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Marine Sediments and Bottom Communities of the Seychelles

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Marine sediments and bottom communities of the Seychelles

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The shoal water region of the Seychelles Bank, covering about 31 000 km², is floored by relatively thin detrital carbonate sediments. Around the granitic and coral islands at least four submarine platforms can be recognized and are tentatively related to Late-glacial and Postglacial sea levels. A shallow discontinuous rim is developed around the margin of the Bank.

The sediments and bottom communities of the open Bank and of the reef flats are described in terms of nine principal environments. Sedimentary facies are distinguished by the proportions of different organic constituents, by variations in grain size and by presence or absence of quartz. Syngenetic pyrite and collophane occur locally as minor constituents. Away from the reef flats the Bank supports a fairly uniform bottom community, the main elements being mollusca and foraminifera.

The reefs may be considered as large intertidal pools with many microenvironments and with a complex zonation of communities showing rapid lateral changes in composition. There is a close relation between the sedimentary facies of the reefs and the distribution of the bottom communities.

Introduction

The Seychelles Bank is an area of 31 000 km² of shoal water with an average depth of 44 to 65 m. It lies between 4 to 6° S and 54 to 57° E. There are two groups of islands; a granitic group, which has associated fringing coral reefs, and a 'coralline' group of low relief.

Submarine platforms

The Seychelles Bank can be assumed to have been a stable block during and subsequent to the Late-glacial period and sea level changes should consequently be eustatic. Various submarine platforms can be distinguished: it is found that these correspond on the whole to platforms recognized on a worldwide basis, and representing Late- and Postglacial changes in sea level (Fairbridge 1961).

The greater part of the bank lies between −44 and −65 m. These levels have elsewhere been identified with the Masurian/Brady and Bölling/Lake Arkona submergences which occurred between 17 000 and 12 500 y B.P. A platform at −32 to −40 m, well marked on Admiralty Charts and on echo-sounder traces, is possibly equivalent to the Alleröd/Two Creeks submergence which occurred about 12 000 to 10 800 y B.P. A platform at −15 to −24 m is well preserved on Owen and Topaze Banks and corresponds in level to the Yoldia/Pre-Cochrane submergence of *ca.* 10 300 y B.P. Outside the existing reefs around Mahé, a terrace is seen at about −10 m. This is equivalent in level to the Hydrobia submergence of the North Sea basin which occurred 7500 to 6700 y B.P.

On the southern face of the Seychelles Bank echo-sounder traces reveal a well defined step, about 300 m wide, at −75 m in the otherwise steep descent from the Bank into deep water. It does not correspond to any known Postglacial sea level, but may have been formed during the Illinoian Glacial period (Fairbridge 1960).

The remains of a former reef can be found at heights up to 12 m on the granitic islands. This possibly represents a higher sea level during an interglacial period.

Environments

The sediments and bottom communities fall into two main categories based upon environment. The first embraces those occurring in the shoal waters of the Seychelles Bank; the second those close to the islands in association with their coral reefs. While these two categories grade into one another, they may be considered sufficiently distinct to warrant separate discussion. Other environments than those described here exist, but they are of minor importance and are omitted for reasons of space. It is hoped that future work will make it possible to define certain facies and subfacies more effectively.

The marine sediments of the Seychelles consist of detrital skeletal carbonates. Terrigenous material, almost wholly consisting of quartz, is occasionally important in the vicinity of the granitic islands.

(*a*) *The Seychelles Bank*

A relatively thin veneer of unconsolidated detrital organic carbonates covers the Seychelles Bank. These sediments have been subjected to little transportation. They may be classified into broad groups, based upon such criteria as nature of the organic content, presence or absence of quartz and grain-size distribution.

It should be emphasized that grain-size distribution, whilst it is important in describing the physical nature of a given bank sediment, is but slightly related to the hydraulic properties of the sediment. Hence sorting coefficients have not been determined for sediments from the Seychelles Bank.

The bottom communities may be related to three different groups of sediments.

