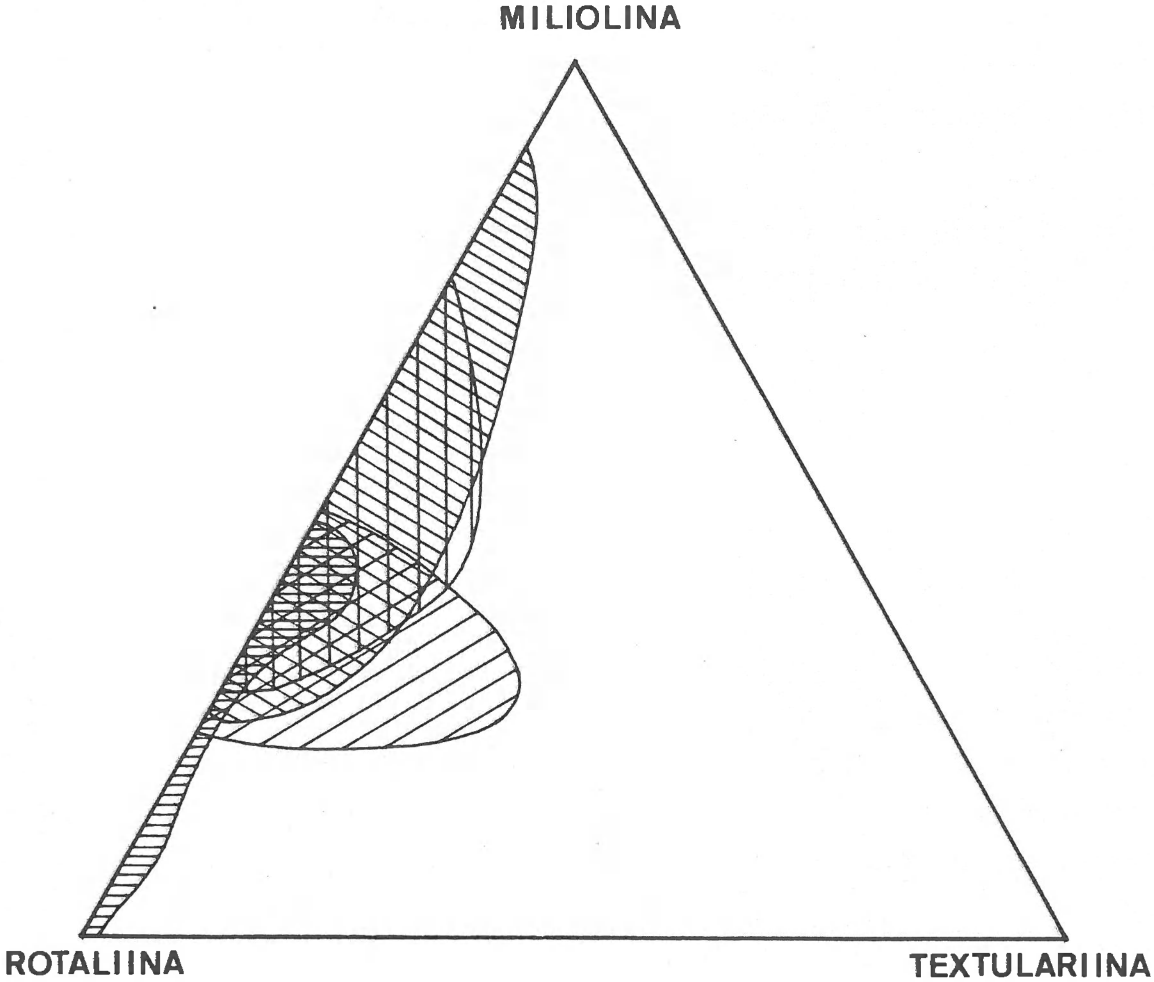
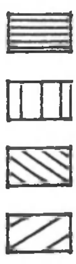


Fig. 35 : Triangular plot of the Lizard Island samples.



= fringing- and barrier reef samples

= lagoonal samples

= samples from the shallow backreef environments

= samples from the Perireefal Area

has been arbitrarily fixed at the - 10 m isobath, it is normal that deeper patchreef samples from the leeward slope tend to increase their percentage of Textulariina with depth, though they generally contain more Miliolina than typical perireefal samples due to the leeward accumulation effects.

- Perireefal samples : occupy a well-confined area near the Miliolina - Rotaliina side, extending further towards the Textulariina - corner. Note the increasing amounts of Textulariina in the Northern and Northeastern Perireefal Area.

- Conclusion : The three environmental categories established on the basis of diversity can also be characterized by the relative proportions of the three main foraminiferal suborders :
1) the fringing- and barrier reef system,
2) the Lagoon and shallow backreef environments and
3) the Perireefal Area.

4.3. Characteristic Foraminifera in the thanatocoenoses

Species have been considered to be characteristic for a given environment on the base of their persistent presence and/or abundance in the thanatocoenoses, i.e. when they are present at least in half of the total number of samples from a particular environment. Species with high abundances in restricted parts of an environment, or in isolated samples, have not been regarded as characteristic.
Frequency and abundance of species can be read from the synoptic table, Annex 5.

The three main types of environment that could be separated from each other on the base of species diversity, each show distinguished associations of characteristic species. These associations allow an easy separation of high-energy, oxygen-rich forereef or open sea environments versus low-energy, protected, oxygen-poor backreef environments.
The results are grouped in fig. 36.

Fig. 36 :

(1) = Fringing- and barrier reef system,

(2) = Lagoon,

(3) = shallow backreef environments,

(4) = Perireefal Area.

- <u>Fringing- and Barrier Reef System</u> (reef flats) :

The three reef flats Coconut Reef, Windward Barrier and Southern Barrier are grouped in this category.
Depth : intertidal to slightly subtidal.
Number of stations : 26
Remark : eventual salinity fluctuations on the reef flats and near the beaches.

- <u>Lagoon</u> :

Depth : subtidal (- 4 m to - 17 m)
Number of stations : 13
Remark : normal salinity.

- <u>Shallow Backreef Environments</u> :

In this category are grouped the Sandy Shoal, the Internal Flat and the Patchreef Area.
Depth : intertidal to subtidal (- 10 m)
Number of stations : 26
Remark : salinity normal except eventual fluctuations on and near Sandy Shoal and Internal Flat.

- <u>Perireefal Area</u> :

Depth : - 10 m to - 32 m
Number of stations : 26
Remark : salinity normal.

Species exclusively characteristic for one out of the four environments are indicated by an asterisk (x) in fig. 36.

Characteristic species in the order given by systematics	(1)	(2)	(3)	(4)	
Textularia foliacea oceanica					
Textularia agglutinans					x
Textularia barkeri					x
Textularia candeiana					x
Textularia pseudogramen					
Textularia pseudogr. kerimbaensis					x
Quinqueloculina neostriatula (infl.)					
Quinqueloculina neostriatula (angul.)					x
Quinqueloculina oblonga s.s.					
Quinqueloculina oblonga incisa					
Quinqueloculina poeyana carinata					
Quinqueloculina montyi					
Quinqueloculina anguina arenata					x
Quinqueloculina crassicarinata					
Quinqueloculina granulocostata					x
Quinqueloculina lamarckiana					
Quinqueloculina pittensis					
Quinqueloculina pseudoreticulata					
Quinqueloculina quinquecarinata					x
Pseudomassilina australis s.s.					
Spiroloculina communis s.s.					x
Triloculina trigonula tricarinata					
Hauerina pacifica					
Hauerina circinata					
Pseudohauerina occidentalis involuta					x
Miliola sublineata					
Schlumbergerina alveoliniformis					
Peneroplis pertusus s.s.					
Peneroplis pertusus planatus					
Sorites marginalis					x
Amphisorus hemprichii					x
Marginopora vertebralis (cren. form)					
Marginopora vertebralis (flat form)					x
Alveolinella quoyi					x

Characteristic species in the order given by systematics	(1)	(2)	(3)	(4)	
Spirillina vivipara - revertens					
Bolivina spinea					
Brizalina striatula					
Mimosina echinata					
Reussella simplex					
Neoconorbina terquemi					
Poroeponides lateralis cribrorepand.					
Glabratella patelliformis					
Amphistegina lobifera					
Amphistegina lessonii					x
Amphistegina cf. papillosa					x
Cibicides aravaensis					
Cibicides lobatulus					
Cibicides cf. pseudolobatulus					
Cymbaloporetta gr. bradyi					
Cymbaloporetta squammosa					
Ammonia tepida					
Ammonia convexa					
Calcarina spengleri s.s.					
Calcarina spengleri mayori					x
Baculogypsina sphaerulata					
Parrellina hispidula					
Elphidium advenum s.s.					
Elphidium craticulatum					x
Elphidium crispum					
Elphidium limbatum					
Elphidium poeyanum					
Operculina ammonoides					x
Nummulites cumingii					
Heterostegina depressa (invol.)					
Heterostegina depressa (evol.)					x
Loxostomum (?) limbatum					x
Nonion (?) gr. scaphum					
Planctonic Foraminifera					

4.4. Variations in test shape, test thickness and test wall thickness with depth

Whereas trials to relate foraminiferal shell form to sediment type already date from the fifties (see e.g. FREYDANCK, 1955; HENDRIX, 1958), changes in test shape related to water depth have repeatedly been observed and commented on by an increasing number of authors during the last decade (REIS & HOTTINGER, 1984, with bibliography). It is suggested in these articles that the patterns of depth distribution in a number of foraminiferal species, as well as test morphology (evolute - involute) and test thickness (e.g. amphisteginids from the Gulf of Elat) are related to endosymbionts and light intensity available in the habitat. Thick-walled and/or involute shells seem to absorb or reflect more light than do thin-walled and/or evolute tests whereas structural devices such as papillae in Amphistegina papillosa may be considered as devices to concentrate light (HANSEN & BUCHARDT, 1977). The trends described in the literature cited above have been observed in our Lizard Island material as well. A commented enumeration follows :

- Suborder Textulariina :

Genus Nouria : It might be possible that Nouria polymorphinoides and Nouria textulariformis armata would only represent depth variants, N. polymorphinoides would then be the compressed deeper-water form.
Genus Textularia : T. foliacea - T. foliacea oceanica : These two subspecies obviously represent depth variants. T. foliacea oceanica is the thick-walled, inflated shallow-water variant which is gradually replaced towards the deeper perireefal waters by the compressed, thinner-walled T. foliacea s.s..
This depth dependant variability of agglutinates is difficult to explain as they have no symbionts and no lamellar calcification mechanism (as far as known today). Nevertheless, as the variability is evident (particularly in the case of T. foliacea) it must be admitted that an unknown biological mechanism is involved in the depth adaptation patterns of agglutinates.

- Suborder Miliolina :

Genus Quinqueloculina : this genus yields a few exquisite examples of depth variants.
Quinqueloculina lamarckiana and its subspecies Q. lamarckiana queenslandica : These two subspecies are clearly depth variants, the queenslandica subspecies being the shallow-water variant frequently occurring upon the reef flats. This variant has developed a peculiar way to increase the chamber volume : the chamber edges are truncated instead of being sharp-angular as in the

lamarckiana s.s. subsp. which occurs mainly in the deeper waters of the Perireefal Area. These two variants are good relative depth indicators.

Quinqueloculina neostriatula : This abundant species displays a very clearly depth-controlled variability. The shallow-water variant, present in all shallow environments of classes 1, 2 and 3 (Fig. 36), has inflated chambers whereas the deeper-water variant which abounds in the Perireefal Area shows chambers which are individually compressed to such an extent that they are sometimes almost keeled. These variants are very good relative depth indicators.

Genus Hauerina : The thick, inflated, solidly built Hauerina pacifica is characteristic of the shallow backreef environments; in the deeper perireefal waters it is replaced by the invariably thinner-walled, compressed, more evolute H. circinata, H. fragilissima and Pseudohauerina.

Among the soritids, the most obvious example is yielded by the two variants of Marginopora vertebralis while other cases hint at the same phenomenon : the intertidal - shallow water species Sorites orbiculus is also more irregularly-built and relatively thicker than its deeper-water equivalents Sorites marginalis and S. discoideus. Marginopora vertebralis abounds in intertidal algal covers where it shows very irregularly built, crenulated, plicated tests which are often fused as a result of overcrowding in the juvenile stages, whereas the deeper Perireefal Area invariably yields relatively thin, strongly flattened and regularly built specimens.

