THE PLAIN MAN'S GUIDE TO ENIGMATIC CORAL REEFS

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by

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Summary

Although by no means monomineralic, reefs are often enigmatic structures because the superficial homogeneity of their carbonate components renders their complex internal histories obscure to many forms of detection. This is particularly evident in the case of seismic studies of subsurface phenomena which tend to yield misleadingly uniform lensoid interpretations resulting from refraction at the shale:carbonate and sandstone:carbonate interfaces beyond the margins of the reef *sensu stricto*. But studies of random sections through reefs can be equally baffling in the field. The reasons for the ensuing confusion often results from attempting to compare different diagenetic grades of the same geological age. This account stresses the interdisciplinary nature of reef analysis irrespective of time by means of models and by analogy with present day tropical coral reefs. By drawing on case histories from Zanzibar and the Seychelles and comparing them with data from Bermuda, Bahamas, Florida and the Australian Great Barrier Reef, the oceanic provinciality of sediments is highlighted, and their local variability is related to their oceanographic and geomorphological setting and consequent settlement pattern which is often wind dominated. Then emphasis is placed on integrating ecosystem analysis of the biota and associated sediments with chemical predictions on the preservability of the fabric following burial in the vadose zone and subsequent loading. Intimate details of present day and vadose Pleistocene reef fabrics are illustrated by scanning electron micrographs which draw attention to the fact that quantitative data are only as good as the natural constraints put upon them. Thus one coral clast featuring no less than eleven adhesive dinoflagellates indicates that all the published sediment budgets are preferentially biased against the interstitial biota, the base of the food chain and the role of organic matter so limiting their potential for ecosystem analysis and biasing their palaeoecological utility. Though more readily quantified, this limitation is no worse than the geochemical parameters encountered during burial diagenesis : hence reefs range from the obvious to the obscure.

The enigma

Reefs fascinate geologists, seafarers, oceanographers, biologists, mareculturalists and tourists alike. Herein lies a major problem, that of semantics; this has tended to increase in direct relation to the burgeoning of the literature on what is essentially a multidisciplinary subject. The reason for this break-down in communication is simple : the geologist is faced with ghostly relics in the geological record, yet to interpret these phenomena he needs a good interdisciplinary knowledge which is hard to muster from a distant study of texts. It therefore follows that many misleading comparisons have been drawn which give rise to yet another generation of enigmas, so interpretation becomes increasingly speculative. This paper endeavours to outline some of the common hazards encountered in the geological interpretation of reefs and suggests some methods of coping with them.

The largest conundrum is that of the three dimensional distribution of reefs. In a few lucky instances, such as the well exposed and deeply dissected Devonian of the Canning Basin of Western Australia (Playford & Lowry, 1966), aerial photographic reconnaissance mapping reveals not only the details of discrete locally developed reefs within the reef system but also the regional morphology of the whole complex, but such clarity is unusual. More commonly, as with most seismic interpretations of the subsurface (text-fig. 1), reefs have been picked out because their essentially carbonate cores contrast with siliciclastic flanking sediments. Thus to many economic geologists reefs are effectively pod- or lens-shaped structures of variable lateral extent and thickness. In the seismic traces the most obvious signals come from refraction at the contact between seemingly homogeneous carbonates and heterogeneous bedded shales and sandstones which reflect geochemical and lithological differences. But the fact that much more can be derived from seismic interpretation of carbonate platforms is

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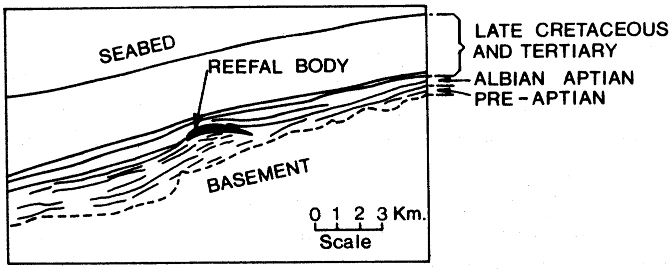
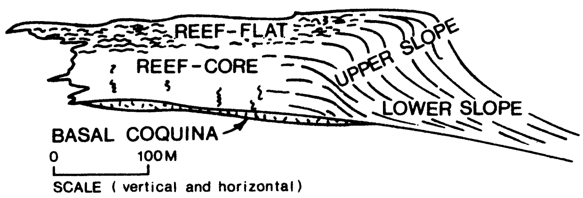
pp. 1-30, 27 text-figs., plates 1-4

eloquently demonstrated in talks on the evolution of the Maldives by Dr E.G. Purdy of Esso Exploration Inc.

The next problem arises from the fact that, as few reefs are well exposed, most geologists are forced to make palaeogeographic syntheses on limited data. Thus it is tempting to attempt to force findings into pre-existing models. The most popular of these is shown in transect form in text-fig. 2. Though, in a generalised way, this model has proved very effective (Wilson, 1975) it seems that many of its users overlook the potential of subtle facies variations within their own case histories, thus limiting the validity of their interpretations.



Text-fig. 1: A typical profile of a subsurface reefal body as detected by multichannel seismic reflections off the pre-Aptian and Albian-Aptian strata of the Porcupine Seabight area on the continental margin S.W. of the British Isles (after Masson & Roberts, 1981).



Text-fig. 2: Profile across a reef depicting the most popularly accepted facies belts of reef core, reef flat, upper and lower slopes on a basal coquina foundation as recorded for the Upper Permian Middle Magnesian Limestone shelf edge reef complex of N.E. England (after Smith, 1981).

The question that arises is how can we effectively improve upon the situation outlined. On the largest scale, to glean more information from seismic sources, strategically placed core, closely related to gamma ray and density - neutron porosity logs is required (Purdy, 1981). But such information needs to be interpreted by someone with experience of the sedimentology and geochemistry of present day analogous reefs and carbonate platforms. So far, only bedded structures have been detected seismically in the Maldives, and these are comparable to those forming around One Tree Island at the Southern end of the Australian Great Barrier Reef to-day (Davies & Marshall, 1981), but frame building reefs have yet to be reported. Not only are these internal textures needed for three dimensional reconstruction, but also, the variation in the geomorphologies of the underlying basement needs to be known. The latter are likely to be of critical importance in determining the resultant geometries, styles and extent of the reefs superposed on them (see Longman, 1981).

Turning to details, which have a considerable bearing on the interpretation of both local and regional geology, the most obvious factor to be considered is the comparability and variability of diagenetic grade. Even in such classic areas as the Canning Basin dispute has arisen over the geological history of the area as a result of earlier studies seemingly evading the diagenetic issue (see Logan & Semeniuk, 1976). Thus, to be effective, like grades must be compared. This, in turn, not only affects but is affected by the palaeontological record which is likely to be artificially skewed towards the silicic and low-Mg calcite members at the expense of the more readily soluble aragonitic and high-Mg calcite components. Hence the lithological end-product needs careful consideration: given a different diagenetic history, the same original sand can result in contrasting rock types with distinctively different biotas (see Reeckman, 1981), while the reef framework can give rise to even more misleading fabrics. Thus preservation has to be analysed carefully before pronouncements can be made on such variables as the influences of both provinciality, reflecting palaeo-oceanographic differences, and evolutionary change, which reflects the time factor.

In summary, the greatest problem facing the reef interpreter lies in the fact that a lack of comparative data on the variability of present day reefs exists with the result that oversimplification has taken place. Thus models based on the Atlantic - Caribbean province have artificially dominated recent thinking. This has resulted in difficulties where (1) data has been forced to fit unnecessarily simple models; (2) variations in microfacies have been ignored at the expense of refining the palaeogeography of the area. Notwithstanding the difficulties of applying uniformitarian principles to the interpretation of ancient environments this lecture attempts to highlight the applicability of some of the variables so encountered.

The consequences of inherited topography

If we accept the principle that inherited topography can have a profound influence on reef configuration (Purdy, 1974; James & Ginsburg, 1979), then it follows that we should consider the variability of facies which ensue. Text-fig 3 depicts the areas of the globe on which there is much intensive literature published in English.It draws attention to the contrasting hydrodynamic and geomorphic settings of the various tropical areas concerned. Though the Florida - Bahamas area has been best known for longest time (see Ginsburg, 1956), representing contrasting settings of drowned Quaternary and Pleistocene limestone terrains, they contrast strongly with the isolated volcanic complex on which Bermuda is founded (Garrett *et at*, 1971) and the even more disparate granitic foundation of the Seychelles Islands (Lewis, 1968). The variability of coastal configurations in relation to prevailing wind systems gives rise to a much greater range of facies patterns and successions than those outlined in synthesis in Hubbard & Swart (1982), herein summarised in text-figs. 4 & 5 respectively. Text-fig. 4 is based on an amalgamation of the salient features seen in transects across the present day Florida and Kenya coasts, where the stepped basement comprises pronounced wave cut platforms intersecting faulted coastal margins. Text-fig. 5 gives an idealised, hypothetical, lithological log of the sequence which could be expected to be formed on a marine regression across text-fig. 4. Within the tidal range, a similar sequence to that proposed could be formed equally well by invoking lateral impounding of the waters by storm induced blockage. But the fact remains that there is considerable variation in coastal configuration as exemplified by comparing the sheltered west coast of Zanzibar from the East African fringing reef system (text-fig. 6) with that of the generally open circulating, mid-ocean situation of Mahé on the Seychelles Bank (text-fig. 7). In turn, these Indian Ocean settings can be contrasted with those Caribbean - Atlantic localities already cited.

Having touched on the theme of the implications of topographic diversity of the basement, it is now proper to turn to the related topic of benthic settlement patterns and the resultant distribution of sediments. Firstly, the settlement of the reef system can be compared with the creation of a rock garden : there are taxa which withstand extremes and others which require shelter. But the majority are fairly hardy and consequently ubiquitous. The tidal regime, current strength, temperature and nutrition impose constraints. In intertidal areas the degree of wetness and desiccation are associated with salinity changes and concomitant chemical fluxes which add further burdens to the ecosystem. In the subtidal areas, fresh water springs and variations in lighting are the chief hazards. Secondly, sedimentation both affects and is affected by benthic distribution patterns : there are regional differences between the gross sediment populations of the Indian Ocean and Caribbean - Atlantic areas described (text-fig. 8). The Indian Ocean populations are more comparable with Pacific distributions, as evidenced by the Australian Great Barrier Reef (Maxwell, 1968), than with the Caribbean – Atlantic province. Thirdly, whereas the present day carbonate sediments of Florida, the Bahamas and Bermuda are all formed on