(i) *Group* 1 *sediments*

A distinct sediment type is associated with the discontinuous shallow rim of the Seychelles Bank. This rim may be as shallow as −14 to −20 m. The related sediments are extremely coarse. Median diameters range from 3·00 to 9·00 mm. Cobbles of encrusting algae form the major constituent. The sediment is white, but branching (*Archaeolithothamnion*) and nodular encrusting (*Lithophyllum*) red algae, and the encrusting foraminifer *Homotrema rubra* are important. In the finer fractions, benthonic foraminifera become important, but pelagic foraminifera remain insignificant. Whole leaves of the green calcareous alga *Halimeda* are common in the larger fractions. Branching bryozoans are also a feature of this type of sediment. Other constituents are only of minor importance.

The bottom community consists of small, isolated corals (*Leptoseris*, *Euphyllia* and *Culicia*), calcareous algae, foraminifera, bryozoa and mollusca. The molluscan community is rather similar to that of the Fore Reef Facies of the islands.

Important species

Prosobranchs

Emarginula peasei Theile
Leptothyra candida Pease
Rissoina ambigua Gould
Erato sulcifera Sowerby

Bivalves

Laevocardium biradiatum (Bruguière)
Tellina fabrefacta Pilsbury

The algal cobbles must be considered as essentially transported, albeit for a relatively short distance. They are usually rounded, but irregular. The other constituents are largely unworn, and have been deposited more or less *in situ*.

One notable feature of this group is the virtual absence of reef-building corals. Apart from the local occurrences, it appears that the shallow rim of the Seychelles Bank, whilst supporting algal growth, does not favour much coral growth. The rim hence appears to be a drowned coral reef, and may once have formed the margins of a vast atoll.

(ii) *Group 2 sediments*

Within this group there is a considerable variation in sediment type. Preliminary work suggests that it may well be possible to distinguish several facies.

Sediments of group 2 cover the greater part of the Seychelles Bank. They occupy the area between the rim and the area influenced by the granitic islands. Grain size varies considerably and median diameters range from 0·06 to 0·70 mm. In general, these sediments first become finer when proceeding inwards from the rim and then become coarser near the individual granitic islands. The sediments tend to be dark in colour, and are often greenish.

The composition varies considerably, but the chief constituents are pelagic foraminifera, notably *Globigerina*, benthonic foraminifera especially *Amphistegina* and benthonic mollusca, which are nearly always present to a greater or less extent. The following may be present in abundance, or may be entirely absent: algal grains, ahermatypic coral remains, echinoid plates and spines and pelagic mollusca, especially pteropods.

Several other organisms are usually present, often in quite considerable amounts. None the less they must be considered as minor constituents. They include Bryozoa, crustacean remains, alcyonarian spicules, ostracods, serpulids and sabellids and *Halimeda*.

In general, sediments with larger median diameters are rich in benthonic remains, or more rarely have a high algal and ahermatypic coral content. Finer sediments tend to be composed of pelagic remains.

Whilst most of the constituents are fresh, certain features are peculiar to particular ones. In the coarse fractions, either bivalves or prosobranchs may be dominant, the former being whole, the latter broken. In the finer fractions, complete prosobranchs are more abundant than bivalves. Pteropods are complete in the fractions larger than 1·50 mm. The scaphapods are whole in the coarse fractions, but many are comminuted in the finer.

The pelagic foraminifera are virtually confined to fractions smaller than 0·50 mm, and are fresh. In contrast, the benthonic forms occur throughout all size fractions. In the coarse fractions they are worn, in fractions below 1·00 mm they are fresh and whole, but with a further decrease in grain size, they become more and more comminuted.

The bottom community is characterized by the ahermatypic corals *Heteropsammia* and *Heterocyathus*, the echinoids *Echinocyanus* and *Clypeaster*, and abundant molluscs, notably many thin-shelled, burrowing bivalves.