There is few mixture of the two variants as a result of post-mortem transport as the intertidal form, though large and thick, disaggregates before reaching the Perireefal Area.

These variants are good relative depth indicators.

- Suborder Rotaliina :

The case of Poroeponides lateralis s.s. and P. lateralis cribrorepandus has been described in Part 2 (taxonomy). The thick-walled, inflated cribrorepandus subsp. is obviously the shallow-water variant which is nevertheless frequently found in the Perireefal Area under the form of more or less abraded specimens as a result of post-mortem transport. The thin-walled, flattened and fragile tests of the lateralis s.s. subsp. though are restricted to the deeper water of the Perireefal Area.

The depth variability in the genus Amphistegina has been amply discussed in recent literature, mainly concerned with the Gulf of Elat (see REISS & HOTTINGER, 1984, for bibliography).

Our Lizard Island material,collected over a much smaller depth gradient (0 m - 32 m) shows a similar succession of species as the one in the Gulf of Elat, viz. A. lobifera characterising intertidal and shallow subtidal environments up to more or less - 10 m whereas A. lessonii, together with a papillosa-like form, exclusively occurs in depths greater than - 10 m. In the Gulf of Elat the lobifera depth range is from 0 to about - 40 m (!) (see HANSEN & BUCHARDT, 1977).

In the genus Heterostegina a comparable depth-conditioned variability is encountered : reef flats and shallow backreef environments are inhabited by a smaller, thicker, involute form lacking the development of large flaring chambers, whereas in the deeper perireefal waters the large, flaring form is found exclusively.

Conclusion :

No absolute depth ranges for species or variants can be established as the environmental conditions differ from place to place. In the Gulf of Elat water transparency is very good and light penetrance is very deep throughout the year, whereas at Lizard Island (and presumably the greater part of the Barrier Reef) water turbidity is very important, at least during the Winter months (Trade Winds) as I personally could find out while diving in clouds of suspended particles which considerably reduce light penetration. As a result it becomes comprehensible that the limiting light intensity barriers lie much higher (30 meters !) in the turbid Lizard Island waters than in the Gulf of Elat.

Anyhow, if direct absolute applications are not yet within reach, we ultimately have relative successions of foraminiferal variants, or taxa, or shape tendencies at hand (REISS & HOTTINGER,1984). When these relative scales are established on a larger scale, the palaeobathymetrist will dispose of very valuable tools which surely will be applied more consistently on fossil material than it used to be the case up to now; this has important bearing on stratigraphical successions.

4.5. Note on ecovariability and morphology - substrate relationship

The characteristic faunas in relation to algal-microbial substrates have been described in the preceding chapters. BRASIER (1972, 1975, 1976) has amply discussed the ecophenotypic adaptational patterns and the relationships between morphology and substrate of a number of benthic Foraminifera (mainly smaller miliolids) from the reefs and shoals of Barbuda (West Indies, Atlantic). Although comparisons between BRASIER's findings and ours appeared to be very promising when this study was initiated, I was subsequently led to abandon any further attempt to devise a generalised scheme comparable with BRASIER's one. The reasons are as follows :

1) The study of the Lizard Island environments gradually convinced me of the fact that a strict separation claimed by BRASIER (1976) between his phytal (algal) substrates - sediment substrates - mixed sediment substrates (mixture of sediment with algal particles) and their respective characteristic fauna's and test morphologies is not of much use to understand our Lizard Island material. A sediment substrate of BRASIER's conception was not found at Lizard Island. Careful observation (in situ as well as of undisturbed samples) revealed the presence of almost continuous microbial coats consisting of cyanobacteria (algal-cyanobacterial coats)except where recent bioturbations had taken place. Sampling by hand disturbs this coating in most cases; algal particles are mixed with the sediment. This phenomenon probably lies at the origin of BRASIER's "mixed sediment substrates". Nevertheless it is mainly the presence of the microbial coating which determines the presence-absence, and likely the (apertural) morphology of a number of Foraminifera, and not the nature of the substrate as such.(This is true for epifaunal species; infaunal or epiphytic forms are less dependant of cyanobacteria in the coats as these coats also contain diatoms and many other organisms).

The underlying substrate may vary from cobble and shingle,mollusc remains, reef rock, to medium-grained and even fine sediment, but as long as a particular type of cyanobacterial coat is present, covering these different substrates in a continuous layer, the foraminiferal fauna which this coating supports will be unaltered. 2 Cases will serve as an example :

- Marginopora vertebralis is generally considered as an epiphyte and is, at Lizard Island, found on Halimeda - dominated algal-cyanobacterial coats. Nevertheless, clumps of living Marginopora have been observed also on finer microbial coats covering shingle, calcareous debris and coarse sand.

- Cibicides lobatulus and allied taxa (C. pseudolobatulus, C. aravaensis, Caribbeanella elatensis) are generally considered to be fixed on solid substrate, even in temperate seas (e.g. MURRAY, 1971, etc.). In the Lizard reef complex environments these taxa are found on the big thalli of the perireefal *Halimeda* - meadows; the foraminifers firmly adhere to the surfaces of the thallus segments of the algae but it is not clear whether they continue to do so after the eventual destruction of the algal thallus and its falling apart into separate (broken or not) segments. Are these *Cibicides* to be considered as epiphytes, or hard surface dwellers ? And in the latter case, is there a relationship with the fine microbial coating covering the sediment consisting to a high degree of these fragmented *Halimeda*-flakes ?

The particular relationship between the foraminiferal epifauna and the microbial (cyanobacterial) coating which is often present upon otherwise barren sedimentary bottoms as well as upon diverse bottoms covered with *Halimeda* - dominated algal growth, appears to be the pertinent and crucial link between "foraminiferal substrate" and epizoan "foraminiferal distribution"; indeed, as to MONTY (oral communication, 1986) this microbial coating on one hand represents food for the epizoan foraminifers and procures at the same time a sizeable holdfast for epizoan foraminiferal pseudopodia; on the other hand the cyanobacteria release toxines which exclude non adaptive taxa unable to cope with these metaboles.

4.6. Summary and final conclusions

(1) The inventory of recent Foraminifera of the Lizard Island Reef Complex and surrounding Perireefal Area yielded over 200 species and subspecies. A few ones have been described as new to science. All taxa are described or/and commented upon as well as illustrated by means of SEM-photographs (see parts 2 and 3 of this study).

(2) A first approach towards understanding the distributional patterns, was devoted to a comparison between living/dead populations. In shallow environments (reef flats, Lagoon, Patchreef Area) direct observation of the living foraminifera and their algal/microbial substrate was possible; elsewhere, the Bengal Rose staining method has been used.

For each environment a comparison between living populations and thanatocoenoses was made on a semi-quantitative basis. Notwithstanding the restrictions inherent to the methods used and to the restricted, one-season sampling, it could be demonstrated that the living Foraminifera associations, though being poorer and generally more patchily distributed than their dead counterparts, did not show significant differences with the thanatocoenoses. Post-mortem transport, though sometimes evident in the case of larger, solidly-built tests such as Amphistegina, Calcarina, Baculogypsina, is generally restricted; burial by bioturbation, reworking and fragmentation seems to take place near the production area; only the final small sized, products of (bio)erosion migrate steadily and massively in a leeward, backreef (NW) direction. This skeletal debris, mainly smaller than 125 µm, contributes to the finer sediments in the W and NW of the main island (leeward slope), as well as to the badly sorted sediments on the Southern and Southwestern beaches of Lizard Island.

(3) Ecovariability within the perimeter of the study area is high and the interrelationships between test morphology and substrate do not necessarily confirm BRASIER's (1972, 1976) strict separation between sediment-, mixed-sediment-, and phytal foraminiferal associations.

(4) Foraminiferal counts in thanatocoenoses have been carried out on about 100 samples covering the major reefal environments as well as the Perireefal Area of the shelf surrounding the reef complex. The results are depicted in circular diagrams (see Annex 1) showing relative contributions of the species in the samples per gram of dry sediment $>$ 74 microns.

These data have been used for the compilation of 15 cumulative traverses showing the variances of foraminiferal faunas in all environments of the reef complex and the Perireefal Area; some of these can partly be compared with the echosounding tracks (Annex 4). Moreover, parallel with these cumulative traverses, the variances in the relative proportions of identified forams-fragments-unidentified fragments have been plotted in continuous cumulative percentual curves (called here the "fragmentation curves"). It has been demonstrated that the fragmentation curve is a tool faithfully reflecting the overall granulometric patterns of the area; as such it fulfils the need of a rapid visualisation of the main dynamic trends throughout the study area (e.g. dominance of production vs. dominance of deposition).
The cumulative traverses illustrate the variations of the major foraminiferal associations in the different environments of the reef complex. In the thanatocoenoses of the Perireefal Area the influence of the reef complex faunas rapidly diminishes with increasing distance from the reef complex sources.

For each species, the quantified thanatocoenose data have been plotted (together with the semi-quantitative biocoenose data) in a synoptic diagram (in Annex 5). Foraminiferal diversities per sample were plotted on MURRAY's (1973) logarithmic base-graph and could be compared with MURRAY's reference graphs.

(5) The link between test shape and test wall thickness with water depth is a phenomenon observed in all three foraminiferal suborders. These examples are commented upon and illustrated (SEM-photographs, Atlas, Part 3). As a rule, it can be said that taxa producing depth-conditioned variants tend to produce thick, or irregular, inflated, thick-walled, involute tests in shallow water and flattened or compressed, thin-walled, fragile, evolute tests in deeper water. The registration of this variability may be helpful in the establishment of relative depth scales.

(6) Integrating points 1-5 allows the grouping of the different environments with respect to foraminiferal associations into a shallow, intertidal, high-energy environment (reef flats), a shallow, intertidal to subtidal low-energy backreef environment and a deeper open-sea environment. The second setting can be divided into two sub-environments which are distinguishable on the basis of sedimentology, characteristic foraminifera and diversities (Fig. 37).

1) Fringing - and Barrier Reef System : reef flats and shallow backreef areas (and to some extent forereef terraces) of the NE fringing reef, Coconut Reef, the Windward Barrier and the Southern Barrier. Depth : intertidal to shallow subtidal.

2a) Shallow Backreef environments : comprising the Sandy Shoal and adjoining beaches, the Internal Flat and Patchreef Area with adjoining beaches : the low-energy backreef area. Depth : intertidal (beaches and near-beach areas of the Patchreef Area) to subtidal (- 10 m, leeward protected slope).

2b) Lagoon : Low-energy, backreef area. Depth : subtidal (down to - 15 m).

3) Perireefal Area : Open sea, inner part of Marginal Shelf. Strong tidal currents and Trade Wind drift. Depth up to - 34 m.

(7) In (6) it has been made clear that the foraminiferal associations at Lizard Island fall apart into a few groupings determined by their corresponding environmental settings. A first approach towards explaining these groupings in environmental terms would be to investigate the influences water depth and -energy. This, however, yields only a distorted and incomplete conclusion : it is necessary to trace the hierarchy of the ecological parameters responsible for the existence of the different foraminiferal associations.

- Tectonic, paleoclimatological and paleohydrological events shaped Lizard Island, a granite basement in dynamic equilibrium with the growing coral reef. This island stands at the inner margin of the Marginal Shelf where water depths do not exceed 45 m. Expected foraminiferal associations will thus be neritic.

Fig. 37 : Distribution of foraminiferal associations.

= Fringing- and Barrier Reef association

= Shallow backreef association

= Lagoonal association

= Perireefal association

- The interaction between the terrigenous basement, the emplacement of the main reef structures following eustatic levels in Quaternary times, and the recent climatological circumstances result in the present - day shape of the reef. The SE Trade Winds are responsible for a predominantly SE - NW surface drift transporting well- oxygenated and nutrient-rich waters towards the steep reef fronts which are mainly oriented SW - NE. This results in a high-energy forereef situation in the SE and a lower to very low backreef situation in the greater part of the reef complex. The vegetation cover is hardly affected by this energy gradient, at least in intertidal to slightly subtidal depths where the Halimeda cylindracea - dominated algal coat covers large areas and supports the characteristic shallow-water foraminiferal assemblage.

- Only in leeward subtidal backreef conditions cut off from the main impact of the SE - NW surface drift, the vegetation cover is considerably impoverished and often reduced to a cyanobacterial coat supporting the characteristic lagoonal and patchreef - epiphytal foraminiferal assemblages. These are joined by a number of infaunal species associated with the finer sediments ($< 125\ \mu$) of the central Lagoon and the Leeward Slope.