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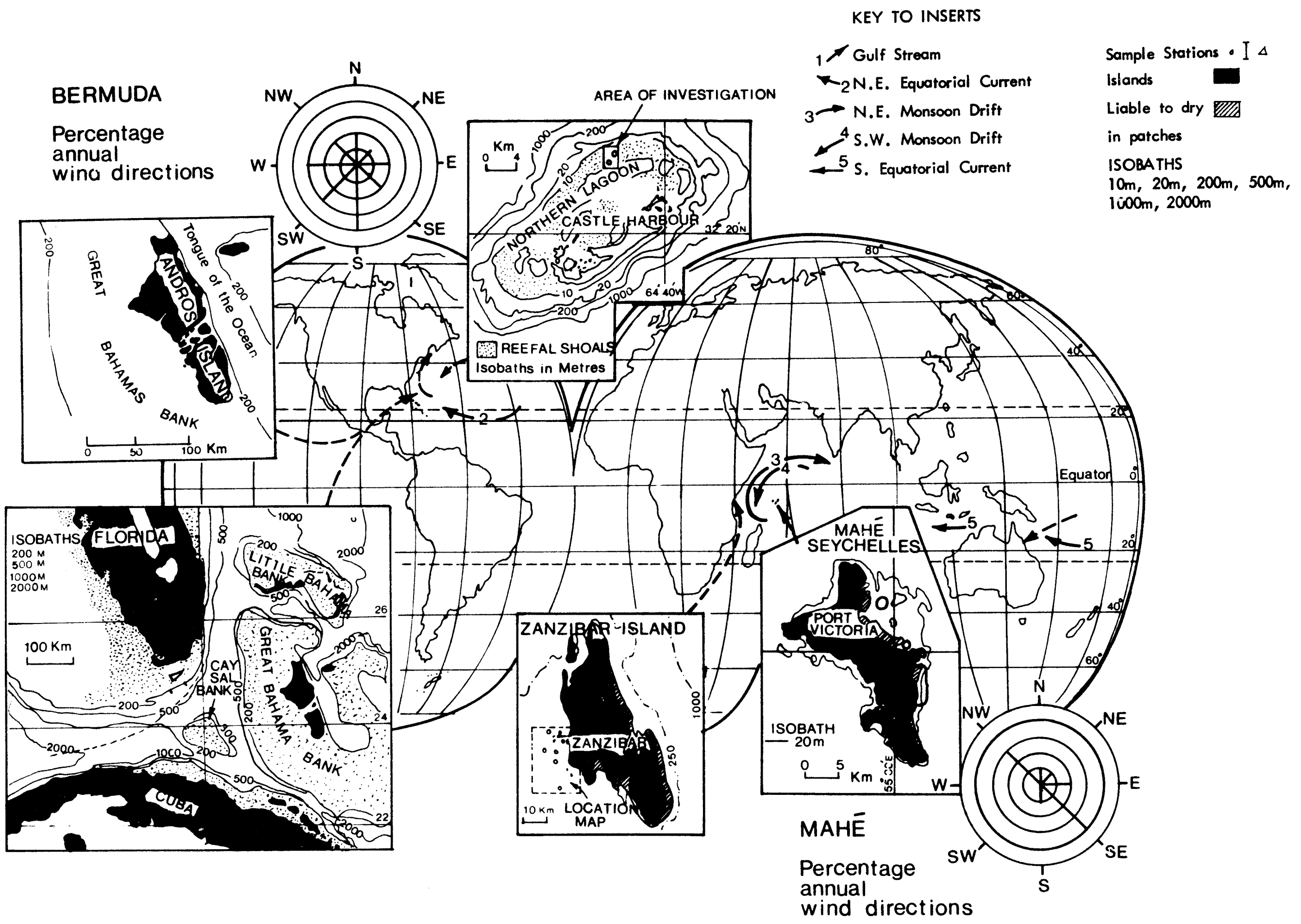
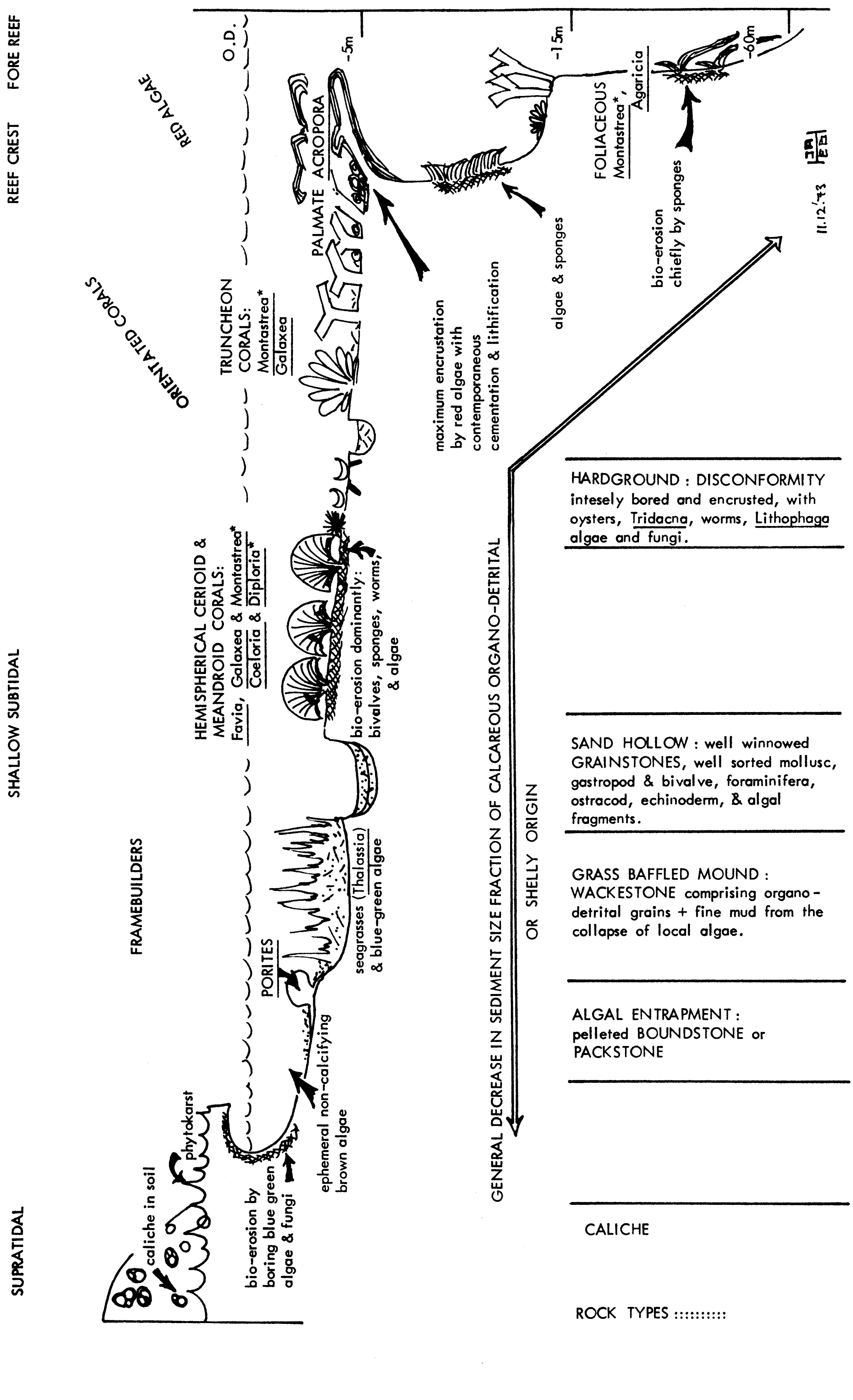
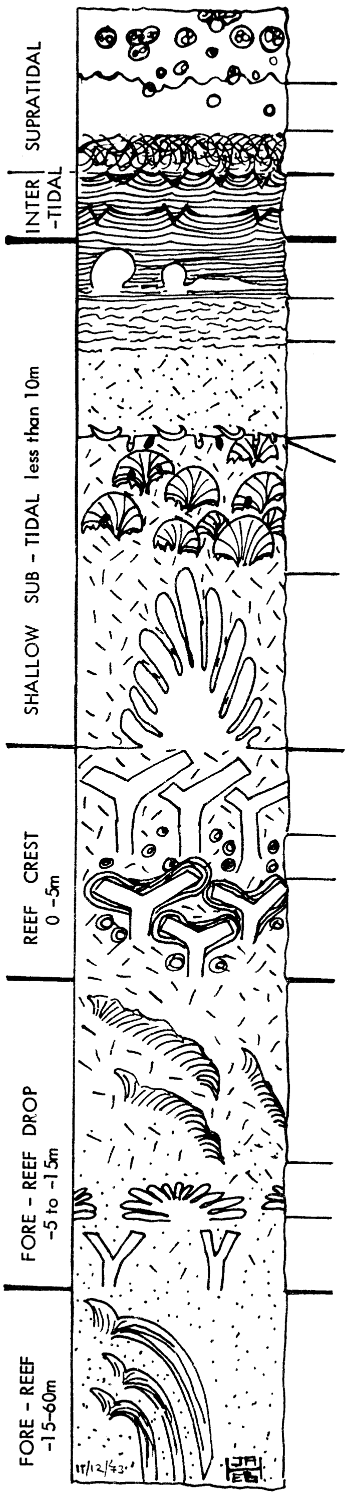


Text-fig. 3: Map of the World to highlight the distribution of the sedimentologically best known carbonate producing tropical reef systems in relation to their oceanographic settings (after Ginsburg, 1956; Lewis, 1969 and Garrett *et al*, 1971).



Text-fig. 4: Schematic section across an idealised reef to show frame-building organism – sediment relationships and their subsequent rock types based on Atlantic – Caribbean and Indian Ocean counterparts. Where these are paired the former are marked with asterisks.



Laterite, caliche or fossil soil.

Unconformity

Calichefield fossil karst - much altered limestone

Limestone ramified with small boring algal and fungal tubes relic from phytokarst

Pelleted fine grained sediments , mud-cracked in the supra-tidal - cracks or polygons increase in size towards the damper areas i.e. towards the sea, pools, or distributaries.

Porites heads and sheets in fine wackestone , the matrix is often pelleted resulting from reworking by herbivorous gastropods (Cerithium & Batillaria).

Algal bound pelleted packstone or boundstone.

Wackestone - bafflestone of algal-mollusc-foraminiferal-echinoderm frame fragments reworked from the contiguous seaward environment with an addition of locally derived fines giving a mud component.

Hardground, disconformity, encrusted with oysters and bored by Lithophaga et al.

HEMISPHERICAL CORAL HEADS characteristically cerioid or "honey comb" (Favia) , meandroid or "brain-like" (Diploria*/Coeloria) in a Halimeda rich algal grainstone matrix with intraskeletal borings filled with locally derived mudstone.

TRUNCHEON type framebuilders with Halimeda algal grainstone matrix.

LOW ANGLE Y (PALMATE) GROWTH of Acropora in Halimeda grainstone

"Rhodolithic" or "Rhodolite" encrusting red algal fragments and indigenous Lithothamnion balls.

PALMATE ACROPORA CHARACTERISTICALLY COATED WITH ENCRUSTING RED ALGA (LITHOTHAMNION) distinguishing the area subject to sporadic desiccation when extreme low tides coincide with a lack of cloud protection.

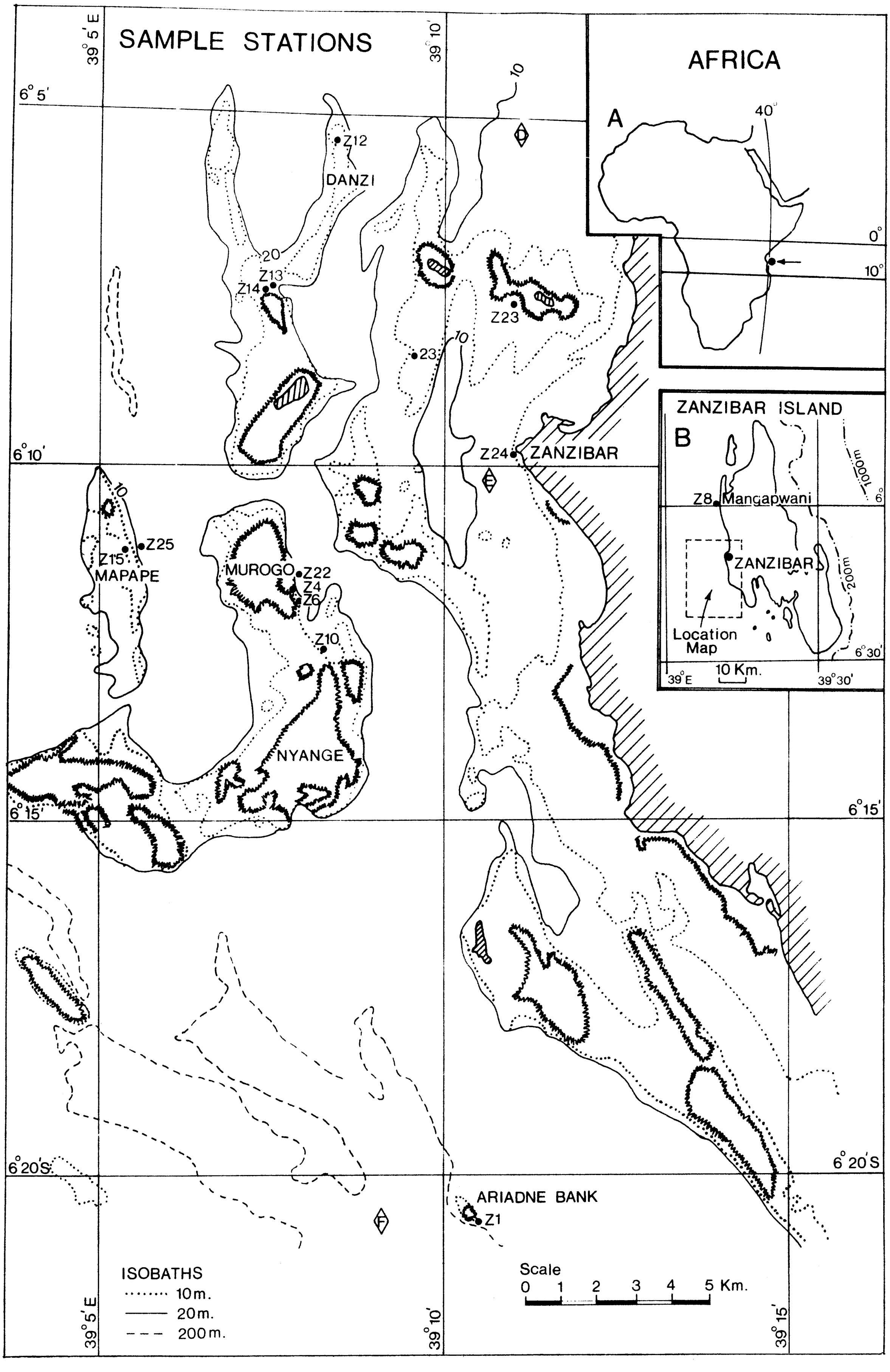
ASYMMETRICAL ENCRUSTING CORALS containing oblique geopetal fabrics filled with locally derived mudstone and set in a matrix of Halimeda grainstone.