Important species

PROSOBRANCHS

Turritella fascialis Menke
Amalthea lissa Smith
Terebellum terebellum (Linné)
Strombus plicata Lamarck
Mitra sculptilis Reeve

PTEROPODS

Cavolina globulosa (Gray)
C. longirostris (Blainville)

BIVALVES

Arca navicularis Bruguière
Barbatia helblingii Bruguière
Chlamys nux. Reeve
Carditella sp.
Nemocardium centumliratum (Melville & Standen)
Clathrotellina elegantissima (Smith)
Fabulina tomlini Salisbury

(iii) *Group 3 sediments*

This is again a broad group. The organic composition and bottom communities are similar to and as variable as those of group 2. However, all sediments belonging to group 3 contain quartz to a greater or less extent. Preliminary work suggests that the area of quartz-bearing sediments embraces all the granitic islands, although locally quartz may be absent. In general, the quartz becomes finer away from the islands, but local variations in the amount and nature of the quartz present may be related to the topography of the Seychelles Bank.

In the coarser fractions, the quartz is unworn. It is then slightly opaque and greyish, showing the same intergrown crystals as are found in the Seychelles granite. With decreasing grain size, it becomes worn, polished, clear and vitreous, sometimes with surfaces showing conchoidal fracture. The quartz content may be as high as 70% of the grains in a given fraction. The median diameters range from 0·10 to 0·70 mm.

A feature common to both groups 2 and 3 is the occurrence of blackened grains. Usually these are subangular, and may be grey to intense black. Occasionally alcyonarian spicules and crustacean remains are also blackened, whilst tests of *Alveolina* are commonly black. Thin-section studies and X-ray powder photographs show that the blackened grains are composed of cryptocrystalline calcium phosphate with small amounts of pyrites forming a rim. Both minerals are syngenetic.

(*b*) *The reefs of Mahé*

The east side of Mahé has a virtually continuous fringing coral reef along its whole length, 27 km. Between South-East Island and Port Victoria the reef is about 2 km wide, but the width is variable to the north and south, being only a few metres at North-East Bay and Anse Forbans. The reefs south of South-East Island are exposed to heavy breakers for part of the year, and in consequence have developed a fine algal rim characteristic of windward reefs of the Indo-Pacific region. Suggestions of spur and groove formation can be seen on the reef edge. However, where the reefs are widest, north of Anonyme, the algal rim is poorly developed.

On the west side of Mahé reefs are very poorly developed and form narrow fringes around bays, notably at Anse à la Mouche and Anse Boileau. These do not possess significant algal rims and wave action is small. The reef development appears to be related to the dominant wind direction from the southeast. The Southeast Trades blow from about April to November and the weaker Northwest Monsoon for the rest of the year.

The reefs are widest in relatively sheltered positions and it also seems that a suitably shallow bottom is important for the growth of wide reefs. None of the living reef fronts was observed to extend to a depth greater than 18 m. Where the reefs are narrowest, as at Anse Forbans and North-East Bay, the bottom shelves off quickly into relatively deep water. On the eastern side of Mahé gaps or reef passes are common, occurring opposite the mouths of streams. Their presence is attributed to the inhibiting effect of fresh water on coral growth.

Once it has formed a solid structure, the reef can be regarded as a large sublittoral pool of the uneven bottom type (Doty 1957). The reef surface, with its innumerable micro-environments and micro-climates, offers an infinite number of ecological niches. An organic zonation is developed parallel to the shore. The zones recognized are (see figure 1): (i) supralittoral and beach, (ii) marine grass, (iii) open sand and algal ridges, (iv) algal rim, (v) reef edge and reef front, (vi) fore-reef.

Each of these zones has a characteristic assemblage of organisms.

Variations in the sediments of the reefs can be related to the different organic zones. The same criteria are used to describe the different types of sediment as those used for the sediments of the Seychelles Bank. However, in these sediments, unlike those of the Bank, transportation plays a major rôle, and hence grain-size analysis not only helps to describe the physical nature of the sediment, but also reflects the hydraulic conditions of the sedimentary environment. It should be remembered that no method of grain-size analysis can take into account all the factors influencing carbonate deposition, since the problem of organisms dying in situ is always present.