- The deeper Perireefal Area shows a particular and varied plant cover, associated with a cyanobacterial coat. Strong tidal currents sweep the sea bottom and nutrient - rich waters are transported from the SE. The rich deeper water, perireefal foraminiferal assemblage encountered here derives its particular characteristics of a richly varied fauna occurring in much shallower depths than e.g. in the Gulf of Elat (REISS and HOTTINGER, 1984), from generated turbidity which reduces light penetration.

- The major parameter affecting the foraminiferal assemblages is the presence or absence of suitable nutrients which, in turn, depends on the water circulation pattern and the presence of proper algal- and cyanobacterial coats. The cryptic algal- or microbial cover indeed may modulate the distribution of foraminiferal substrates by inhibiting the growth of given taxa due to production of toxines, and by enhancing that of others through release of recycled nutrients (MONTY, oral communication, 1986). The development of an algal cover favours the proliferation of an epiphytic foraminiferal fauna as it harbours great quantities of nutrients in the form of microorganisms (diatoms,nitrogen fixing cyanobacteria, etc.) and offers shelter and support for the pseudopodia.

- Thus the distribution of foraminiferal assemblages is influenced by a number of (interacting) environmental parameters of which the most influential ones are :

1) the availability of nutrients (as a consequence of the water circulation pattern and productivity;
2) depth (as a consequence of either light or water energy gradients or both);
3) light which would control foraminiferal diversity via algal substrates, photosynthetic activities of symbiontic green algae and perhaps via a number of unknown microbial biochemical processes.
4) The fourth parameter is the presence of cyanobacterial coats positively or negatively influencing the quality and the availability of proper nutrients and microhabitats.

These interactions are summarized below, Fig. 38.

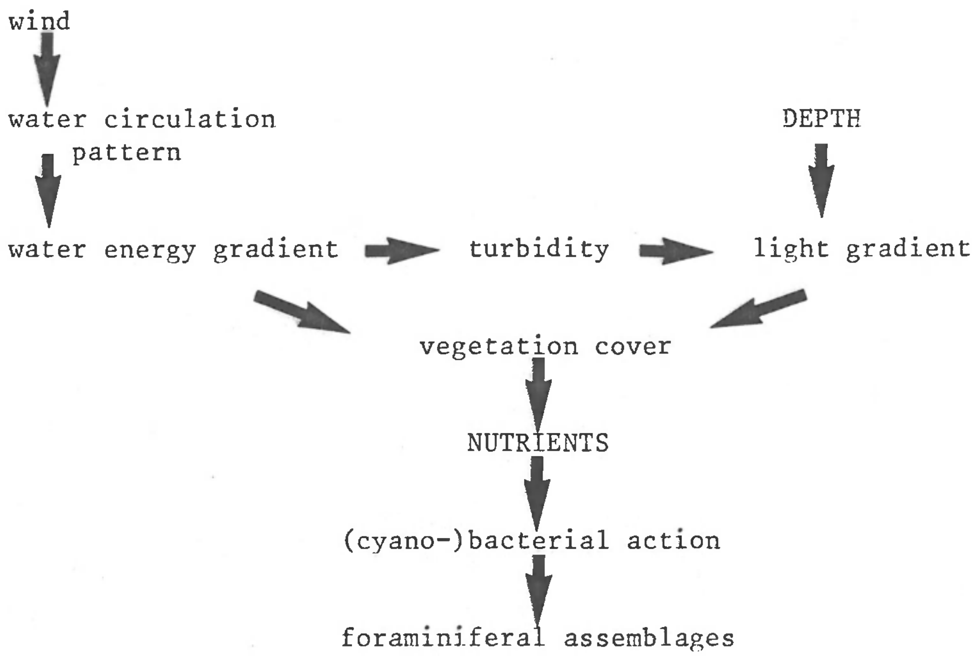


Fig. 38 : Interaction of environmental parameters affecting foraminiferal assemblages.

- Those who try to apply the present - day knowledge of foraminiferal distributional patterns to fossil material should be aware of the fact that the present state of knowledge about the interactions of physiological and ecological processes in the vegetation cover is not good enough to provide the paleoecologist with sufficiently reliable models suitable for large-scale

application. Available data are indeed much too incomplete to allow a generalised application to paleosystematics and/or stratigraphy. Attempts to delineate the range of (crypto-)biotic and (micro-) environmental interaction could therefore be considerably misleading. The setting up of workable syntheses, to be expected from multidisciplinary research already in progress, will doubtlessly result into new approaches to foraminiferal ecology.
Apart from the fact that these syntheses will, as a matter of course, encompass a much broader array of cryptic, biotic and environmental factors than can be achieved today, their repercussions upon paleoecology, stratigraphy and economic models promise to be revolutionary.

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LEGENDS OF PLATES

PLATE 1 : 1. Aerial view on the NE face, Crystal Beach and the NE fringing reef of Lizard Island.

2. View on the Lagoon Entrance,Bird Islet, the Windward Barrier and its reef flat, backreef shoals, coral pinnacles and staghorn coral forests, and transition towards the Blue Lagoon. South Island is at the right hand side in the foreground whereas the mainland (Cape Flattery) can be perceived in the background. North Direction Island and South Direction Island are visible at the horizon.

PLATE 2 : 1. Coconut Reef flat and -beach, NE side. Algal coat is dark grey, sandpockets and sandy channels are pale blue.

2. Coconut Reef flat; micro-atoll zone. Note hemispherical microatolls. Algal coat is dark grey.

PLATE 3 : 1. Coconut Beach, wave-sorting of foraminiferal tests. Marginopora-gravel is white, concentrations of Amphistegina - Calcarina - Baculogypsina tests are reddish.

2. Id, close-up of Marginopora-gravel consisting almost exclusively of empty Marginopora-tests with broken-out embryonic apparatus.

PLATE 4 : 1. Reef flat, Southern Barrier, algal flat covered with boulders of reef-rock. Algal coat can be seen in the foreground.

2. Id, close-up of algal coat (algal flat). Living Marginopora can be seen on the coat.

PLATE 5 : 1. Development of algal coat on the reef flat, Windward Barrier; transition rubble zone - microatoll zone. Algal - cyanobacterial coat shows a greyish-black colour against the pale blue colour of the sandpockets.

2. Algal-cyanobacterial coat around a sandpocket; reef flat,microatoll-zone, Windward Barrier.

PLATE 6 : 1. Windward Barrier, backreef area, slightly subtidal (- 1,5 m). Staghorn coral forests with bioturbated sand in the foreground.

2. Id, close-up of Acropora-colonies. Living parts are pale pink whereas dead branches are immediately overgrown by an algal coat.

PLATE 7 : 1. Sandy Shoal, - 2,5 m. Rippled sand with temporary Thalassia-bloom.
2. Id with isolated Halimeda-tufts.

PLATE 8 : 1. Sandy Shoal, - 2,5 m. Halimeda-patch and reefrock-boulder overgrown with algal coat.
2. Sandy Shoal, - 2,5 m. Cyanobacterial coat and beginning Thalassia-bloom.

PLATE 9 : 1. Leeward Patchreef Area, - 3 m. Patch with algal coat on reefrock boulders.
2. Id algal coat with Marginopora (living and empty tests).

PLATE 10 : 1. Coconut Reef flat : thallus of Halimeda cylindracea with other algae adhering to the thallus on top of the sediment substrate, and sediment-binding root system (right hand side of photograph).
2. Coconut Reef flat : development of algal coat on reef-rock fragment, showing several algal species and foraminifers (note Amphistegina and Baculogypsina-tests, central area of photograph).

PLATE 11 : 1. Coarse sediment from sandpocket, reef flat, Coconut Reef, microatoll zone. The sediment consists largely of Amphistegina - Calcarina - Baculogypsina tests (sample SEGERS).
2. Badly sorted mixed sediment from sandpocket, recolonised front, Internal Flat (sample SEGERS).

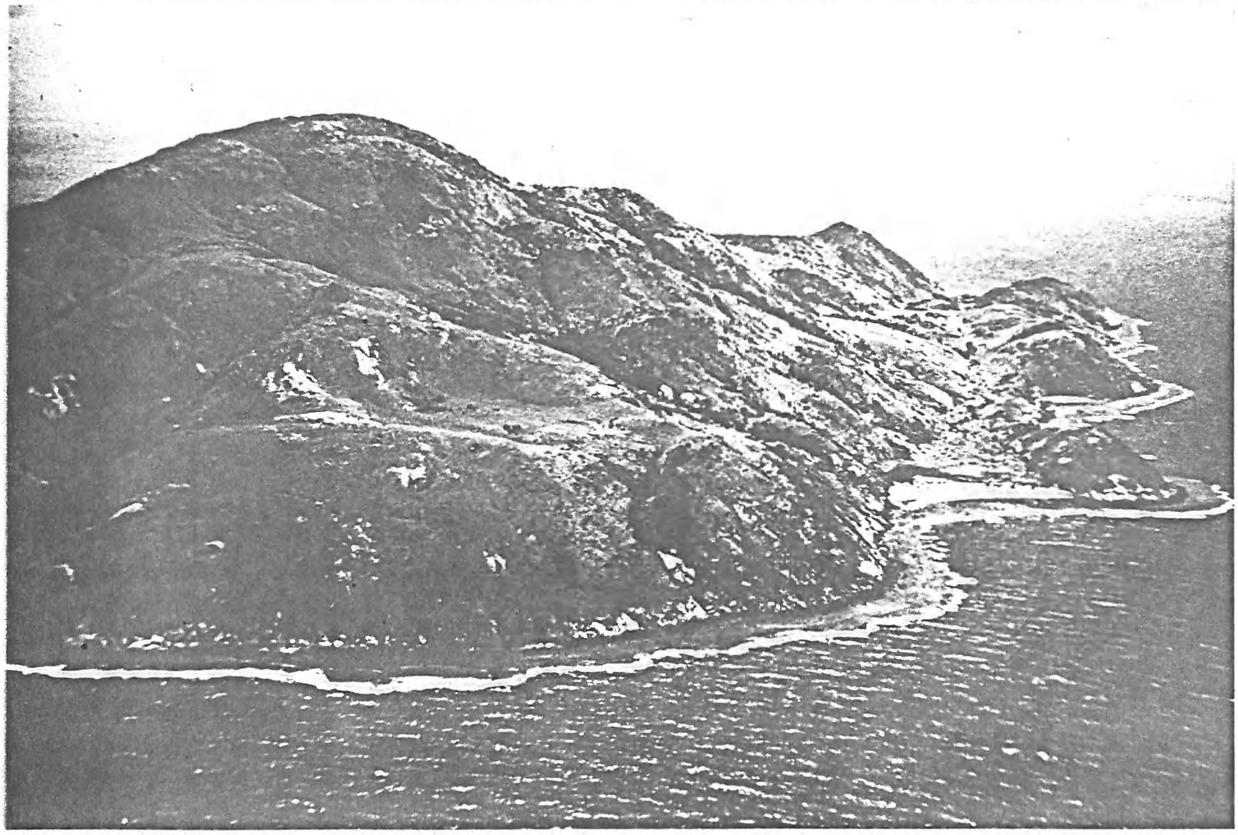
PLATE 12 : 1. Badly sorted, mixed sediment, Patchreef Area near Internal Flat (L 161).
2. Very badly sorted bimodal sediment (coral shingle), foot of drowned patch (L 155).

PLATE 13 : 1. Badly sorted organoclastic sediment, Eastern Perireefal Area (L 64).
2. Halimeda-rich, muddy sediment, Eastern Perireefal Area (L 75).

PLATE 14 : 1. Badly sorted mixed sand with high terrigenous component (note angular quartz grains); transitional area patchreefs - leeward slope (L 103).
2. Badly sorted organoclastic sediment, Eastern Perireefal Area (L 55). Note Marginopora- and Alveolinella-tests.

PLATE 15 : Medium - to fine mixed sand with high terrigenous component. Note remains of cyanobacterial (Lyngbya) coat; Sandy Shoal, central area (sample SEGERS).