SQUAT SCRUBBY TRUNCHEON MOUNDS of Montastrea*/Galaxea set in a grainstone matrix.

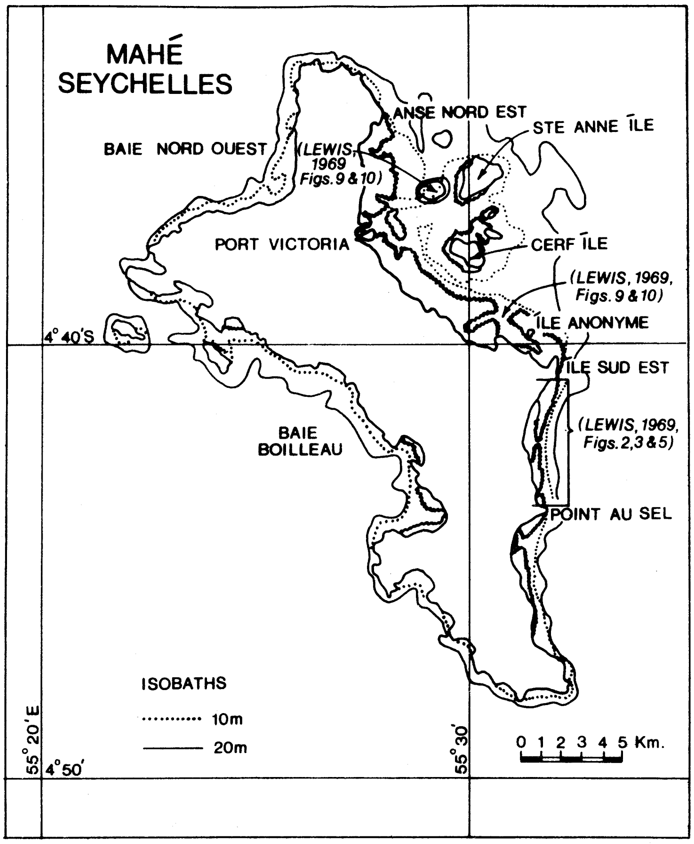
STEEP Y (PALMATE) GROWTH of Acropora set in a Halimeda grainstone matrix.

FOLIACEOUS GROWTH FORMS, heavily infested with sponges, and thereby extremely prone to collapse if subjected to the slightest currents; set in a wackestone or mudstone matrix.

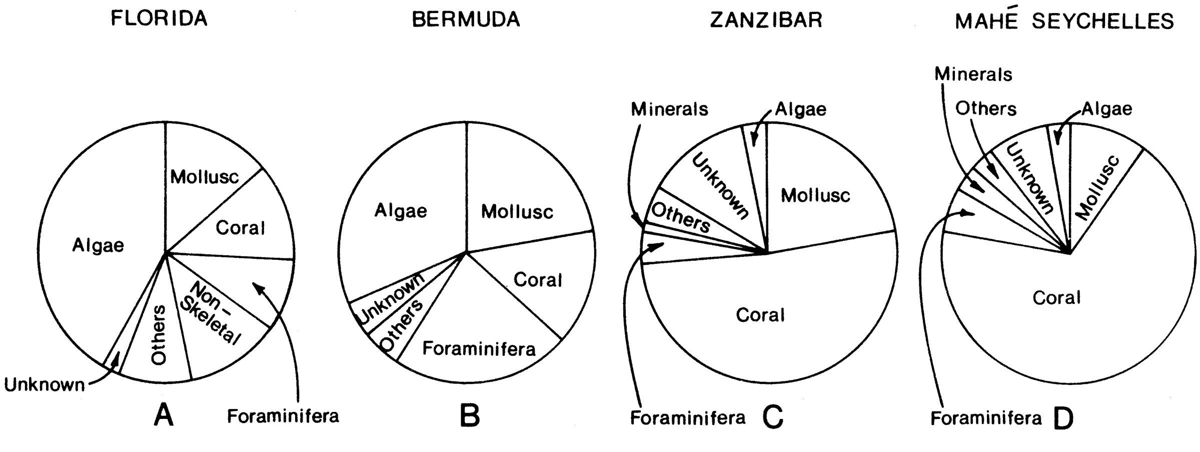
Text-fig. 5: Schematic section through a regressive cycle in a Recent – Pleistocene coral – algal reef based on the hypothetical profile outlined in text-fig 4. As in text-fig 4 where Atlantic – Caribbean and Indian Ocean coral counterparts are paired the former are denoted with asterisks. N.B. since preservation is dependent on the amount and intensity of contemporaneous bio-erosion and subsequent erosion and diagenesis, complete preservation is unlikely.



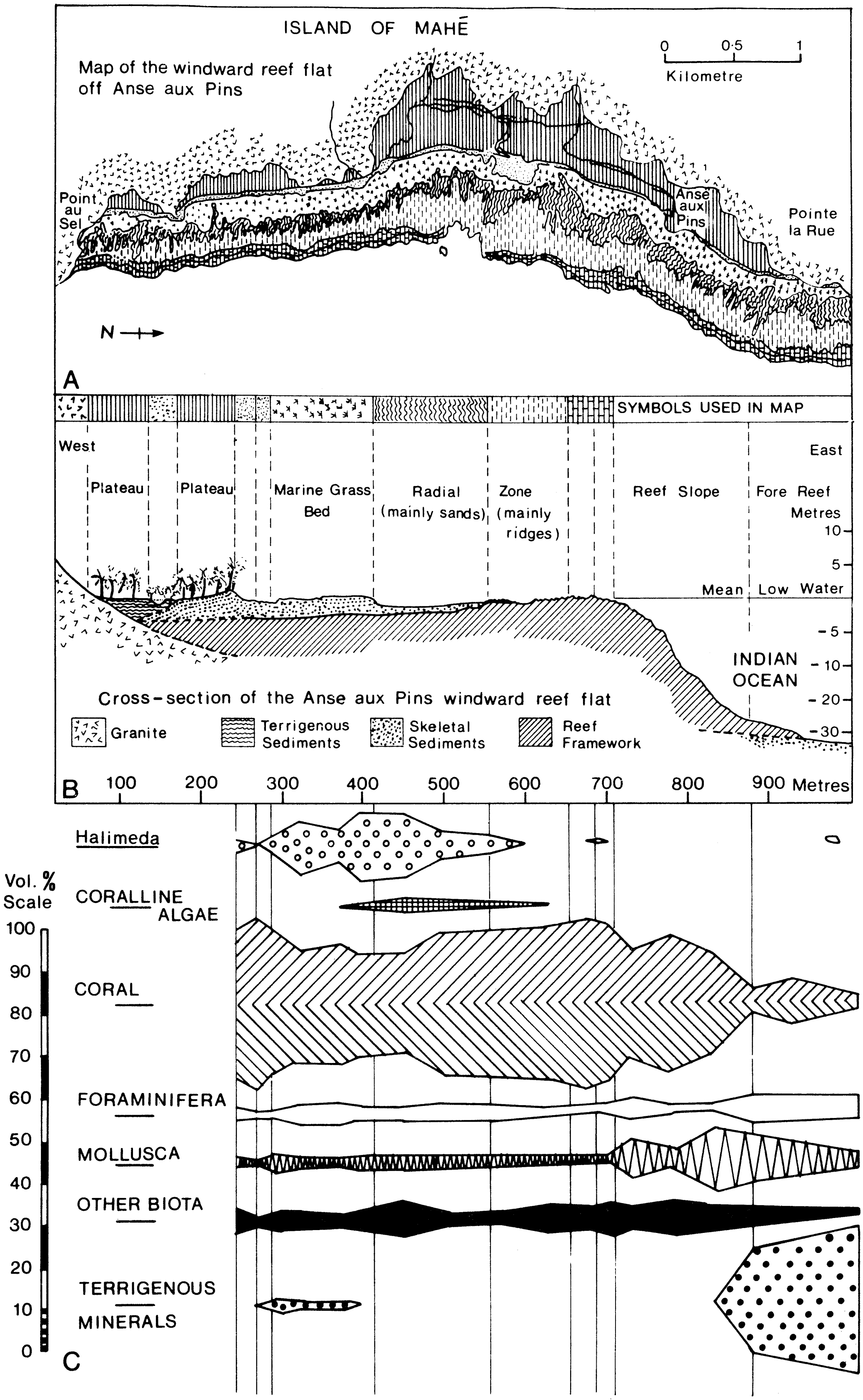
Text-fig. 6: Map of the regional setting of Zanzibar in relation to the African continent (A), and of the local sediment – sampling stations west of Zanzibar in relation to the shelter provided by Zanzibar Island in general (B).



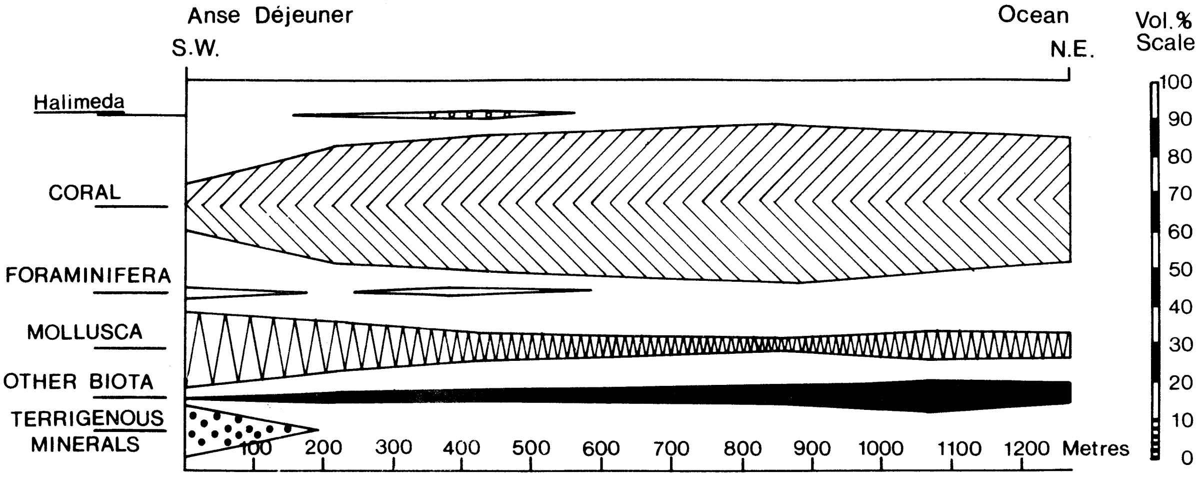
Text-fig. 7: Detailed map of Mahé, Seychelles, to show the variations in coastal configuration and localities from which Lewis (1969) took sediment samples. For half the year the Ísle Sud Est – Pointe au Sel coast is the windward side, while the Port Victoria – Ísle Ste Anne – Cerf – Annonyme area is sheltered throughout the year.



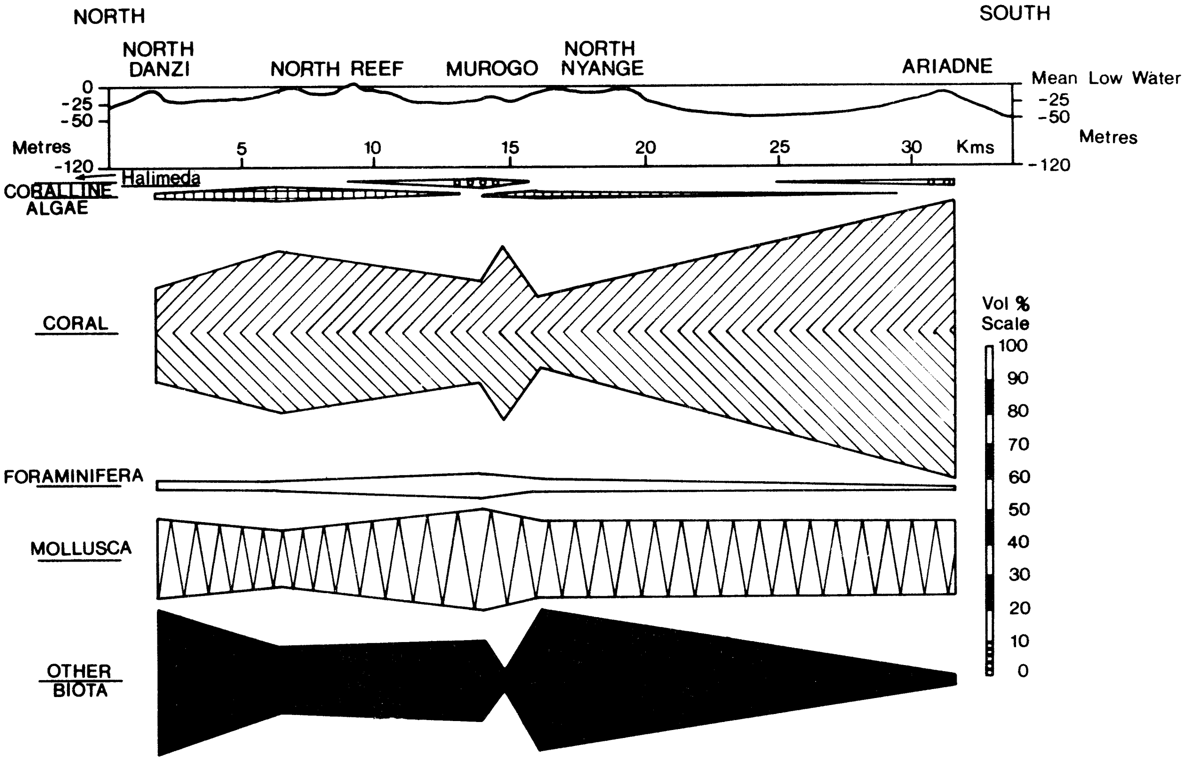
Text-fig. 8: Gross composition of the sediments of Florida (A), Bermuda (B), Zanzibar (C) and Mahé (D) plotted as pie diagrams to emphasize the degree of similarity between areas from the same Ocean (A & B; C & D) and dissimilarity between the Oceans (A & B versus C & D). Notably, whereas the epifaunal coral does not exceed 20% of either A or B it exceeds 50% in both C & D, while the epifloral algae have the reverse representation occupying more than 25% in both A & B and less than 10% in C & D.