(i) *Supralittoral and beach zone*

Supralittoral environment. The vegetation upon the upper beach is zoned according to the resistance of the plants to salt-spray and to periodic uprootings. The outpost species low on the beach are the creeper *Ipomea pes-caprae* and the grass *Sporobolus*. Behind this is a dense thicket of *Scaevola frutescens* and behind this *Cocos nucifera*, *Casuarina equisetifolia* and *Calophyllum inophyllum* are typical. A characteristic inhabitant of the upper beach is the crab *Ocypode ceratopthalma*.

Beach environment. This constantly shifting environment is largely devoid of life except for three bivalves which, because of their burrowing ability, are able to maintain their position. All three are suspension feeders.

Important species

Donax faba Chemnitz *Donax cuneatus* Linné *Atactodea glabrata* (Gmelin).

The beach sediments are characteristically well sorted. Sorting coefficients are of the order of 1·5 or less. Median diameters are variable, ranging from 1·50 to 0·10 mm. On some beaches there is a gradation from coarse to fine sediment from one end of the beach to the other. This is related to the prevailing wind direction.

Many of the beach sands are quartz-rich, with the amount of quartz increasing towards the base of the beach. Wave-marks composed of coral and algal cobbles and of shell debris are common and generally the sands become coarser towards the base of the beach.