Plate 1



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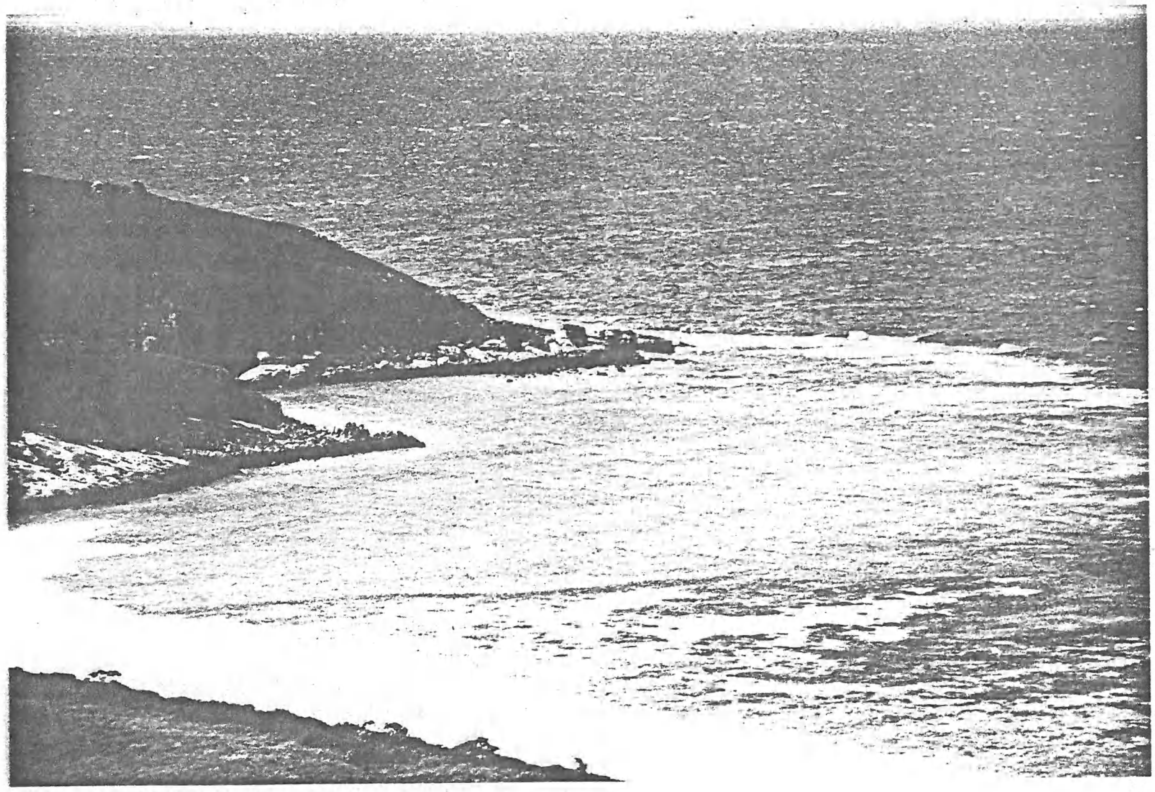

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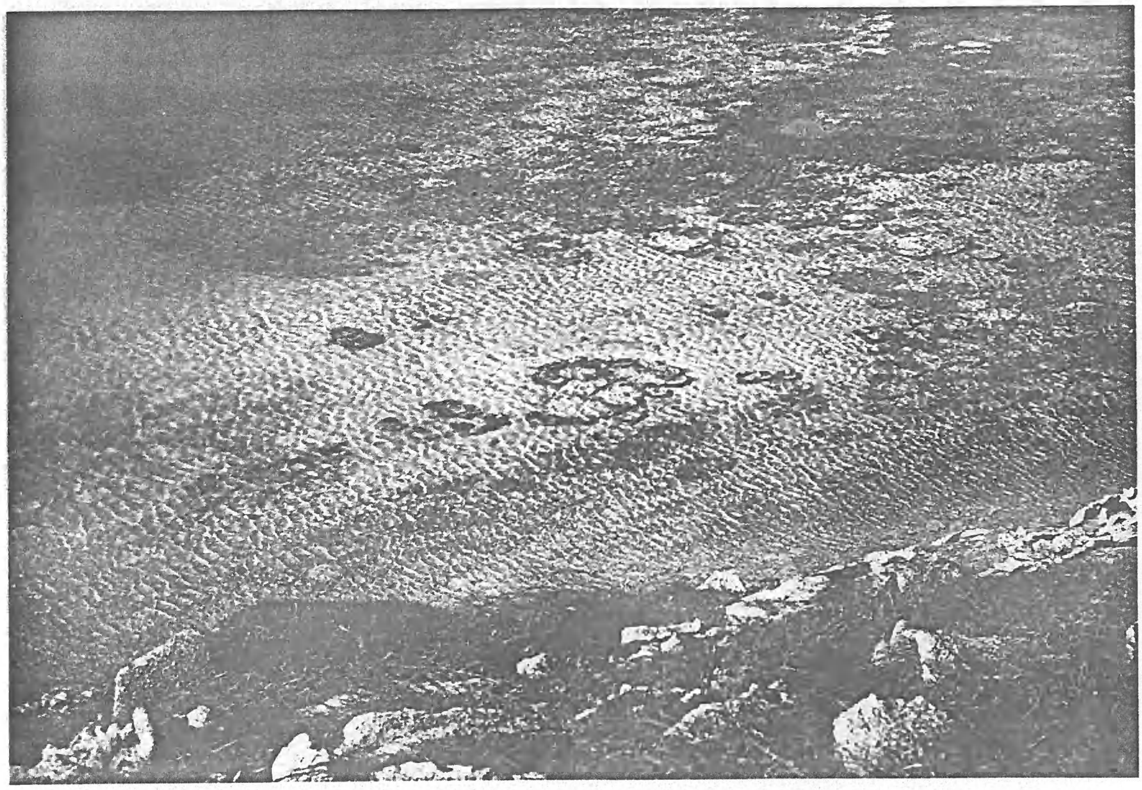

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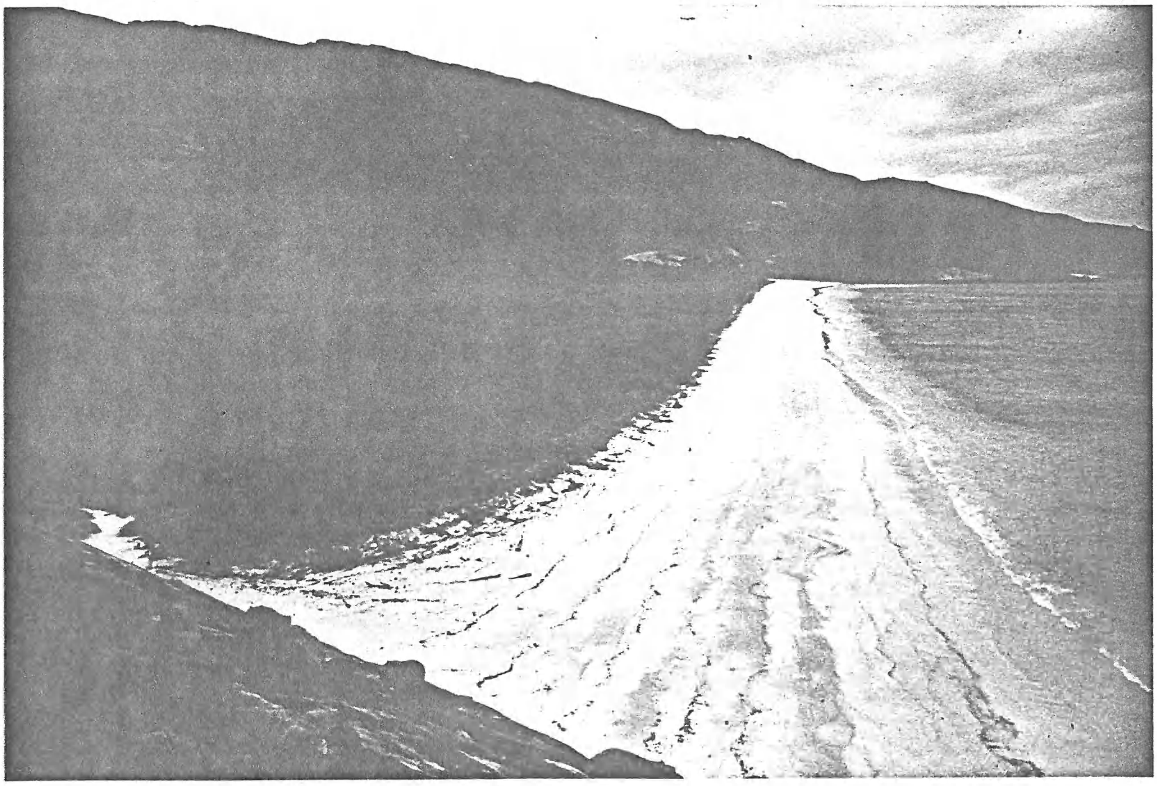

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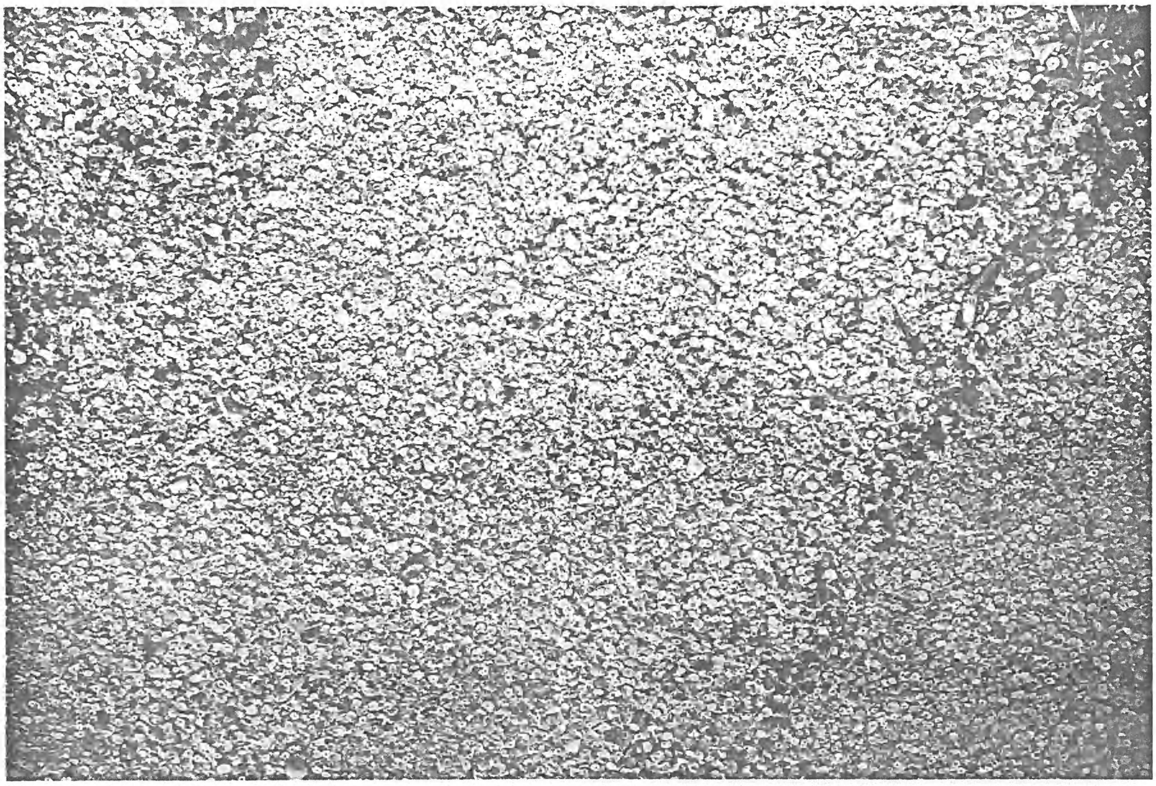