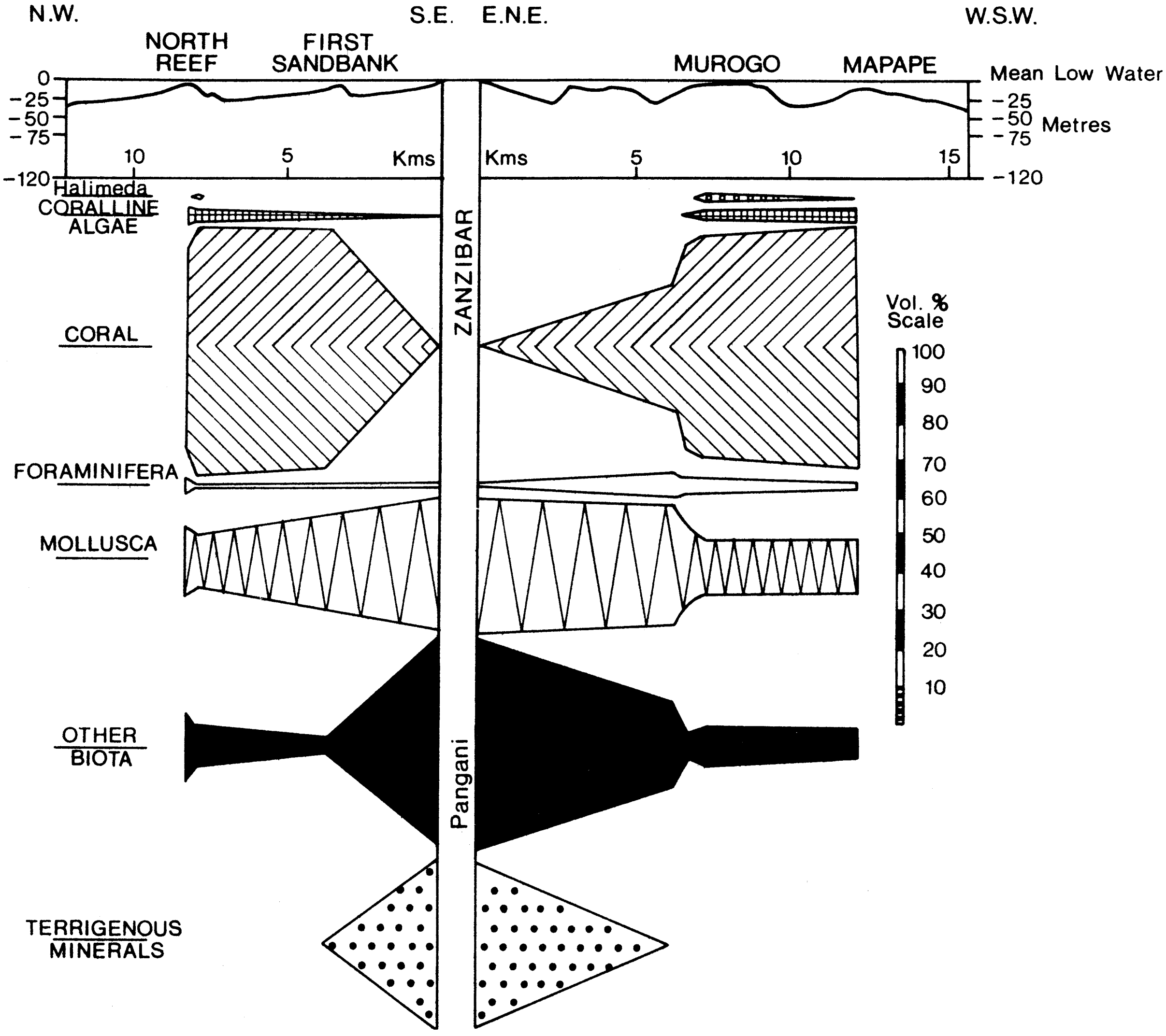
Text-fig. 9: The sediment distribution patterns of the windward reef flat of Anse aux Pins, S.E. Mahé, Seychelles (text-fig 7) are summarised in relation to (A) a map of the local setting, (B) a profile across the area, and (C) a graphical presentation of the variations in constituent composition of the sediment fraction larger thn 0.125mm in diameter across the profile (B). (A & B are after Lewis, 1969)



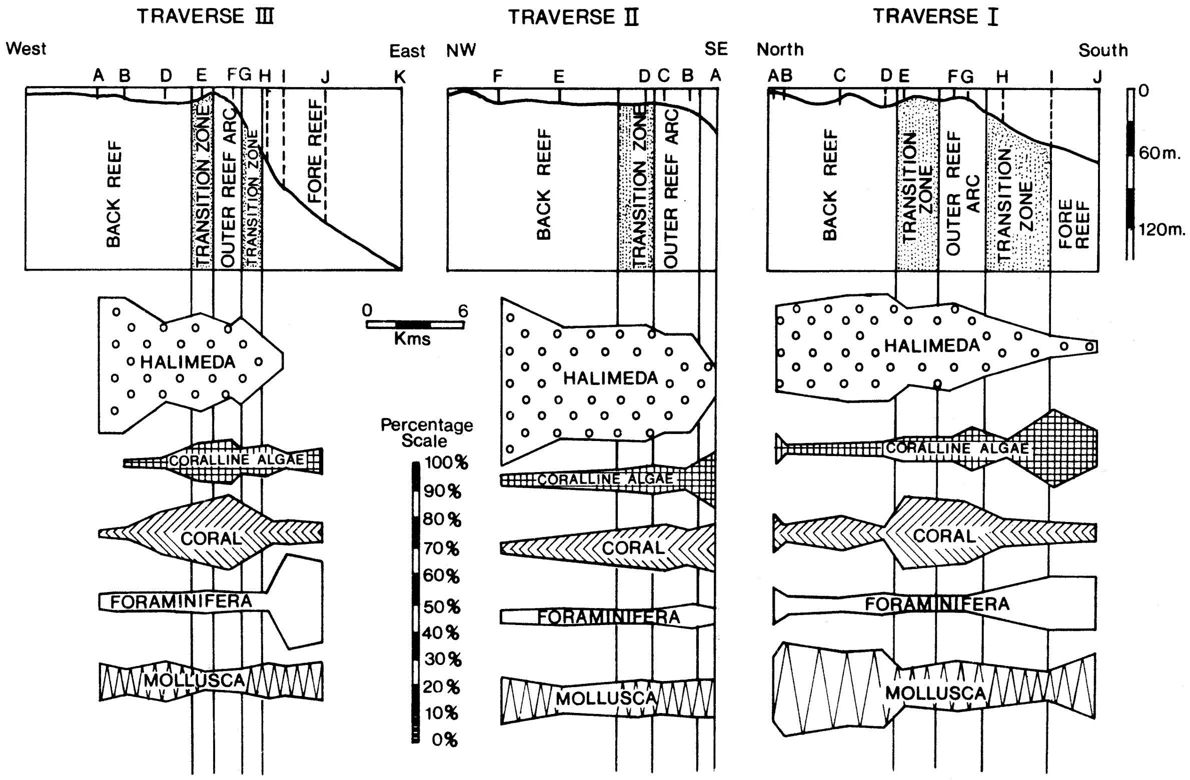
Text-fig. 10: Graphical representation of the sediment distribution patterns of the variations in constituent composition of the sediment fraction larger than 0.125mm across the sheltered reefs seawards of Anse Déjeuner, near Ísle Anonyme, E. Mahé, Seychelles (text-fig. 7).



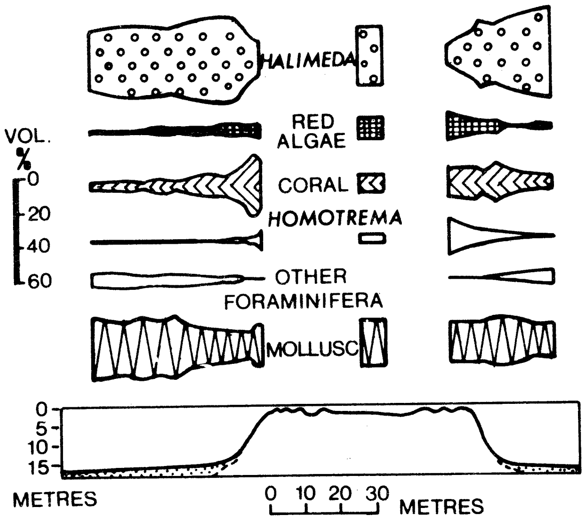
Text-fig. 11: The sediment distribution patterns of the more open circulating sheltered waters seawards of Zanzibar along a profile (A) from N. Danzi in the more restricted North to Ariadne in the more open circulating waters of the South (see text-fig. 6) to show variations in constituent composition of the sediment fraction larger than 0.25mm (B).



Text-fig. 12: The sediment distribution patterns of Zanzibar illustrating the effect of terrigenous in - put at Pangani (B) on the variation in constituent composition of the sediment fraction larger than 0.25mm approximately north west and west of Pangani (A) (text-fig. 6).



Text-fig. 13: A graphical presentation of three profiles across the Florida reef tract (A) to show the variation in constituent composition of the sediment fraction greater than 0.125mm (B) on the open shelf (see text-fig. 3). (After Ginsburg, 1956).



Text-fig. 14: A graphical presentation of the variation in constituent composition of the sediment fraction larger than 0.25mm across the comparatively sheltered Make - Do patch reef, N.W. Bermuda (see text-fig. 3). (After Garrett *et al*, 1971).

pre-existing limestones, the Seychelles, being mounted on a granite, has a considerable siliciclastic in-put. The Zanzibari sediments, by contrast, contain reworked Miocene millet seed dune quartz and heavy minerals from another source.

The range of variability in present day sediment distribution patterns in the Seychelles is well exemplified by Lewis (1969), here synthesised in text-figs. 9 & 10. The former is concerned with the windward profile, while the latter refers to the sheltered reefs. These are matched with comparable plots showing the influence of opening circulation (text-fig. 11), and of terrigenous in-put (text-fig. 12), on the more sheltered coral thickets of Zanzibar.They contrast with the distributions around windward Florida (text-fig. 13) and leeward Bermuda (text-fig. 14).

The influences of provinciality

The most obvious present - day expression of provinciality exhibited by the Indian Ocean as compared with Atlantic - Caribbean biotic distribution is to be found in the ratio of algae to corals. This is marked in the sediment analyses of the Indian Ocean localities, which are consistently higher in their coral component (see text-fig. 9,10,11 & 12), while the Atlantic - Caribbean province are equally consistently dominated by algae (see text-fig. 13 & 14). This Indian Ocean trend is found to extend both into the marginal conditions of Arabian Gulf (Purser, 1973) and into the open circulating system of the Pacific of the Australian Great Barrier Reef (Marshall, 1968). This is perhaps a little surprising when the geographical settings of the sampling areas are considered : the Atlantic - Caribbean and Zanzibari samples are all subtidal in origin, but much of the Seychelles profile lies in the intertidal. In terms of preservation potential there are profound implications in these distributions. The corals and many of the algae are aragonitic, they will be unstable in groundwaters and are liable to be dissolved; at best they are likely to occur as moulds. The coralline algae, by contrast, are calcitic and as such have a chance of detailed preservation.

In quantitative terms the provinciality of the sand-sized sediments discussed is well illustrated in text-fig. 15, while the effect of environment on these distribution patterns is emphasised in text-fig. 16, and their comparability with Australian data is highlighted in text-fig. 17. That there is a certain general consistency superimposed upon local variation can be detected in all these areas (Ginsburg, 1956; Garrett *et al*, 1971; Lewis, 1969; and Maxwell, 1968) including Zanzibar (text-fig. 18). That the Zanzibari sediments bear a very close relation to the thickets of corals which produced them is evident from the fact that they lie loose on a lithified Miocene dune substrate. Thus they are, like petals in a rose garden, closely identifiable in contrast to those of the majority of areas where present day corals grow on inherited Pleistocene reef limestones. On the whole there are more similarities within localities than between similar depth intervals at different localities; the differences here are set by initial settlement patterns.