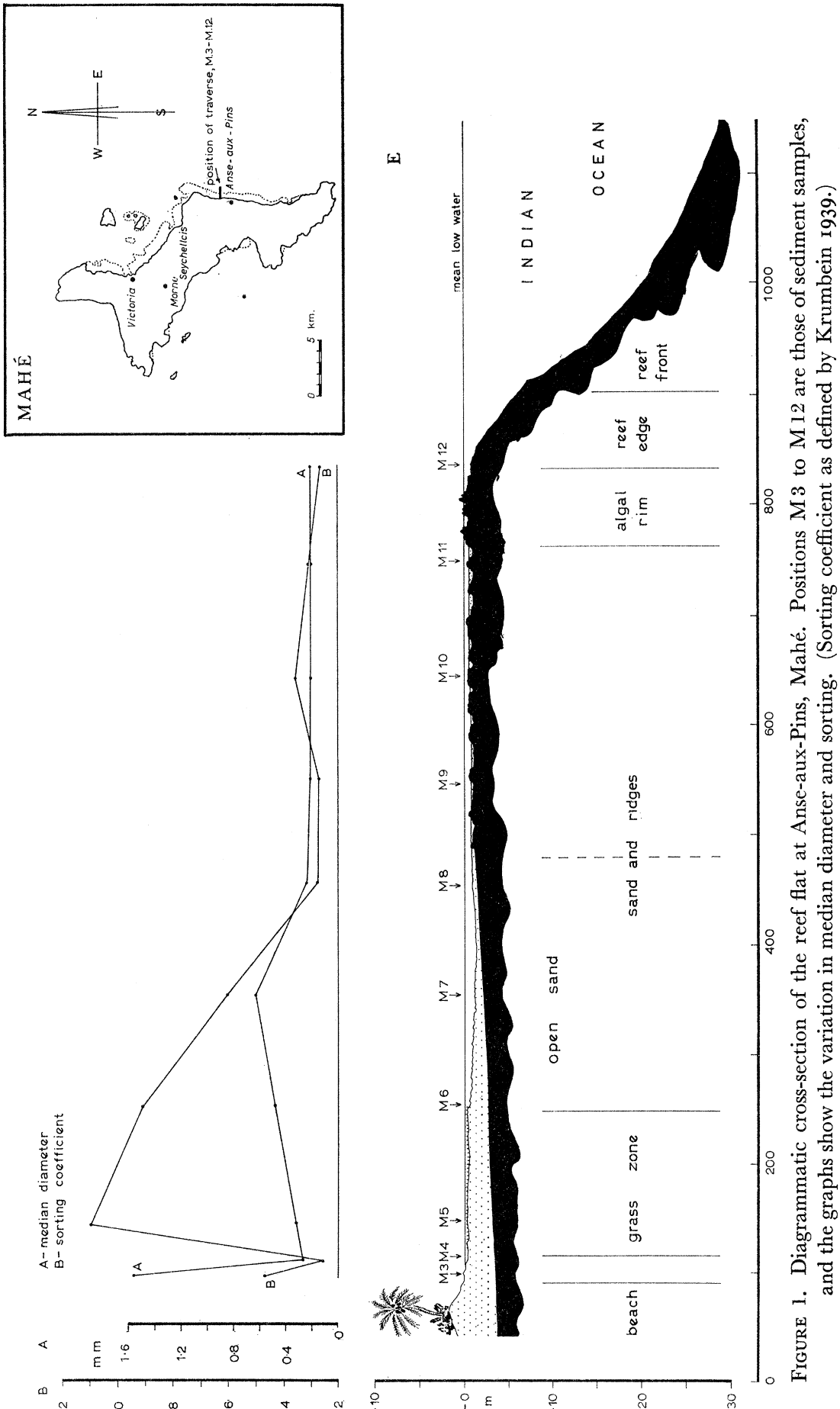

FIGURE 1. Diagrammatic cross-section of the reef flat at Anse-aux-Pins, Mahé. Positions M3 to M12 are those of sediment samples, and the graphs show the variation in median diameter and sorting. (Sorting coefficient as defined by Krumbein 1939.)

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Apart from quartz, coral and algal grains make up the bulk of the sands. Other skeletal remains may be important. The individual grains are usually well worn, and on some beaches a high degree of sphericity is found, associated with a high polish.

At the base of the beach a strip, a few metres wide, of strongly rippled sediments, which are very coarse in the troughs, is often found. Elsewhere, this belt consists of very fine grained sediments, with median diameters of about 0·22 mm and sorting coefficients around 1·2. These values reflect a high energy environment, for it is here that waves break.

(ii) *Marine grass zone*

Marine angiosperms of the genera *Cymodocea*, *Thalassia*, *Syringodium* and *Enhalus* form thick beds up to several hundred metres in width. It is here that unconsolidated sediments reach their maximum thickness on the reef flats. By means of the rhizomes and roots and the epiphytic red algae on the leaves, the angiosperms cause the accumulation of the sediment. The sediments themselves are continually disturbed by suspension and deposit-feeding burrowing bivalves and by polychaete worms, and on the surface by holothurians. The bivalves have densities up to about 130/m^2 and holothurians up to 3/m^2. The result is an extremely poorly sorted sediment. Median diameters range from 0·30 to 0·60 mm, while sorting coefficients are about 1·9 to 2·2 (figures 1 and 2).

On the surface of the grass beds the predatory *Conus* and the herbivorous *Strombus* are common. On the undersides of occasional coral cobbles and blocks, *Cypraea annulus* and *C. moneta*, and ophiuroids are frequent. Small coral patches of *Psammocora* and *Pavona*, and small isolated *Porites* occur.

Important species

Grasses

Cymodocea ciliata (Forskal)
C. rotundata Aschers & Schweinf
Syringodium isoetifolium (Aschers)
Thalassia hemprichii (Ehrenberg)
Enhalus acoroides (Linné)

Prosobranchs

Cerithium asperum (Linné)
Natica marochiensis (Gmelin)
Nassarius albescens (Dunker)
N. coronatus (Bruguière)
Cypraea annulus Linné
C. moneta Linné
C. tigris Linné
Conus betulinus Linné
C. litteratus Linné

Bivalves

Codakia punctata (Linné)
C. tigerina (Linné)
Pinna muricata Linné
Gafrarium tumidum (Röding)
Pitar obliquata (Hanley)
Quadrans palatam (Iredale)
Tellinella staurella Lamarck
Leptomya gravida Hinds

Corals

Pavona frondifera Lamarck
Porits sp.—rounded
Porites sp.—finger shaped
Psammocora contigua (Esper)

In organic composition the sediments are much the same as those of the beach, but molluscan remains are often greater. These provide a good example of organisms being deposited in their place of life and death. Benthonic foraminifera occur but are seldom important. The bulk of the sediment is composed of coral and algal remains. The former