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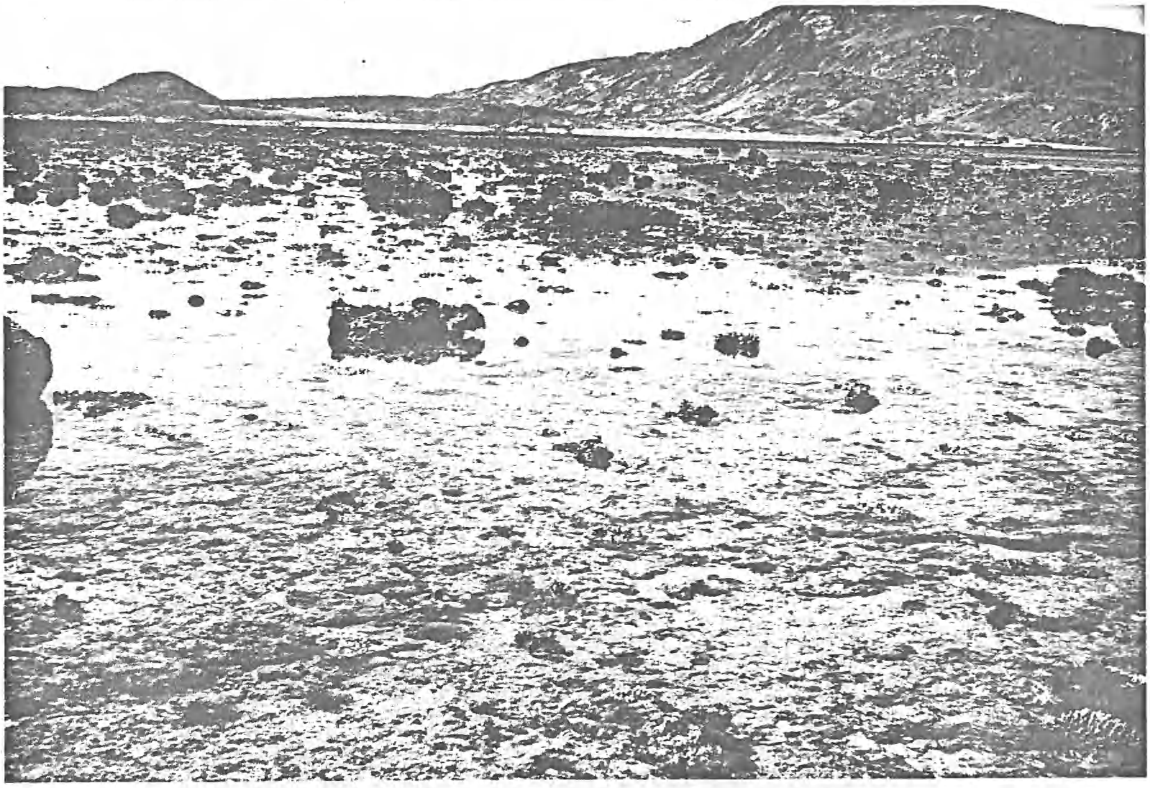

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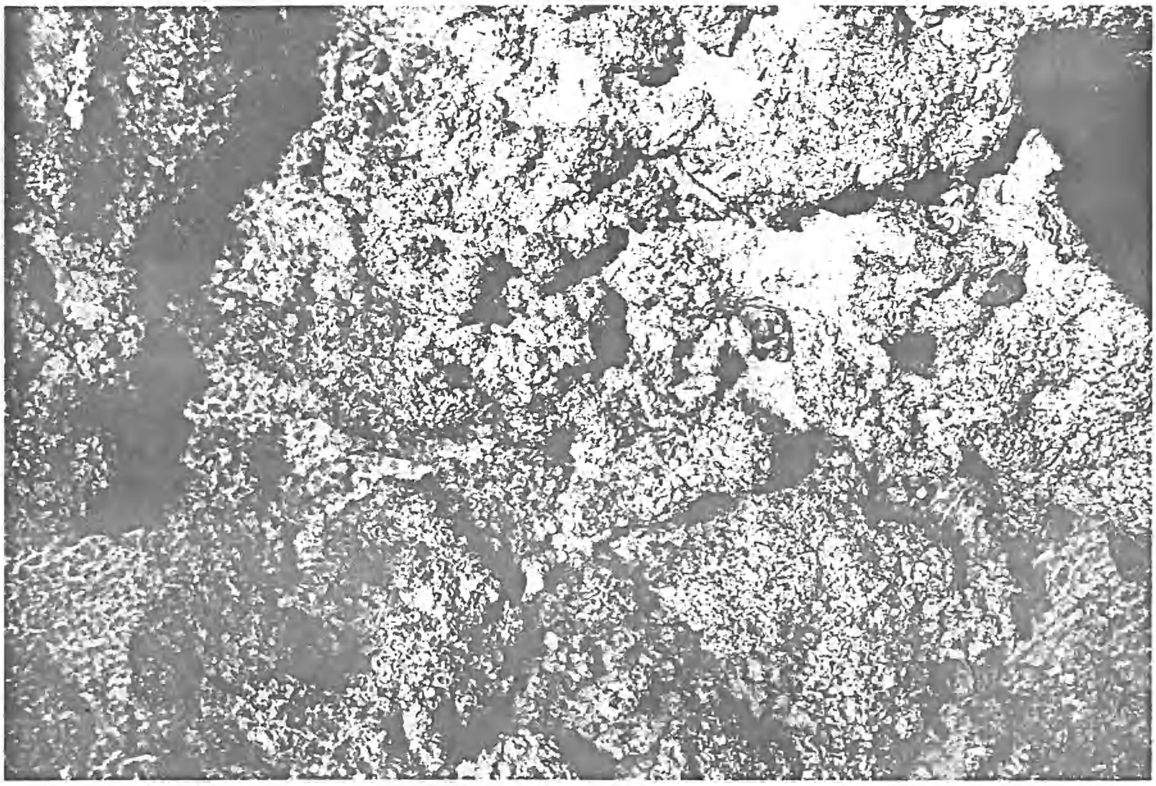

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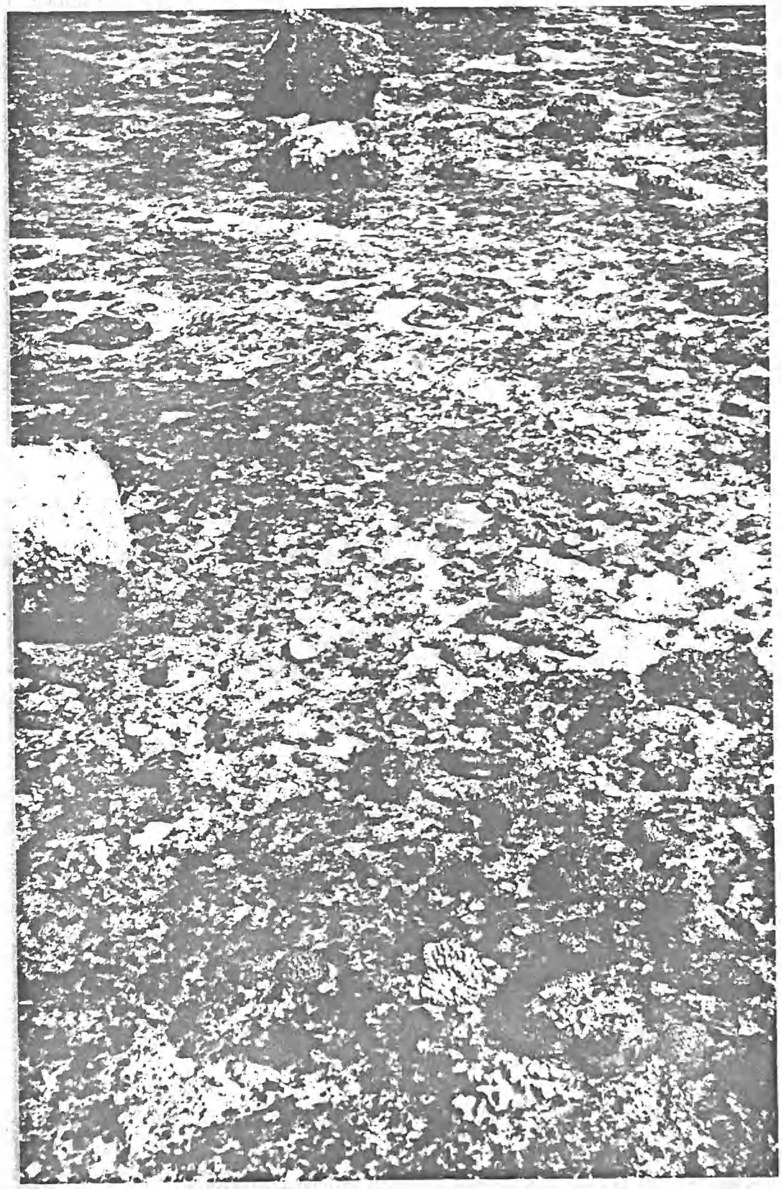

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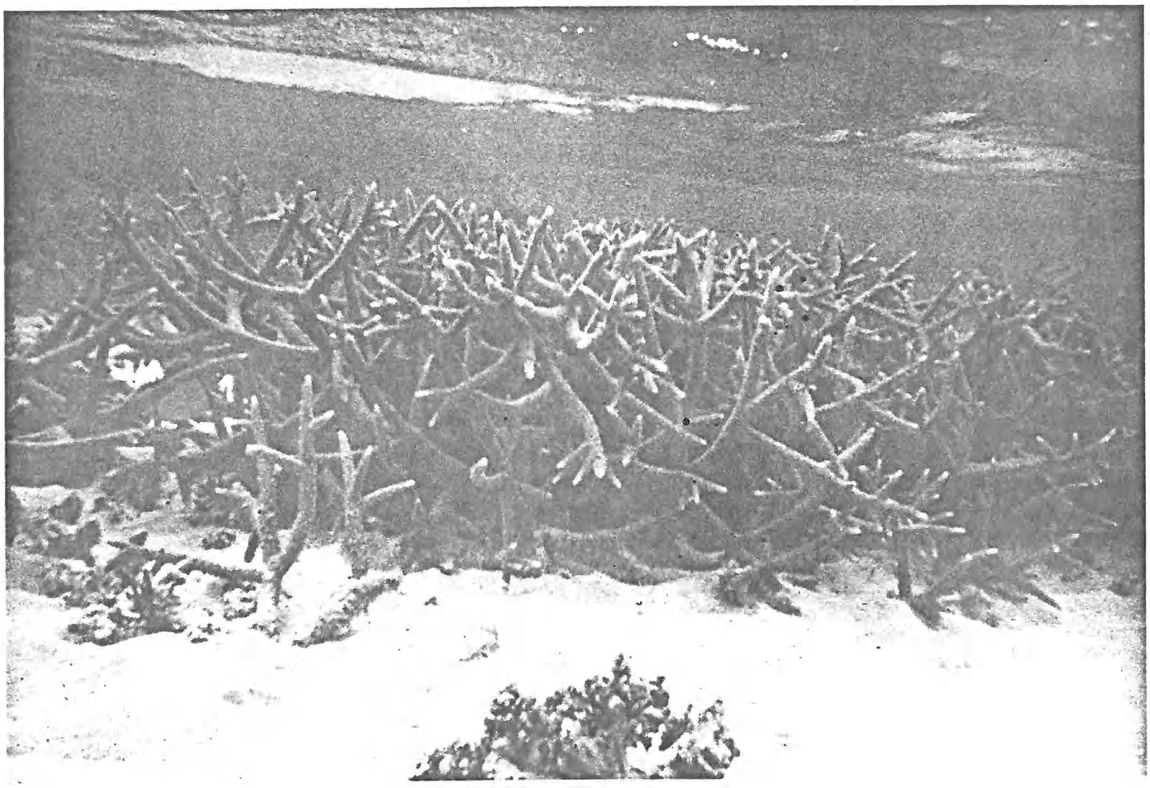