That scleractinian coral settlement patterns would appear to be hierarchically organised is perhaps more apparent in the more limited populations of the Atlantic - Caribbean province than in the Indo - Pacific (see Hubbard, 1974). Certainly the model given in text-fig. 19, which is based on Atlantic - Caribbean distributions, requires modification in that the Indo - Pacific communities would appear to be dominated generally by foliaceous and branching rather than head forms with the result that the common patch reef outlined is less conspicuous, while complex thickets of shingling, leafy and arborescent growth abound. Thus the resultant geometry, on preservation, will be considerably more complex than the simplified model given in text-fig. 20 which is based upon the modification of a head coral. That such complexities in the variations in scleractinian coral distributions already exist in the pleistocene of East Africa are clearly evidenced by taxonomic and palaeoecological studies (Crame, 1980 & 1981).

The partiality of preservation

Preservation can be described in two forms *viz* real and apparent. The former concerns three dimensional structures in their entirety from general configuration to the intimate details of atomic lattice structure. The latter, by contrast, is a visual anomaly that results from the aberrations that planar sections through three dimensional forms can produce. Text-fig. 20 synthesises the first problem by reference to data obtained from a median section through one coral head in different circumstances. The point of origin in the ecosystem is totally integrated, but what can be inferred from it depends not only on its actual state of preservation, but also on the analysts' capacity for interpreting data perceived. At a glance it is evident that the mouldic form of preservation (text-fig. 20H) is difficult to interpret: in fact this is merely the mirror image of text-fig. 20F which is a montage of repetitions of the initial unit (text-fig. 20A) having undergone the sorts of preservation outlined in text-figs. 20E & 20G. Precisely how much detail will be discernible is dependent on how the specimen has been preserved (see Cullis, 1904). In an area where the unit has been buried in a coarse sand and then been subjected to vadose cementation a mould resembling text-fig. 20B may result. By contrast, if initially cemented at the reef crest and coated in red algae or embedded in clays and fine sediments, then a state more comparable to text-fig 20C might arise.

Text-fig. 21 summarises the second problem, that of having to work with optical illusions caused by random sections through imperfectly preserved materials. Text-fig. 21A represent a hemispherical cerioid or plocoid coral preserved in its entirety, while its bioeroded state is depicted in text-fig. 21B. Text-fig. 21D is a variant on the theme, it represents a fasciculate coral in its entirety as compared with its bioeroded counterpart (text-fig. 21E). As with variations in interpretation of the whole corallum, corallite geometry also appears different in various planes of section : true cross sections (text-figs.-21, A3.2, 21, B3.2, & 21, D3.2) appear to be circular, while oblique sections appear to be oblong (Text-figs 21, A2.2, 21, B2.2, and 21,D2.2). More misleading still is the fact that different planes of section through the corallum can result in misinterpretations of the size of the coralla concerned: marginal sections (text-figs. 21, A4, 21, B4.1, & 21, D2.1) appear to be smaller than their median counterparts (text-figs. 21, A1, 21, B1, & 21, D1). Thus random sections through a collection of coralla and their associated matrices can lead to a variety of interpretations on their palaeoecology and distribution patterns. Similarly the planes of sections through either a deeply bioeroded hemisphere or an initially mushroom-shaped corallum can be equally misleading (see text-figs. 21, B42.1 to 21, B4.6). As if these problems alone were not enough to contend with, there remains a further variable, that is the state of preservation of the component parts, here illustrated by reference a section of the theca and three septa (text-fig. 21,C). Text-fig. 21, C1 shows the skeleton in its entirety, text-fig. 21, C1.1 show the affects of dissolution and precipitation on the same skeletal elements, while text-fig. 21,C1.2 shows its weakening by infestation by endolithic algae and fungi, its preservation by coralline algal encrustation (text-fig. 21, C1.3) and its disintegration by boring sponges (text-fig. 21, C1.4).

So far, in considering 'apparent' variables we have concerned ourselves with phenomena that can readily be checked by using careful measurements of the three dimensional geometrical inter-relationships of the corallites to coralla and of the corallites' details to endoliths, epiliths, cements and sediment-matrices. This means firstly, recording the angles of divergence of internal and external features in order to reconstruct the coralla; then, secondly, relating these data to the sedimentological interpretation of their histories of accumulation and subsequent diagenesis. The models illustrated in text-figs. 20 & 21 are comparatively simple. Supposing the corals are scleractinians they would originally comprise aragonitic skeletons, which in life may record subtle chemical variations (see Swart & Coleman, 1980), but they have little hope of recording the majority of such details on fossilisation: most of the corallum is likely to be dissolved and replaced by low-Mg calcite, only by lit-par-lit cementation can the details be recorded in the associated endoliths and epiliths. The calcitic encrusting algae and bryozoa stand a good chance of detailed preservation and a stable geochemical trace. But, though some secrete calcareous tubes, many of the worms by contrast, are only liable to leave their siliceous cetae and jaw apparatuses in the associated sediments; like the zooxanthellae, on which so much of the corals' metabolism depends, being both loose and tiny they are liable to get washed leewards and landwards of their sites of origin. Whether the boring and encrusting bivalve molluscs are preserved in detail, in part, or as moulds, would depend on whether their skeletons are composed of calcite, mixed calcite and aragonite or solely aragonite respectively. Similarly, precisely how much of the integrity of the voids is recorded would depend on their histories of coelobitic encrustation, internal sedimentation and cementation. In the Pleistocene reef facies of East Africa mouldic preservation of endoliths and coralline algae is common (see Hubbard & Swart, 1982).

Turning to the preservation of corals (text-fig. 21, C1, C1.1, C1.2, C1.3, & C1.4) it is possible to predict the areas in which these styles most commonly occur. Specimens with advanced dissolution and syntaxial precipitation (text-fig. 21, C1.1) are most likely to have experienced an history of burial including a phase in the splash zone of the supratidal area; while specimens which are riddled with bacteria and endolithic algae and fungi (text-fig. 21, C1.2) are best developed in the intertidal zone, though also known from the subtidal. Those corals most heavily encrusted with coralline algae commonly occur on the reef crest and in areas of high energy exposed at low tide (text-fig. 21, C1.3). Those with endolithic sponges beneath the coralline algae (text-fig. 21, C1.3) frequently occur seawards of the reef crest, but are not unknown landwards of it too. The same phenomena affect coral clasts and as such can be used as indicators of coastal proximity (Hubbard, 1976; Hubbard & Swart, 1982). The most heterogeneous facies represented is the storm ridge which accumulates the products of a succession of drastic events. Migrating just seaward of this and slightly more homogeneous are the clasts of the strand line shingle. While the highly infested algal - fungal - bored assemblage represents much of the intertidal storm debris; the coralline algal encrusted debris is largely derived from near the reef crest and analogous high energy which are subject to sporadic

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AVERAGE GRAIN SIZE AND CONSTITUENT COMPOSITION OF REEF-TRACT SEDIMENTS FROM FLORIDA, BAHAMAS, BERMUDA, ZANZIBAR AND SEYCHELLES.

	FLORIDA REEF TRACT (GINSBURG, 1956) (25 SAMPLES)	BAHAMAS		BERMUDA PATCH REEF (GARRETT et al, 1971) (TABLE 3) (3 SAMPLES)	ZANZIBAR REEF THIS PAPER (13 SAMPLES)	SEYCHELLES (LEWIS, 1969) (FIGS. 10 & 12) (60 SAMPLES)
		REEF TRACT (FIG. 11) THORP (1936) (10 SAMPLES)	MARGINAL SHELF EASTERN BAHAMAS ILLING (1954, p.17) (5 SAMPLES)			
GRAIN SIZE WEIGHT PERCENTAGE LESS THAN $\frac{1}{16}$ mm.	9	4	0		8	6
CONSTITUENT COMPOSITION						
ALGAE	42	30	39	35	4	4+
MOLLUSC	14	15	18	25	22	10
CORAL	12	12	12	13	51	68*
FORAMINIFERA	9	26	13	16	4	5
NON-SKELETAL	12	9	14	-	-	3
MISCELLANEOUS	9	8	4	5	7	6
UNKNOWN	8	-	0	6	12	4

Text-fig. 15: Tabular summary of the average grain size composition of the reef tract sediments from Florida, Bahamas, Bermuda, Zanzibar and Seychelles showing distinct oceanic provinciality. * Category includes reef building organisms, corals and algae. + Category includes both the free standing red alga *Amphiroa* and the free standing green alga *Halimeda*.

REGION	FLORIDA (GINSBURG, 1956)		BAHAMAS (THORP, 1936)		BERMUDA (GARRETT et al 1971) (TAB. 3)	ZANZIBAR (THIS PAPER)		SEYCHELLES (LEWIS, 1969) (FIG. 5)						(FIG 10)	(FIG. 2)
SITES	FLORIDA BAY (17 SAMPLES)	REEF TRACT (25 SAMPLES)	WEST SIDE ANDROS IS. (FIG. 10)	REEF TRACT ANDROS IS. (FIG. 10)	PATCH REEF ((3 SAMPLES)	TOWN * (1 SAMPLE)	REEF (13 SAMPLE)	BEACH (5 SAMPLES)	RIPPLED SANDS (1 SAMPLE)	GRASS BED (10 SAMPLES)	RADIAL ZONE (21 SAMPLES)	ALGAL RIDGE (4 SAMPLES)	REEF EDGE (3 SAMPLES)	SHELTER REEF (6 SAMPLES)	WINDWARD FORE-REEF (10 SAMPLES)
GRAIN SIZE WEIGHT PERCENTAGE LESS THAN $\frac{1}{8}$ mm.	49	17	68	4		11	8								
CONSTITUENT COMPOSITION															
ALGAE	½	42	5	30	35	-	4	1+	½+	13+	8+	3+	½+	1+	-
MOLLUSC	76	14	14	15	25	36	22	4	1	6	4	4	3	18	16
CORAL	0	12	0	12	13	-	51	78*	80*	67*	67*	79*	76*	67*	46
FORAMINIFERA	11	9	23	26	16	1	4	3	2	4	4	4	5	1	10
NON-SKELETAL	3^4	12	48^5	9	-	-	-	-	-	-	-	-	-	5	5
MISCELLANEOUS	½	9	10	8	5	16	7	3	1½	5	6	10		7	9
UNKNOWN	1	8	-	-	6	1	12	11½x	15x	3x	3x	3x	1x	1	-
OSTRACODS	2	-	-6	-6	-	-	-	-	-	-	-	-	13	-	-
QUARTZ	6	-	-	-	-	44	1	-	-	-	-	-	-	5	14

Text-fig. 16: Tabular summary of the comparison of grain size and constituents of the sediments from Florida, Bahamas, Zanzibar and Seychelles showing the influence of environmental setting on quantitative in - put. * Category includes reef building organisms, corals and algae. + Category includes both the free standing red alga *Amphiroa* and the free standing green alga *Halimeda*.

AVERAGE GRAIN SIZE AND CONSTITUENT COMPOSITION OF SEDIMENTS FROM FLORIDA BAY AND REEF TRACT, BERMUDA PATCH REEFS, ZANZIBAR THICKETS, SEYCHELLES AND AUSTRALIAN GREAT BARRIER REEF

	FLORIDA BAY (17 SAMPLES¹)		REEF TRACT (25 SAMPLES)		BERMUDA PATCH REEFS (GARRETT 1971) (23 SAMPLES ?)		ZANZIBAR THIS PAPER (13 SAMPLES)		SEYCHELLES (LEWIS 1969) (60 SAMPLES)		GREAT BARRIER REEF AUSTRALIA (MAXWELL 1968)	
	Average %	Range %	Average %	Range %	Average %	Range %	Average %	Range %	Average %	Range %	Range %	
GRAIN SIZE WEIGHT PERCENTAGE LESS THAN mm. <+3ø	49	10-85	17	0-68			8	0-33	6	0-12	Reef	Inter Reef
CONSTITUENT COMPOSITION OF FRACTION GREATER THAN mm. <+3ø												
ALGAE	½	0-1	42	7-61	35	28-47	4	1-8	4+	0-34	27-70	5-80
MOLLUSC	76	58-95	14	4-33	25	23-27	22	15-34	10	0-39	4-15	20-35
CORAL	-	-	12	2-26	13	9-17	51	25-76	67 *	11-86	20-40	5-10
FORAMINIFERA	11	1-32	9	3-32	16	2-23	4	0-8	5	0-17	8-20	15-40
NON-SKELETAL	3	0-3	12	3-24	-	-	-	-	-	-	-	-
MISCELLANEOUS	½	0-4	9	2-23	5	5-6	7	0-38	7	1-20	0-5	5-30
UNKNOWN	1	0-3	8	4-15	6	5-7	12	-	4	-	-	-
OSTRACODS	2	1-6	-	-	-	-	-	-	-	0-2	-	-
QUARTZ	6	0-20	-	-	-	-	1	0-1	3	0-63	-	-

1 Only surface scoop samples and the upper parts of cores are included in this average

* Catergory includes reef building organisms, corals and algae

\+ Amphiroa and Halimeda

Text-fig. 17: Tabular summary of the average grain size and constituent composition of sediments from Florida, Bahamas, Zanzibar and Seychelles compared with those of the Australian Great Barrier Reef. *Category includes reef building organisms, corals and algae. + Category includes both the free standing red alga *Amphiroa* and the free standing green alga *Halimeda*.