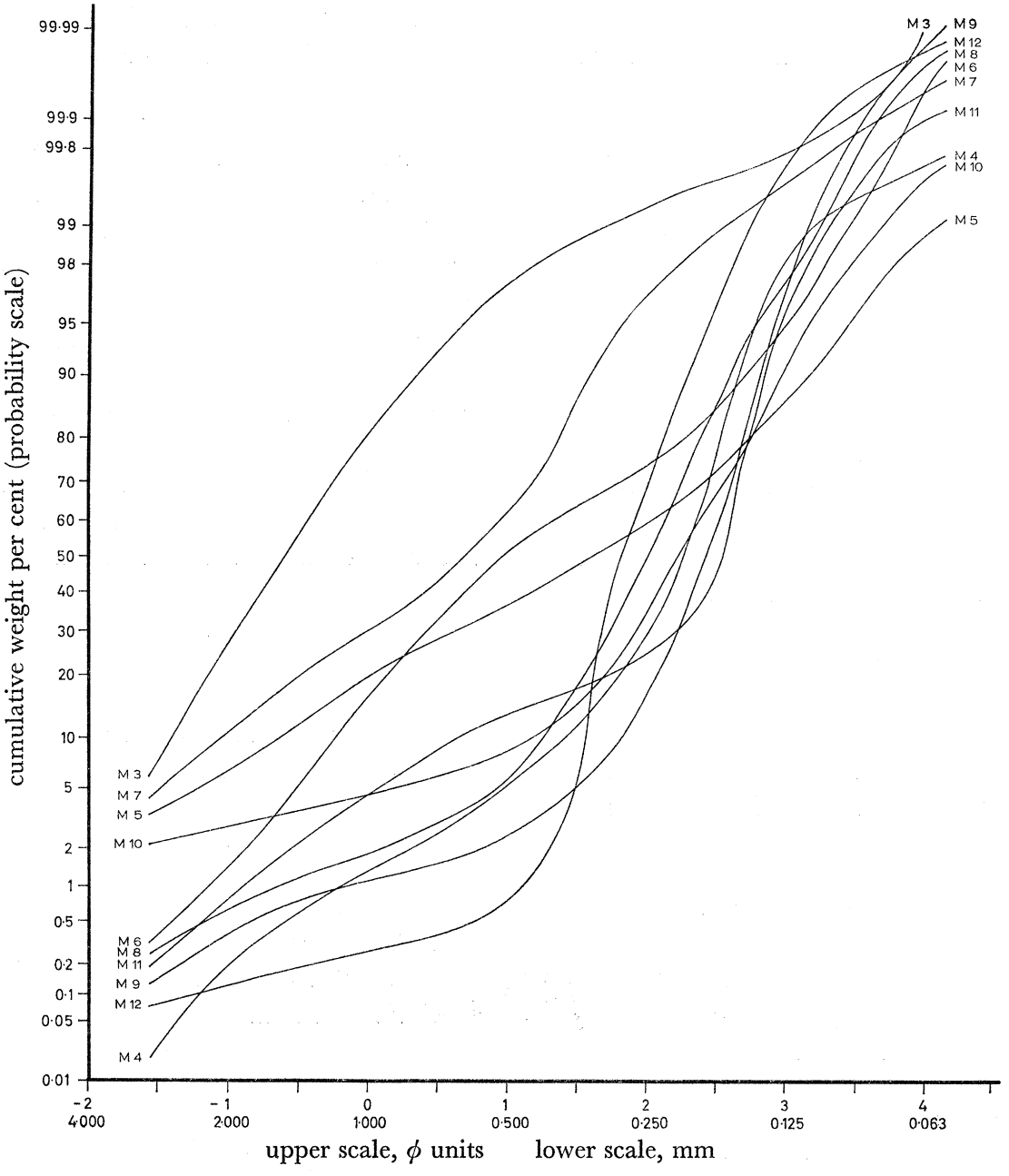

FIGURE 2. Cumulative curves for sample traverse M 12 across the reef flat at Anse-aux-Pins, Mahé.

are often encrusted by algae. In colour many of the grains are grey, giving the sediment a generally dirty appearance. Many of the grains are worn, but if rounded, are still irregular and unpolished.