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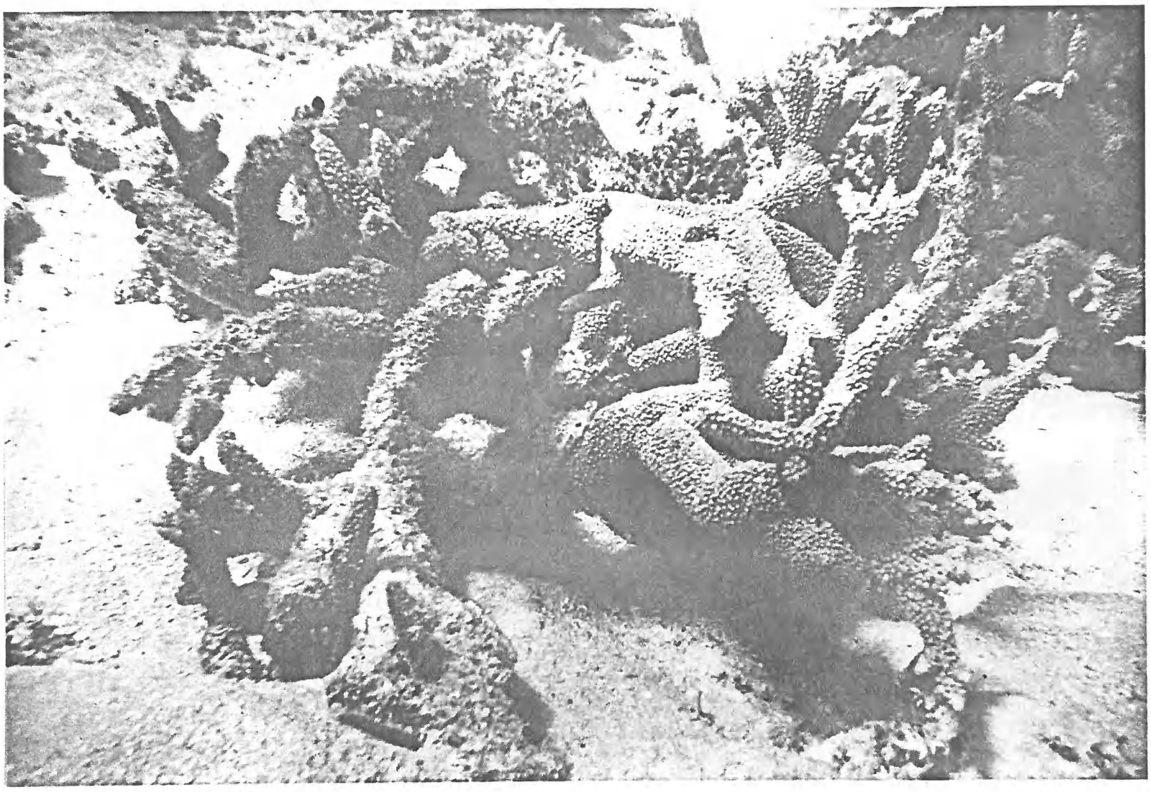

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Plate 7

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Plate 8

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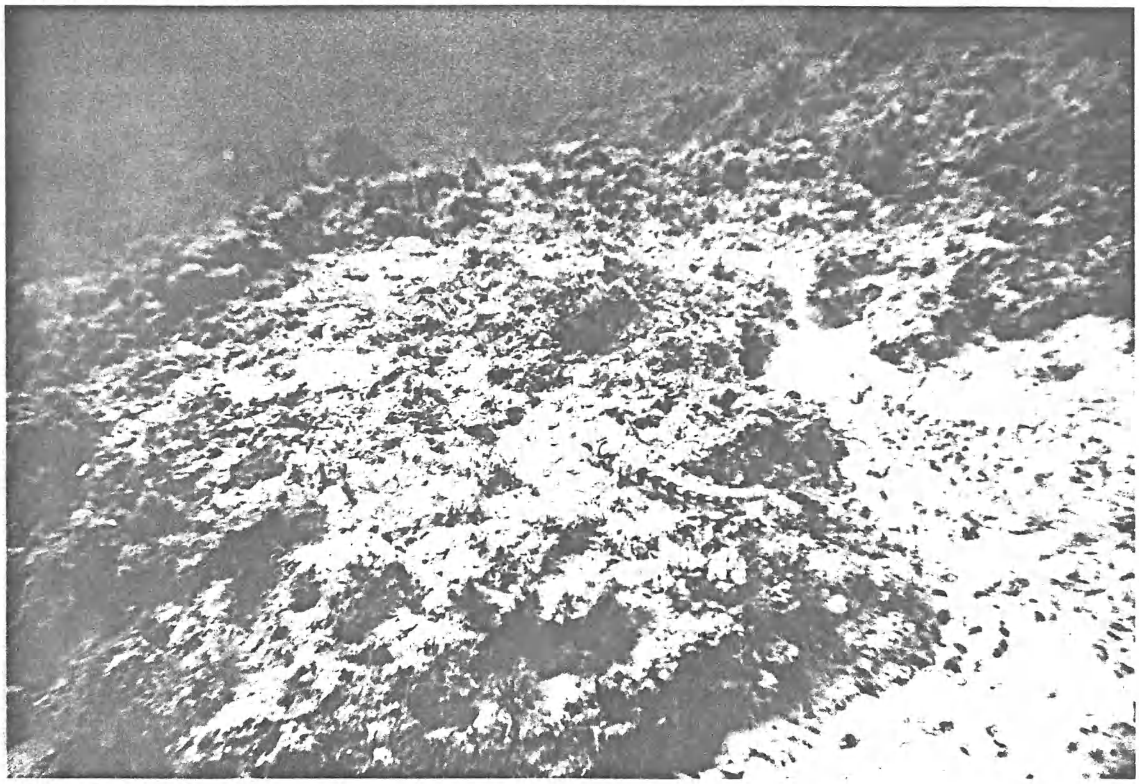

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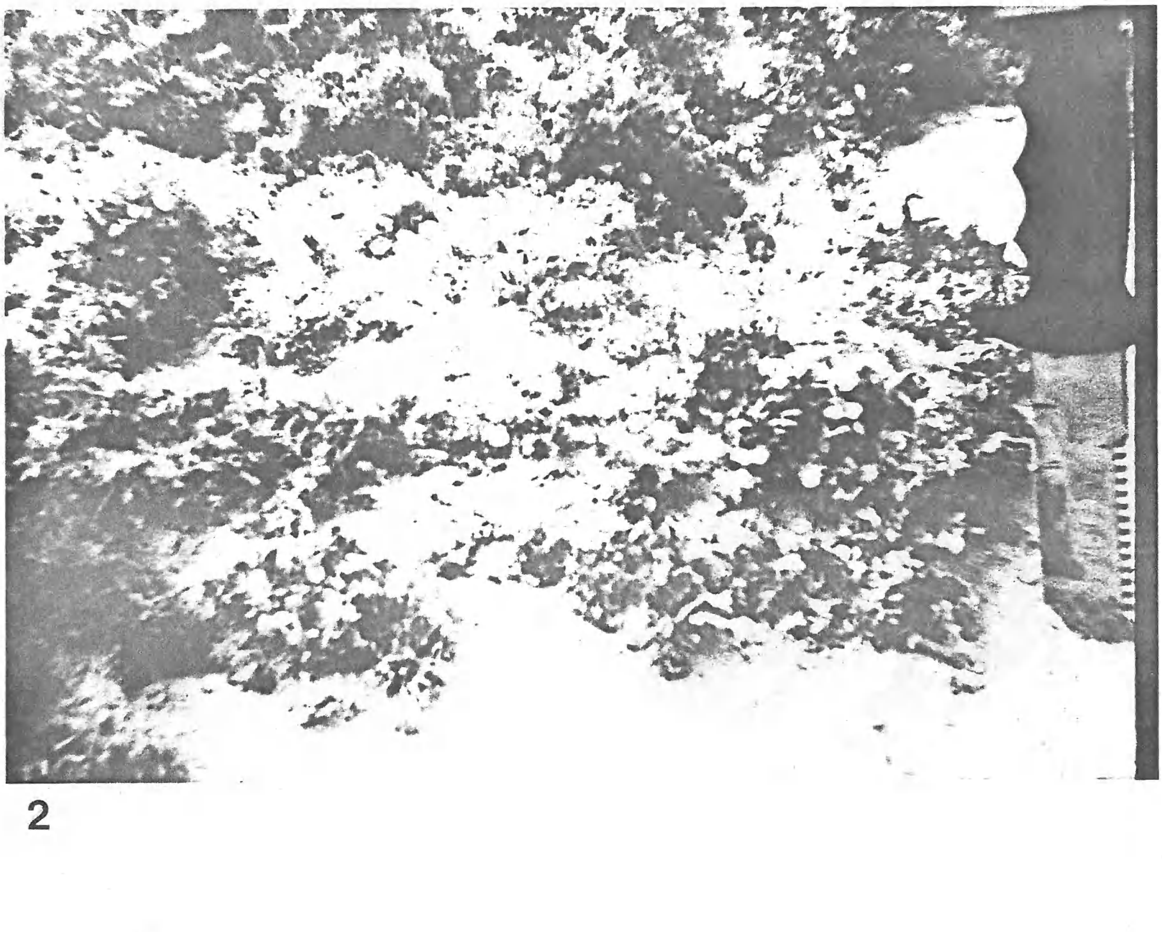

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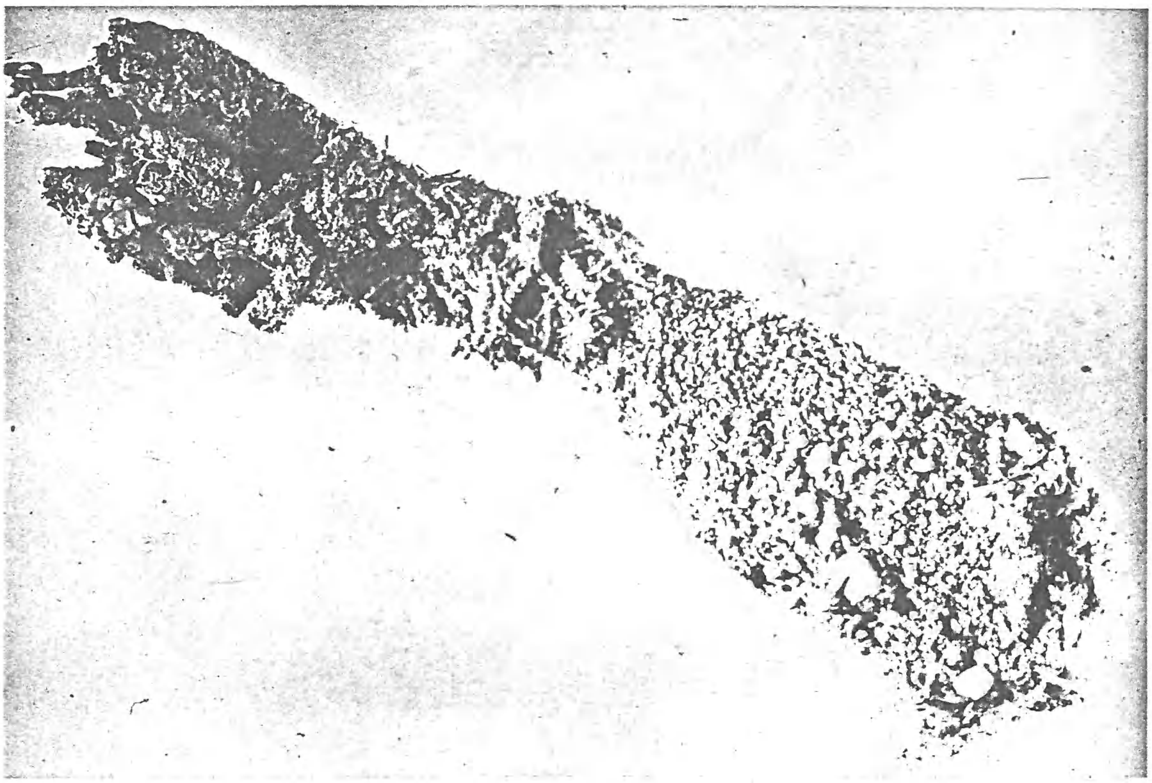