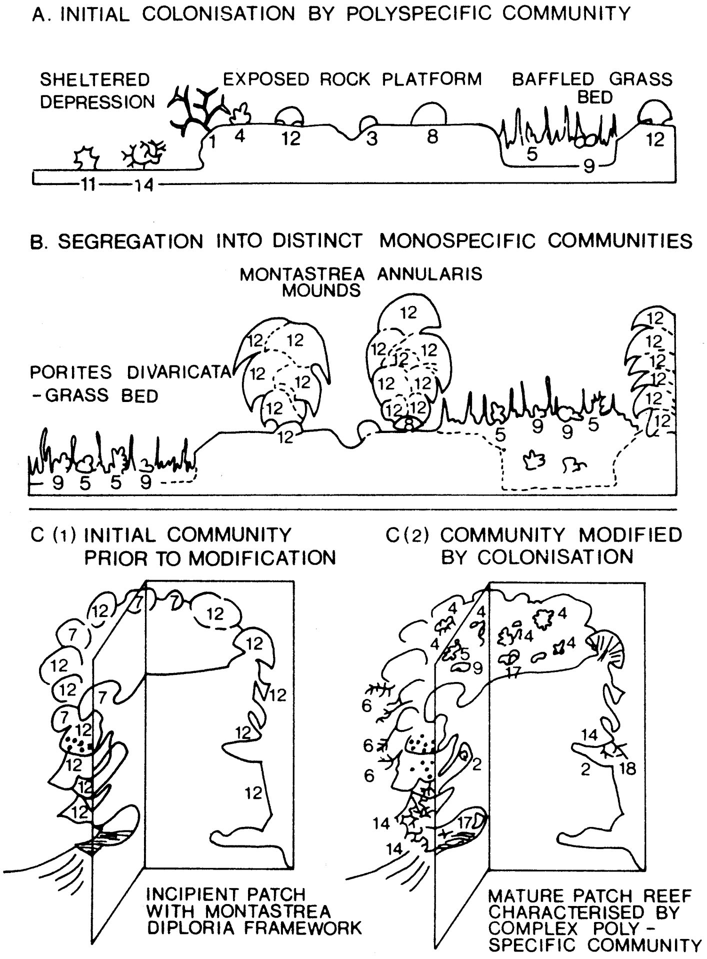
CONSTITUENT PARTICLE COMPOSITIONS % GREATER THAN ¼mm.		SAMPLE NUMBER LOCATION AND DEPTH	GRAVE ISLAND Z23-8'	FIRST SANDBANK Z3-20'	MUROGO LAGOON Z6-5'	MUROGO LAGOON Z4-30'	MUROGO LAGOON Z22-66'	MAPAPE Z15-15'	MAPAPE Z25-75'	N. NYANGE Z10-20'	NORTH DANZI Z12-20'	MANGAPWANI Z8-4'	NORTH REEF Z14-6'	NORTH REEF Z13-40'	ARIADNE Z1-40'	LABORATORY FILTER Z24-12'
ALGAE		Halimeda	-	-	4	-	-	-	3	-	-	-	-	-	2	-
		CORALLINE ALGA	8	2	3	1	-	7	1	1	2	1	7	4		-
MOLLUSCA		GASTROPOD	10	4	5	6	5	4	6	10	5	6	3	5	-	11
		BIVALVE	20	19	10	20	26	10	29	16	21	11	15	10	16	25
CORALS	SCLERACTINIA	Scrlatopora	4	1	10	7	3	15	1	4	4	-	5	4	18	-
		Acropora	36	16	6	33	23	39	25	18	15	3	42	55		-
		FAVIID	7	12	10	16	7	10	5	2	5	14	3	9	44	-
		Galaxea	1	-	1	-	1	1	-	-	-	-	-	1		-
		Coeloria	-	-	-	-	-	-	-	-	-	-	1	-		-
		Porites	1	37	32	-	-	1	-	-	4	31	-	-	13	-
	OCTOCORALIA	Tubipora	-	-	1	-	-	-	-	-	-	-	-	-	4	-
		Heliopora	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		OCTOCORAL	-	-	-	-	-	-	-	-	-	-	-	-	2	-
		GORGONIAN	-	-	1	-	-	-	-	-	1	-	-	-	-	-
		FORAMINIFERA	-	1	5	5	8	1	10	7	3	6	3	1	-	1
		ECHINOID	-	1	3	2	1	2	3	1	2	5	3	2	-	-
		VERTEBRATE	-	-	-	-	-	-	-	-	-	-	1	-	-	-
ARTHROPODA		CRUSTACEAN	8	-	1	1	-	2	2	-	1	6	6	4	-	-
		OSTRACOD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		CIRRIPEDE	-	-	-	-	-	-	-	-	-	1	-	-	-	15
		SPONGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		BRYOZOAN	-	-	-	-	-	-	2	3	-	2	1	-	-	-
		WORM	2	2	-	2	1	1	-	-	1	-	-	-	-	1
		BIOCLAST	-	3	5	6	23	4	10	37	38	11	9	5	-	1
		QUARTZ	-	-	-	-	-	2	3	-	-	-	-	-	-	38
		GREEN MINERAL	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		BLACK MINERAL	-	-	-	-	-	-	-	-	-	-	-	-	-	3
		ORANGE MINERAL	-	-	-	-	-	-	-	-	-	-	-	-	-	2
		Md ø	1.95	0.80	-0.20	1.28	1.58	0.95	1.75	1.15	0.60	1.95	1.25	1.00	0.20	1.10
		Qd ø	0.05	0.75	-0.10	1.07	0.90	0.10	0.30	0.20	0.25	0.57	0.08	0.92	0.30	0.45

Text-fig. 18: Tabular summary of the average composition of the sediments greater than 0.25mm expressed as percentages for individual localities and depths west of Zanzibar (see text-fig. 6).

Key to scleractinian taxa:

Sub-order ASTROCOENINA
Family ACROPORIDAE
1. *Acropora cervicornis*
Family AGARICIDAE
2. *Agaricia agaricites*
Family SIDERASTREIDAE
3. *Siderastrea siderea*
Family PORITIDAE
4. *Porites astraeoides*
5. *Porites divaricata*
6. *Porites furcata*
Family FAVIIDAE
7. *Diploria labyrinthiformis*
8. *Diploria clivosa*
9. *Manicena areolata*
10. *Cladocora arbuscula*
11. *Solenastrea hyades*
12. *Montastrea annularis*
13. *Montastrea cavernosa*
Family OCULINIDAE
14. *Oculina diffusa*
Family TROCHOSMILIIDAE
15. *Dichocoenia stokesi*
Family MUSSIDAE
16. *Mycetophyllia lamarkiana*
17. *Isophyllia sinuosa*
Sub-order CARYOPHYLLINA
Family CARYOPHYLLIDAE
18. *Eusmilia fastigiata*

(After Hubbard, 1974, Proc. IV Intnat. Coral Reef Symp.)

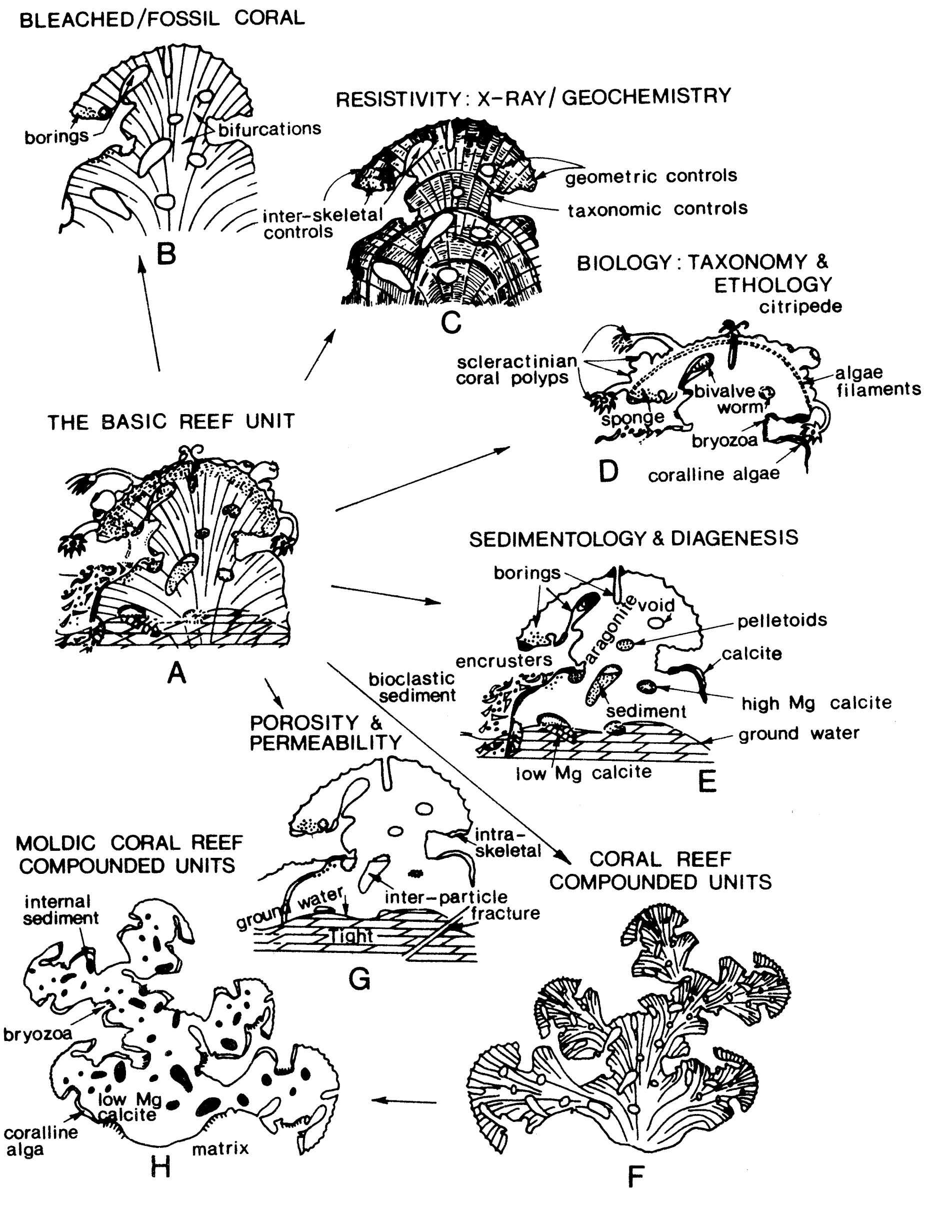


Text-fig. 19: Graphically summarises the relationship between scleractinian coral settlement pattern and community evolution in the Caribbean - Atlantic Province.