Despite the proximity of this zone to the shore, quartz is rarely important. When

present, it occurs as occasional very worn grains. Only around the Cerf Island reef-complex does quartz become significant, and here it is less worn.

(iii) *Open sand and algal ridge zone*

This zone consists of open sand areas with cobble ridges cemented by *Lithophyllum*, running normal to the reef edge and terminating some distance seaward of the grass zone. The cobbles have been piled on one another, forming, together with portions of the former Algal Rim which remain after the gradual advance of the reef edge, the ridges.

Coral clumps are common, their height being controlled by low-tide level. The infauna of the sands consists of the fast burrowing bivalves, *Tellinella* and *Quadrans*, and of the predatory prosobranchs, *Terebra*, *Conus*, *Pleuroploca* and *Oliva*. Sabellid and polychaete worms are important.

The algal ridges are clothed in a dense cover of *Sargassum*. The fauna is mostly an epifauna, *Drupa*, *Cypraeids*, *Coralliophilia* and *Trochus* being common. *Tridacna* and *Pteria* may be considered as infaunal. The echinoids *Tripneustes* and *Echinometra* are common.

Important species

PROSOBRANCHS

Cypraea helvola Linné
C. isabella Linné
C. lynx Linné
Drupa morum Röding
D. ochrostoma (Blainville)
D. ricinus (Linné)
Conus tessulatus Born
Terebra affinis Gray
T. crenulata (Linné)
T. laevigata Gray

BIVALVES

Pinctada margaritifera Linné
Tridacna elongata Lamarck
Quadrans gargadia (Linné)
Tellinella crucigera Lamarck
Fabulina rhomboides (Quoy & Gaimard)

ECHINOIDS

Toxoneustes gratilla (Linné)
Tripneustes pileolus (Lamarck)
Echinometra mathai (de Blainville)

CORALS

Acropora divaricata (Dana)
A. diversa (Brook)
A. pharaonis (Milne Edwards)
Pocillopora damicornis (Pallas)
Cyphastrea chalcidicum (Klunzinger)
Porites sp.

In contrast to the Grass Zone, the sands of this zone are white and finer, save where debris from colonies of branching *Acropora* occurs. Median diameters range from 0·20 to 0·60 mm, and sorting coefficients are around 1·3 to 1·6. The sediments become finer towards the reef edge, and better sorted (figures 1 and 2).

Encrusting algal grains form the bulk of the sediment, with coral fragments forming the next most important constituent. Benthonic foraminifera are of some importance. Debris from thick growths of *Halimeda* and *Amphiroa* is locally a major constituent. Quartz is insignificant, only occurring as rare well worn grains.

(iv) *The algal rim*

This is a cavernous structure, some $\frac{2}{3}$ m above the general reef level. It is formed by the encrusting calcareous red algae *Lithophyllum* and *Porolithon* and the branching *Amphiroa*.

The crevices contain pockets of loose, well sorted sands. These are composed of coral and algal grains, in similar proportions. Benthonic foraminifera are of some importance. Median diameters range from 0·15 to 0·25 mm and sorting coefficients are about 1·2. Both values are directly related to the high energy conditions of this environment.

The algal rim is covered by a dense coating of *Sargassum* which is gradually replaced by *Turbinaria* as the point of wave breaking is approached. The molluscan fauna is rather sparse as might be expected in an area of strong wave-action. The species which do occur, if exposed, are thick-shelled, strongly adherent forms such as *Turbo* and *Trochus*. Other molluscs occur beneath cast-up blocks of algal and coral material. These include several species of *Cypraea* and *Conus*, also *Drupa* and *Peristernia*. The echinoids *Diadema* and *Echinometra* occupy crevices in the rim.

Important species

Prosobranchs

Turbo argyrostomus Linné
T. setosus Gmelin
Trochus flammulatus Lamarck
T. maculatus Linné
Tectus mauritianus (Gmelin)
Cypraea fimbriata Gmelin
C. vitellus Linné
C. histrio Gmelin
Columbella turturina Lamarck
Peristernia nassatula (Lamarck)
Drupa morum Röding
Conus lividus Hwass
C. rattus Hwass

Echinoids

Diadema setosum (Leske)
Echinometra matthai (Blainville)

(vi) *Reef edge*

Two distinct reef edge coral communities can be recognized.