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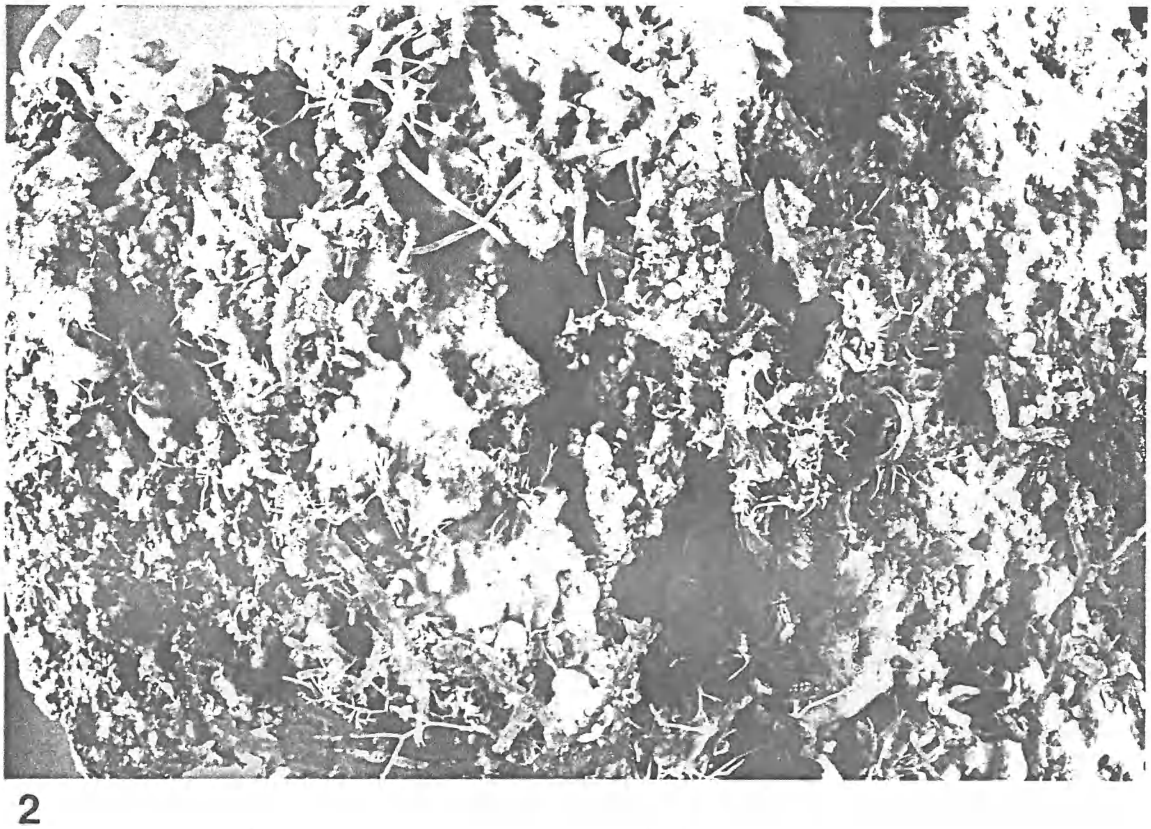

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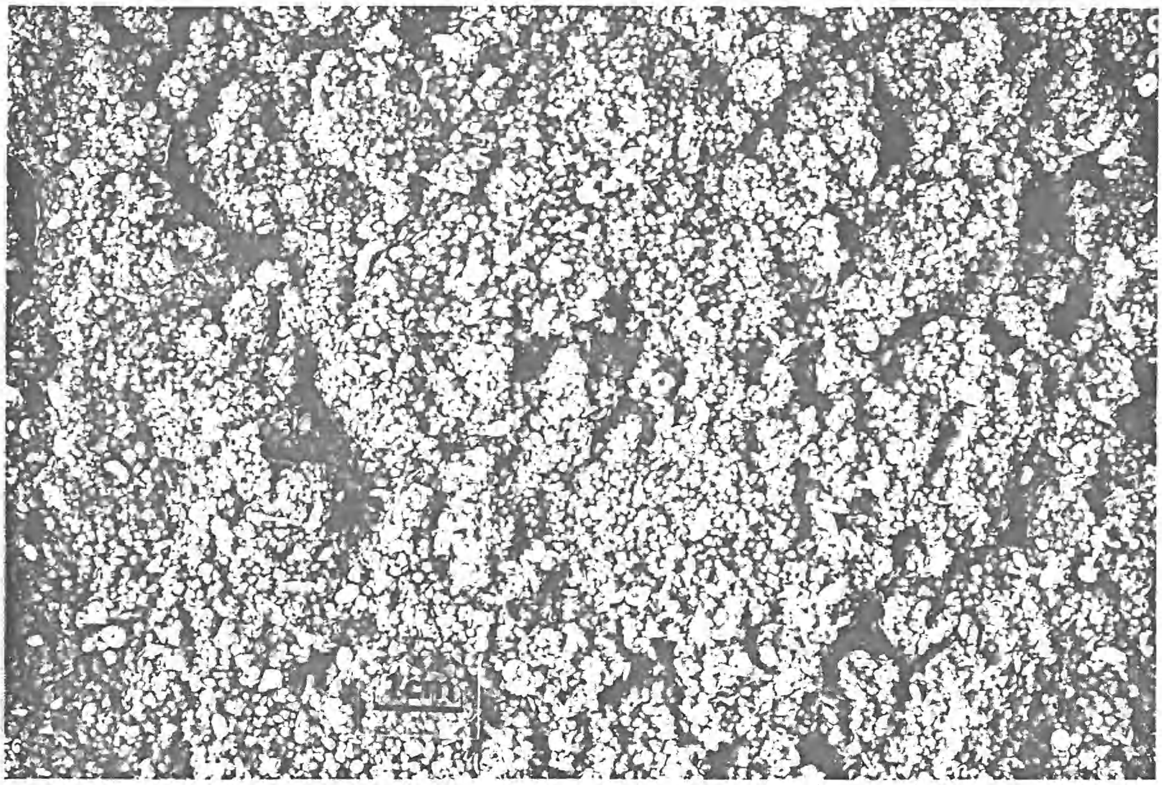

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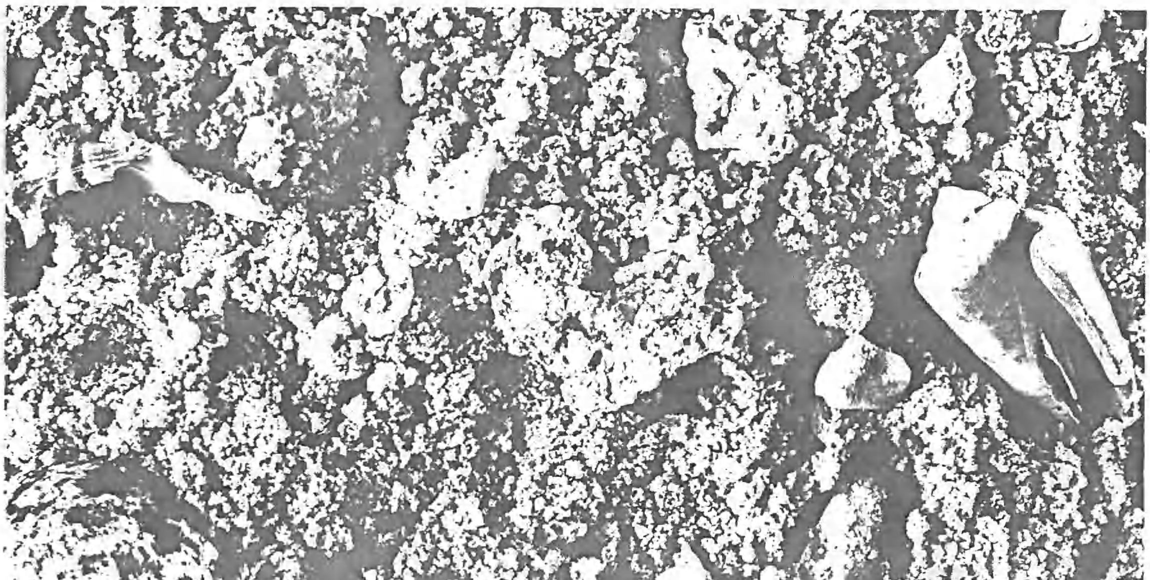

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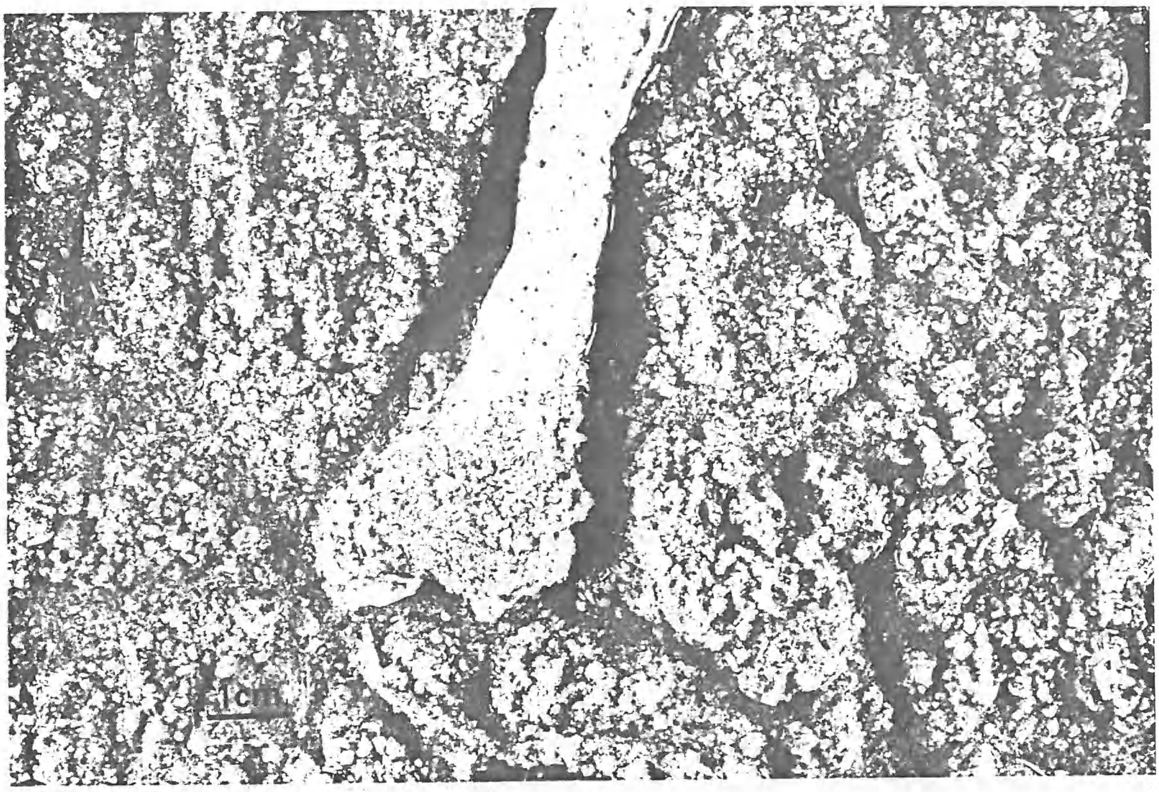

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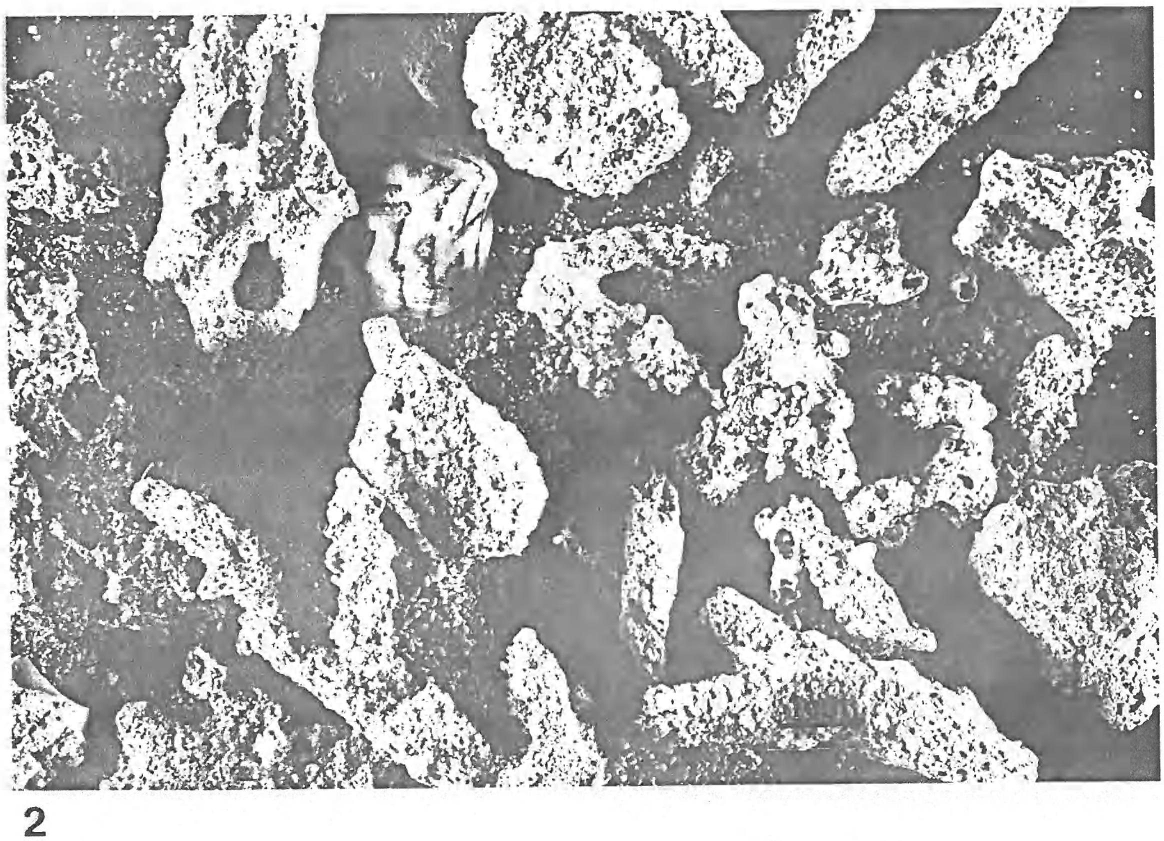