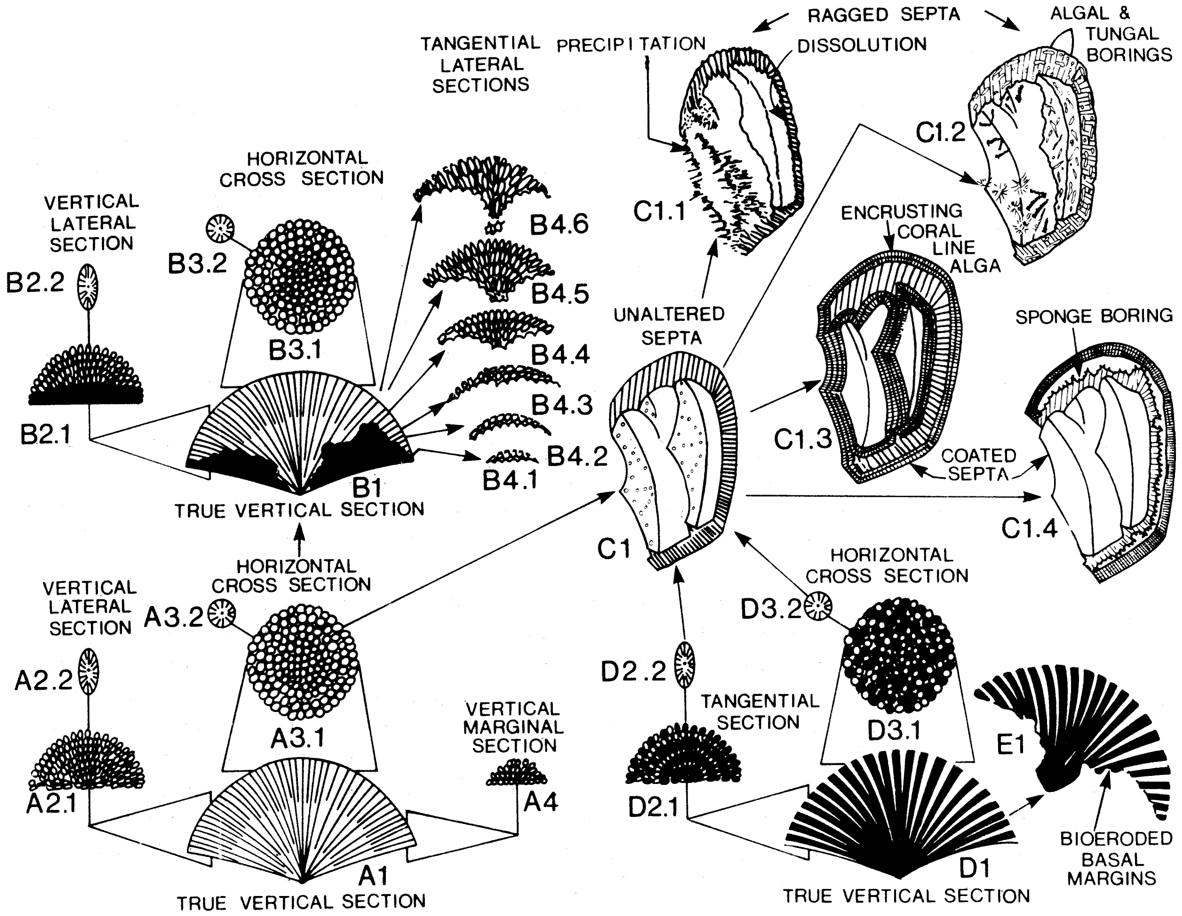
A shows that the original colonisation pattern can be divided into three polyspecific communities representing exposed rock platforms, sheltered depressions and baffled grass beds.

B shows secondary segregation into distinct or monospecific communities dominated by grass bed communities as opposed to open circulating mounds.

C, by contrast, shows the complexity of patch reef development from B by initially segregated settlement in C(1) to complete community modified by subsequent colonisation and niche exploitation in C (2). (After Hubbard, 1974).



Text-fig. 20: This is a graphical summary of the history of preservation of an individual coral head (A) and its associated endoliths and epibionts (D) sediment and cements (E) and their interpretation from bleached or fossil material (B), from X-ray resistivity patterns or geochemical analyses (C) and from the industrialists' porosity-orientated view-point (G). F resembles reef material in that it is made up of a composite of modules of B, while H shows a mirror image replica of F on its preservation in a largely Low-Mg calcite mouldic state after the solution of its originally aragonitic components on its burial in the vadose or phreatic zones.



Text-fig. 21: A flow diagram of the types of optical illusion that random sections through coral heads can cause from the same parent stock. A1 true vertical median section through a hemispherical plocoid or cerioid colony; A2.1 lateral vertical section through the same colony appearing to be smaller than A1; A2.2 cross section of an individual corallite in a quasilongitudinal plane appears to be oblong in contrast to the circular outline seen in true cross section A3.2); A3.1 marginal horizontal section mainly cutting across corallite axes at right angles (A3.2). B1 true vertical median section through a similar corallum to A1 which has been affected by extensive bio-erosion of the undersurface as indicated by the blackened area in B1 and B2.1. B2.1 gives a first impression of being more foliaceous in form than A2.1; while B3.1 shows no sign of difference from A3.1; but tangential sections from the marginal B4.1 to the near median plane (B4.6) show apparently different forms ranging from foliaceous concavo-convex sheets at the margin to pronounced mushroom shape (B4.5) and isolated coral pairs (B4.6) near the middle of the hemisphere, in contrast to the plano-convex sections of A2.1 and A4. D1 represents a true median vertical section through a hemispherical fasciculate form with its analogous lateral (D2.1) and horizontal sections (D3.1) and its bio-eroded counterpart (E1); the blackened areas represent the intercorallite voids. Just as corallite shape appears to vary in geometry according to plane of section as shown by the true cross sections A3.2, B3.2, and D3.2 as opposed to A2.2, B2.2 and D3.2, so too can corallite morphology and septal detail vary according to their state of preservation. C1 represents an unaltered slice of theca with two major and one minor septum and their original surface ornament; the same structures are depicted in shaggy outlines after syntaxial cementation and after preferential dissolution in C1.1; after endolithic algal and fungal boring and bacterial infestation in C1.2; after preservation by red algal encrustation in C1.3; and after partial mouldic formation by the combination of red algal external coating and marginal sponge - mining in C1.4.

desiccation. The sponge-bored red algal encrusted material is slightly more difficult to locate precisely, but it is most likely to have migrated landward from the deeper parts near the reef crest, or seaward down shutes.

So much for the preservation potential of the hermatypic corallum and its associates; they are important on the surface of the living reef, perhaps comprising 25 - 30% of the surface area, whereas void space or cavities occupy another 40 - 60% spatially, and algae appropriate the remaining 30% or, sometimes, much more. But there is a multitude of other actors on the reef scene and they too, can be argued to follow analogous preservational pathways, their degrees of preservation being directly related to their original chemical compositions and habitats within the ecosystem. The sedentary benthos may stay in place if buried, but the vagrant benthos, mobile infauna and nektonic let alone planktonic creatures and plants are liable to be drifted leewards, which is usually landwards, by the prevailing and storm currents.

Let us now consider the implied in-put of sediment particles which fill so much space in the present day reef. Text-fig. 22 outlines the variability of bulk sediment composition amongst Bermuda, Seychelles & Zanzibar reefs. It not only highlights the compositional aspects, but also the fact that the sizing of clasts varies between locations. In the Atlantic – Caribbean it is common to think of the scleractinian corals dominating the finer sand grades (Ginsburg *et al*, 1956 & Garrett *et al*, 1972), but this bias does not appear in the Indian Ocean locations cited here. What is uniformly significant is the fact that there is so much aragonitic material available for dissolution on burial in the vadose zone. Hence the geological record is bound to be compositionally patchy, geometrically holey and geochemically as well as mechanically condensed.

If we consider the sediments in analysing micro-ecosystems it is evident that there is much variation in both bulk terms (text-figs, 9, 10, 11, 12, 13, 14, 15, 16, 17) and in details (text-figs 18, 22, 23 & 25). Text-fig. 24 graphically outlines the succession of contents of a nest of sieves through which one 250 cc sample of sediment has been passed. It clearly demonstrates that the foraminifera, gastropods and micro-bivalves have several distributional peaks; these indicate both in-put of different sized taxa and the fact that non-spherical particles fall through square grids in an irregular manner. But, whereas the former concept is well known to biologists, and is recorded in passing by Garret *et al.* (1971) this aspect is often over looked by sedimentologists who are concerned with the latter fact. That this distribution pattern, taken from –10.2 m at Ariadne (see text-fig 6) is not a standard for all areas and all depths can be seen from comparing a like sample from –1.524 m at Murogo (text-figs 25--). The shallower of the samples contains herbivorous echinoid and algal matter, as well as ostracods in addition. The sands thus represent a mixture of dead bioclastic fragments, and live interstitial and surface biotas.

SIZE		2.0 - 4.0 mm			1.0-2.0 mm.			0.5-1.0 mm.			0.25-0.5 mm.		
CONSTITUENT PARTICLE COMPOSITION \ LOCATION		ZANZIBAR This paper (13 Samples)	SEYCHELLES (Lewis, 1969, Fig. 9, 6 Samples)	BERMUDA (Garrett et al, 1971, Tab 3)	ZANZIBAR	SEYCHELLES	BERMUDA	ZANZIBAR	SEYCHELLES	BERMUDA	ZANZIBAR	SEYCHELLES	BERMUDA
ALGAE	Halimeda	1	-	5	-	-	14	1	1	15	1	4	8
	CORALLINE	7	-	12	3	-	19	2	-	14	4	-	16
MOLLUSCA		42	33	23	23	23	22	21	16	26	22	11	15
SCLERACTINIAN CORAL		36	59	5	59	65	11	63	64	14	44	71	44
FORAMINIFERA		-	-	38	-	1	25	4	-	18	7	1	1
UNKNOWN		6	-	10	9	-	5	1	-	4	16	-	10
OTHERS		9	35	7	6	11	4	8	-	9	6	13	6

Text-fig. 22: Grain size percentage constituent particles in reef-top sediment samples from the Zanzibar, Seychelles and Bermuda islands highlighting both compositional and sizing differences amongst localities.

Plots of the bioclastic fragments and mineral matter taken in isolation from the living components of the microecosystem, look quite different (see text-figs. 26 & 27). The scleractinian taxa not only dominate the sand fraction (text-fig. 26) but also vary in their taxonomic in-put. The tougher astrocoeninan skeletons (see Hubbard, 1976 ; & Hubbard & Swart, 1982) have a bimodal distribution dominating granule and fine sand ranges; the faviids dominate the sand sizes showing an artifact, or geometry-dependent, bimodality; and the fungiids, being the most friable, show an unimodal distribution (text-fig. 27).

Just as we have shown that quantitative studies taken in isolation of a mineralogical and geochemical understanding can lead to misconceptions concerning population distributions in fossil reefs, quantitative studies of bulk sediment samples alone can be equally misleading. A single sponge may include as many as a thousand inhabitants, so too a single coral clast is liable to contain a host of algae and sponges (plate 1). How these components are preserved is dependent on their mineralogy and the subsequent chemistries of their microenvironments (plates 2,3, & 4). Plate 1 illustrates the diversity of an individual coral clast's preservation and associated biota from –10.219m at Ariadne (text-fig 6), Zanzibar : A is a general view of a fragment of *Seriatopora* showing four corallites in various stages of preservation; B is a close-up of one of the more poorly preserved corallites showing that a sponge (C) is responsible for its roughening; D shows another calice with unicellular algae adhering to it detailed in E & F; and G shows an algally bioeroded septum of the worst preserved calice and its associated epiflora (H & I). Views J to N show a sequence of close-ups of faecal pellet production by a worm within some hurricane transported acroporid shingle on the intertidal reef flat at Heron Island on the Australian Great Barrier Reef.It is evident that both the foraminiferan (K) and coral bioclasts (M) are incorporated in this organically bonded morsel. O is a similar ostracod containing pelletoids attached to the interstices of a coral fragment from the same sample.

Plate 2 illustrates the inception of algal alteration and its mineralogical consequences. A is a cross section of the thallus of the codiacean alga *Halimeda*; B shows the details of its wall structure essentially comprising complexly interwoven tubes. C, D, E & F show increasing magnification of the external surface at the top of A, clearly depicting the characteristic aragonitic internal fabric. Sequences G to P, by contrast, show increasing magnifications of a fractured surface of the scleractinian coral *Coeloria* from the Pleistocene of Malindi, Kenya. They illustrate the low-Mg calcite forming the mouldic replacement of the septa (G & H), which in turn are cut by an endolithic filamentous alga (I & K) thus introducing secondary void space (L, M & N) through which late stage fluids are passing and cementing remaining voids (O, P & Q).

Plate 3 compares living materials with the earlier phases of cementation in the splash zone of the supratidal. A, B & C show increasing magnifications of an encrusting lithothamnioid red alga from -15m at Heron Island, while D, E & F illustrate similar enlargements of its mouldic formation on fossilisation. G & H give details of syntaxial aragonite cementation on the scleractinian coral *Porites* from the storm ridge at Heron Island, while I shows the relationship and succession of syntaxial aragonitic needle cement followed by rhombic high-Mg calcite micrite cement on an acroporid coral which is also from the storm shingle at Heron Island. J, K & L give the sequence of syntaxial aragonitic cementation and overgrowth filling an intraskeletal void a little deeper in the same acroporid, while M, N & O show substantial rhombic high–Mg calcite micrite cementing the internal interstices of the *Porites* illustrated in G & H.

Plate 4 illustrates the relationship of initial aragonitic cementation to the end - product of mouldic preservation by low-Mg calcite in a Pleistocene acroporid from Malindi, Kenya. A shows coarse vadose cement between spar filled septa. B shows sediment filling the axial corallite and low-Mg calcite spar filling the intrasketetal voids. C is a close-up of the relationship between the sediment filled mouldic axial corallite and the associated vadose spar filling which illustrates at least two generations of vadose cementation. These contrast in scalar details with the acroporid (E), acroporid-aragonite syntaxial needle cement (F), and high-Mg calcite rhombic-cement (G) shown in Plate 3, I.