The Acropora *community*. This occurs on windward reef edges where the water is turbulent, because of wave action, and relatively clear. The corals tend to be branching types, although at the actual point of wave-break they are modified to short, stumpy forms. *Acropora* has the highest oxygen consumption of reef-building corals and also probably has the fastest growth rate in terms of the area occupied by the coral as opposed to the actual volume increase of the skeleton. The species characteristic, but not necessarily limited to this community, are:

Stylophora pistillata (Esper)?
Pocillopora danae-meandrina series
Acropora divaricata (Dana)
A. diversa (Brook)
A. humilis (Dana)
A. irregularis (Brook)
A. pharaonis (Milne Edwards & Haime)
Goniastrea retiformis (Lamarck)
Leptastrea purpurea Dana
Millepora (branching form)
Millepora (plate form)

The Porites *community*. This community is found characteristically around the edges of the many channels and gaps in the reef, particularly in the area from Anonyme to North-East Point. The waters here are quiet with little agitation. They also tend to be very turbid with fine, suspended matter. Along the actual channels reduced salinities occur. The colonies of this community tend to be massive and rounded. *Porites* is one of the most tolerant of coral genera. Mayor (1918) found that it can survive reduced salinities and Kinsman (1964, personal communication) recorded that it occurs in the Persian Gulf in extraordinarily high salinities. Manton & Stephenson (1935) found that *Porites* is efficient in removing fine sediment, but is less so with coarse sediment. The species characteristic of this community are:

Pocillopora eydouxi (Milne Edwards & Haime)
Porites sp.
Favia abdita (Ellis & Solander)
Goniastrea pectinata (Ehrenberg)
Leptoria phyrgia (Ellis & Solander)
Platygyra daedalea (Ellis & Solander)
Echinopora lamellosa (Esper)
Galaxea clavus (Linné)
Symphyllia sinuosa (Quoy & Gaimard)

(vi) *Fore Reef*

The bottom community consists mainly of small prosobranch and bivalve molluscs. The solitary corals *Heterocyathus* and *Heteropsammia* and the echinoid *Echinocyanus* are common.

Important species

PROSOBRANCHS

Fennela pupoides A. Adams
F. scabra A. Adams
Rissoina media Schwartz
Pyrene troglydytes (Souvier)
Nassarins albescens (Dunker)
Cythara euselma Melvill & Standen

BIVALVES

Arca navicularis Bruguière
Laevocardium biradiatum (Bruguière)
Ctenocardium sueziense Issel
Lioconcha picta (Lamarck)
Circe scripta (Linné)
Ervilia bisculpta (Gould)
Cadella semen Hanley
Tellina fabrefacta Pilsbry
Corbula subquadrata Melvill & Standen

The sediments of the Fore Reef pass rapidly into group 3 Bank sediments, the latter occurring within Victoria Harbour and even in the channels which are a feature of the reefs off Cascade. The Fore Reef sediments reflect closely the nature of the reef edge. For instance, where the *Acropora* community occurs, branching coral debris forms the bulk of the sediment. Remains of encrusting algae, echinoids, molluscs, bryozoans, crustaceans and of green algae are of varying importance. Benthonic foraminifera are often abundant. Similar sediments are also associated with some of the coral knolls in Victoria Harbour.

Superficially these sediments are not dissimilar to those belonging to group 1 of the Seychelles Bank sediments, but they are distinguished by the importance of reef-building coral remains, the presence, often abundance, of quartz and the occurrence of fragments of *Tubipora*. Despite considerable variation in the results of grain-size analyses, the sediments

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characteristically contain less than 0·3 wt. % of material finer than 0·045 mm and less than 5·0 wt. % of material finer than 0·125 mm. Median diameters are very variable, ranging from 0·50 to 2·50 mm. As already mentioned, such variations reflect the nature of the neighbouring reef-edge, and are to be expected.

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