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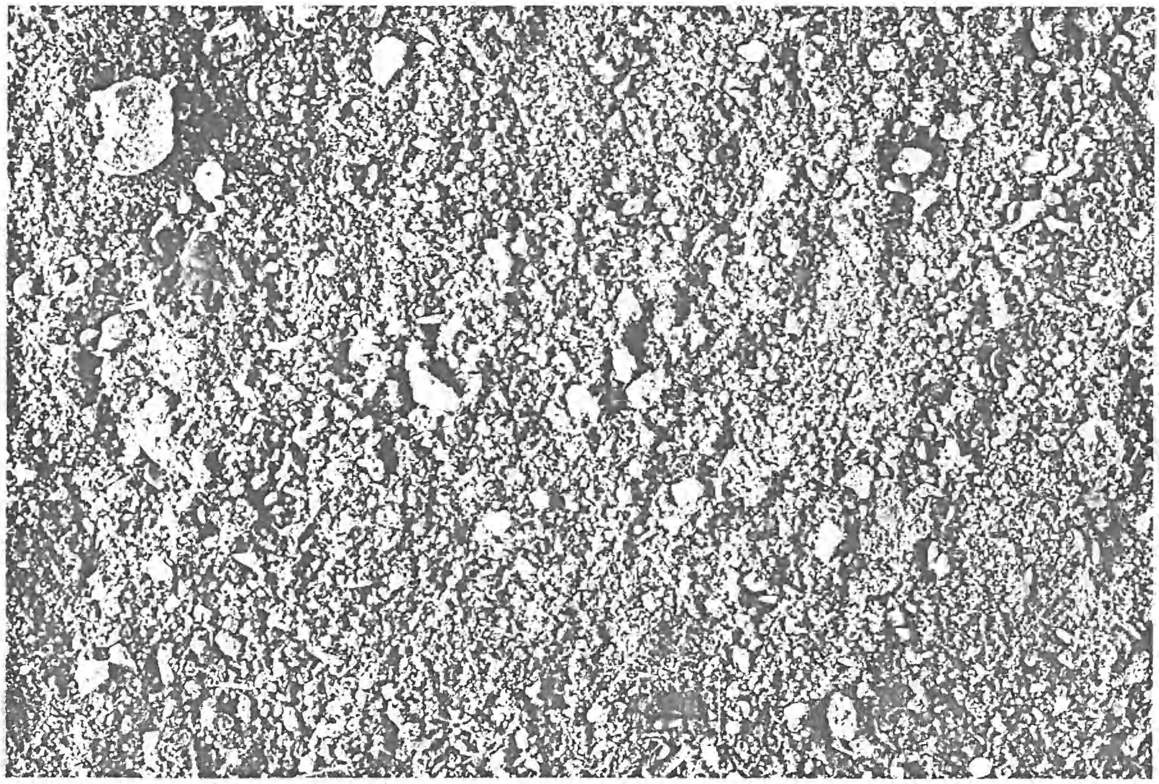

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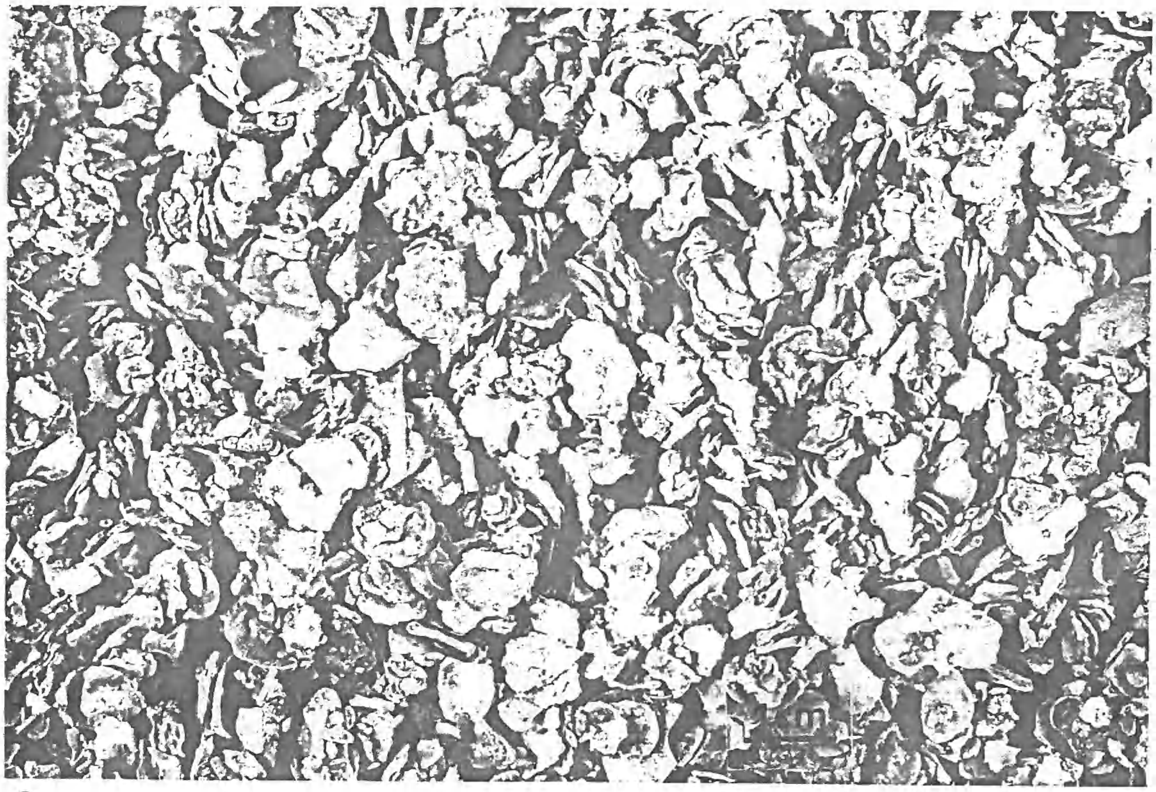

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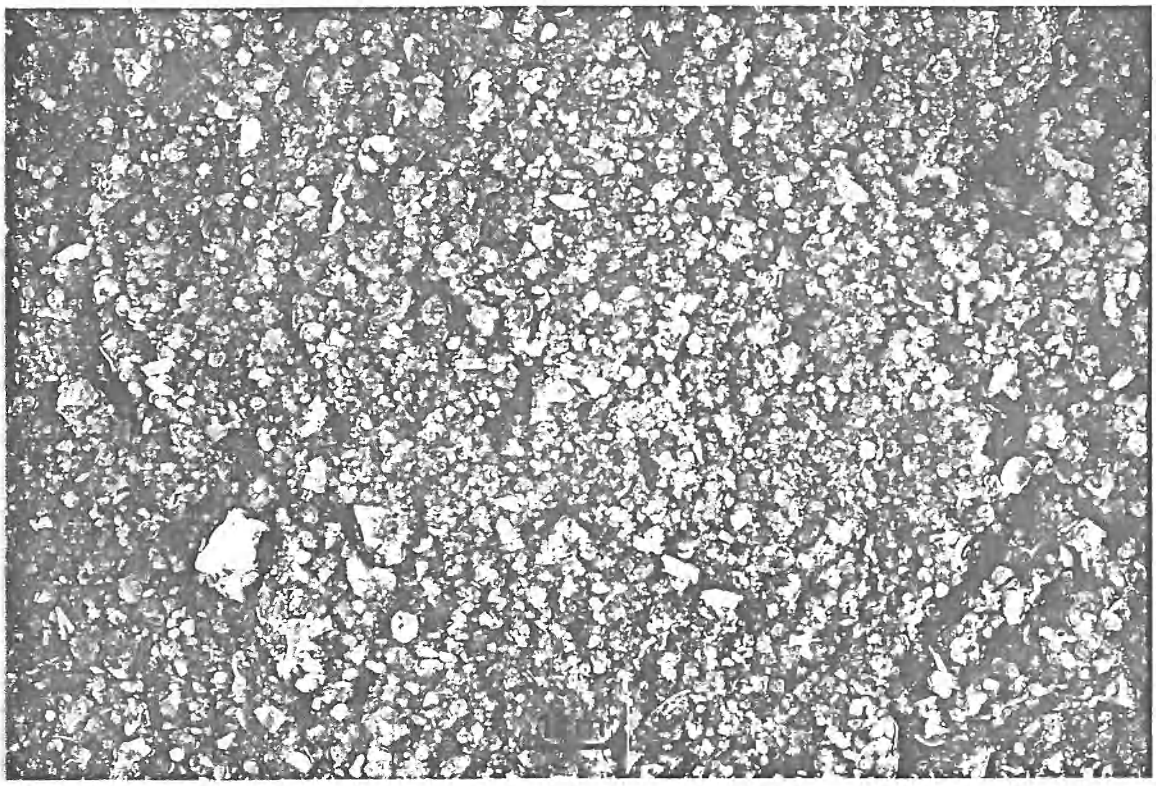

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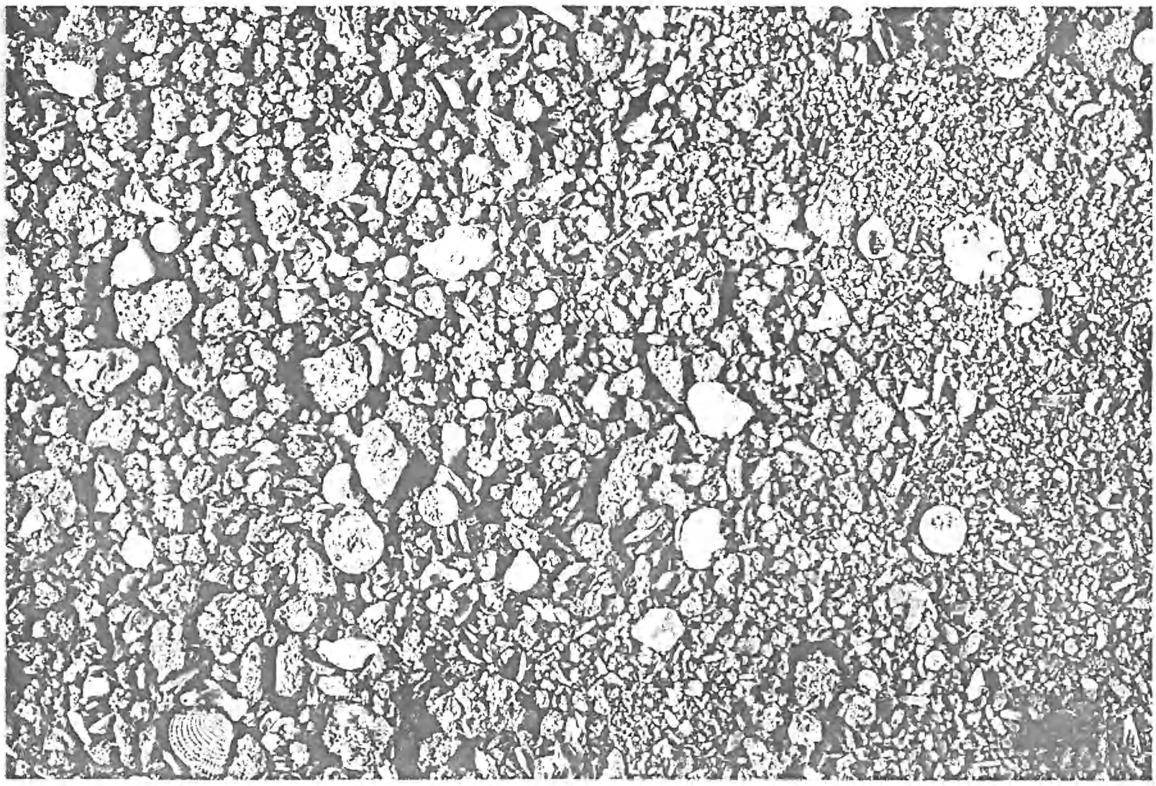

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