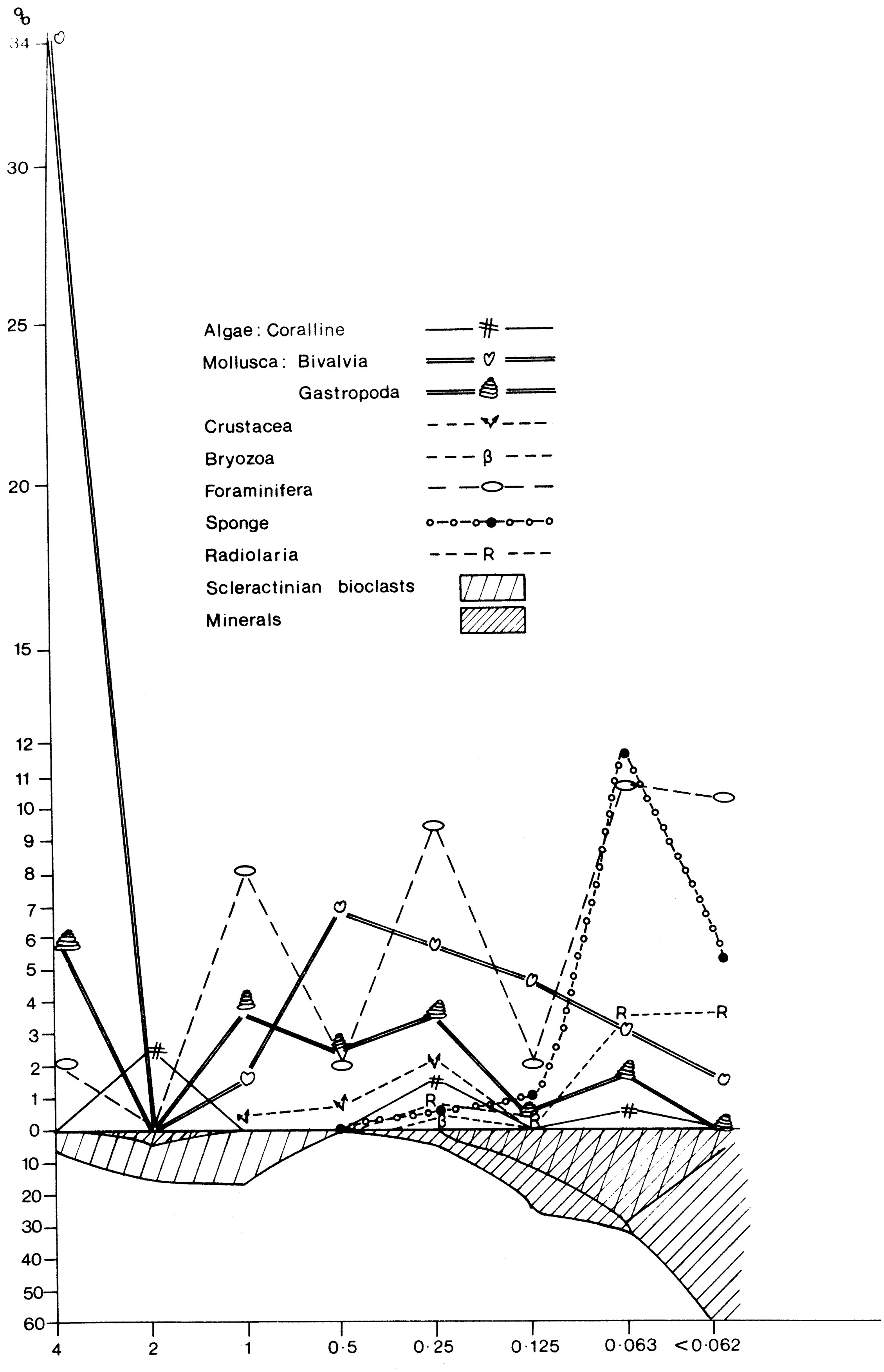
PERCENTAGE OF CONSTITUENT PARTICLE TYPES

CONSTITUENT PARTICLE COMPOSITIONS		PARTICLE SIZE	2-4 mm. FRACTION		1.00-2.00 mm. FRACTION		1.5-1.00 mm. FRACTION		0.25-0.55mm. FRACTION		WHOLE SAMPLE SUMMATION	
	ALGAE	*Halimeda*	1	8		2	1	3	1	5	1	2
		CORALLINE ALGA	7		3		2		4		3	
	MOLLUSCA	GASTROPOD	6	42	5	23	6	21	6	22	5	23
		BIVALVE	36		18		15		16		16	
CORALS	SCLERACTINIA	*Seriatopora*	15	36	13	59	4	63	3	44	7	53
		Acropora	12		26		33		20		24	
		FAVIID	3		13		14		10		12	
		Galaxea	3		1		-		-		1	
		Coeloria	-		-		-		-		-	
		Porites	2		5		12		11		10	
	OCTOCORALLA	*Tubipora*	-		1		1		-		1	
		Heliopora	-		-		-		-		-	
		OCTOCORAL	-		-		-		-		-	
		GORGONIAN	-		-		-		1		-	
		FORAMINIFERA	-		-		4		7		4	
		ECHINOID	-		2		2		2		2	
		VERTEBRATE	-		-		-		-		-	
	ARTHROPODA	CRUSTACEAN	2		2		3		2		3	
		OSTRACOD	-		-		-		-		-	
		CIRRIPEDE	-		-		-		-		-	
		SPONGE	-		-		-		-		-	
		BRYOZOAN	2		-		1		-		1	
		WORM	1		1		-		1		1	
		BIOCLAST	9		10		1		16		9	
		QUARTZ	-		-				-		-	
		GREEN MINERAL	-		-		-		-		-	
		BLACK MINERAL	-		-		-		-		-	
		ORANGE MINERAL	-		-		-		-		-	

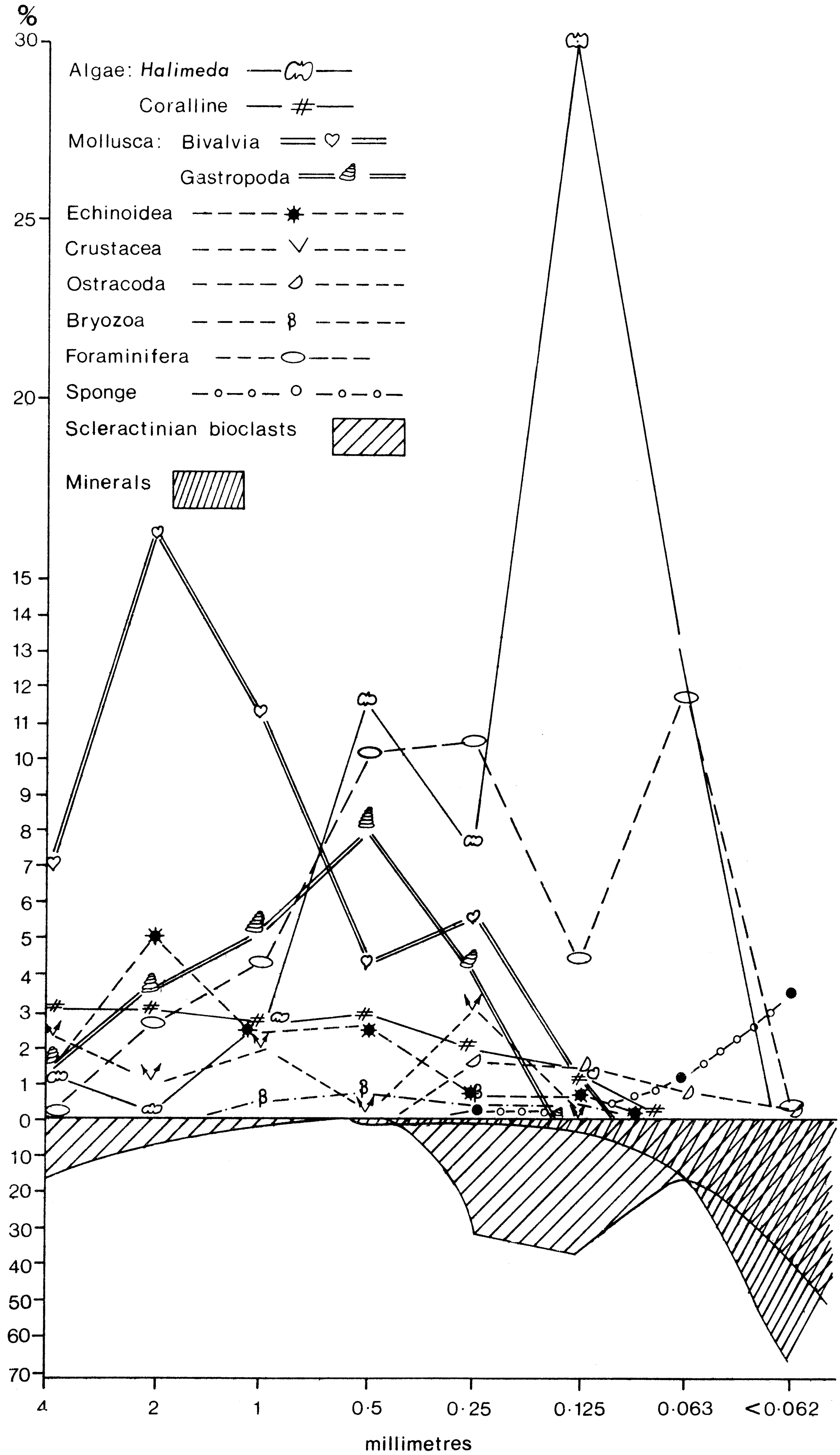
Text-fig. 23: Grain size percentage of constituent particles in reef-top sediment samples from Zanzibar highlighting initial differences in the taxonomic in-put of the grades considered in bulk in text-fig.22.

The time factor

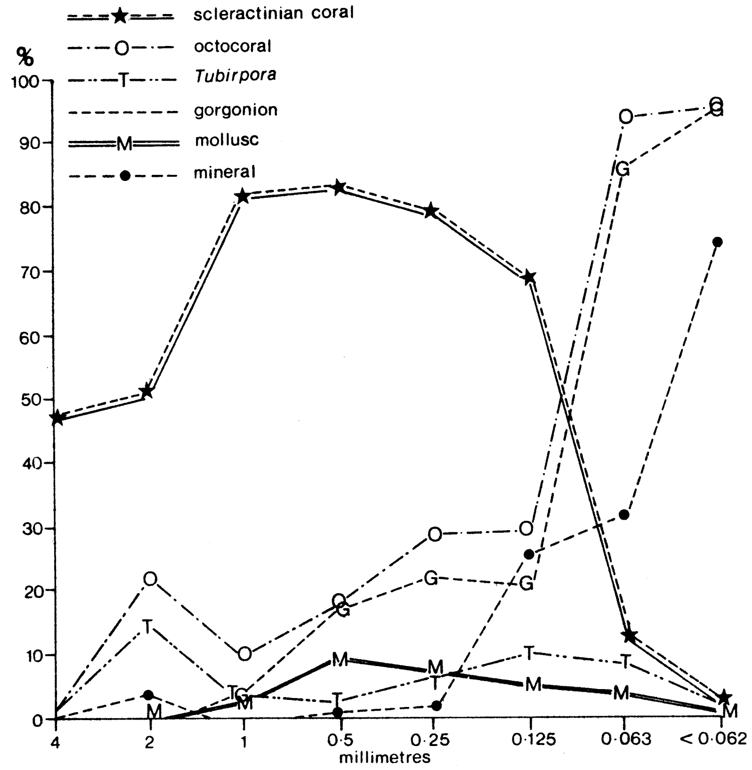
In assessing the variables which affect present - day reefs we are struck by the fact that their chances of preservation, as we see them now, are distinctly limited. Firstly, the external morphology of the reef complex bears little resemblance to its fossilised counterpart. The former is dominated by a conspicuously rugged topography, while the latter contains a seemingly disproportional amount of planar sand bodies and storm accumulates filling the erstwhile hollows. Secondly, the internal textures are subject to considerable alteration by bioerosion, sedimentation and cementation : like a good mature stilton cheese, the reef is often crusted on the outside and shot with diffuse cavity systems on the inside. Thirdly, a high proportion of the frame-building organisms are aragonitic and, as such, unstable out of seawater; consequently the chances are high that either they will be dissolved in the groundwaters, or if lucky, they will be preserved as moulds. Many of the vagrant benthos are equally susceptible to chemical loss. Consequently sound palaeoenvironmental interpretation is difficult. It demands high standards of theoretical knowledge of both ecosystems analysis and skeletal chemistry combined with acute three dimensional field recordings supported by critical petrological details. Whereas modern reefs comprise perhaps as much as 70% voids, and unloaded Pleistocene reefs may contain say 40% voids, many ancient reefs contain less porosity than this; and some, such as those of the Miocene of the Philippines, show considerable evidence of loading in the form of pressure solution affecting constituent particles. All these reefs thus record different states of cementation and diagenesis testifying to the mobility of calcium carbonate during the process of burial. Yet this phenomenon and its related effects are seldom



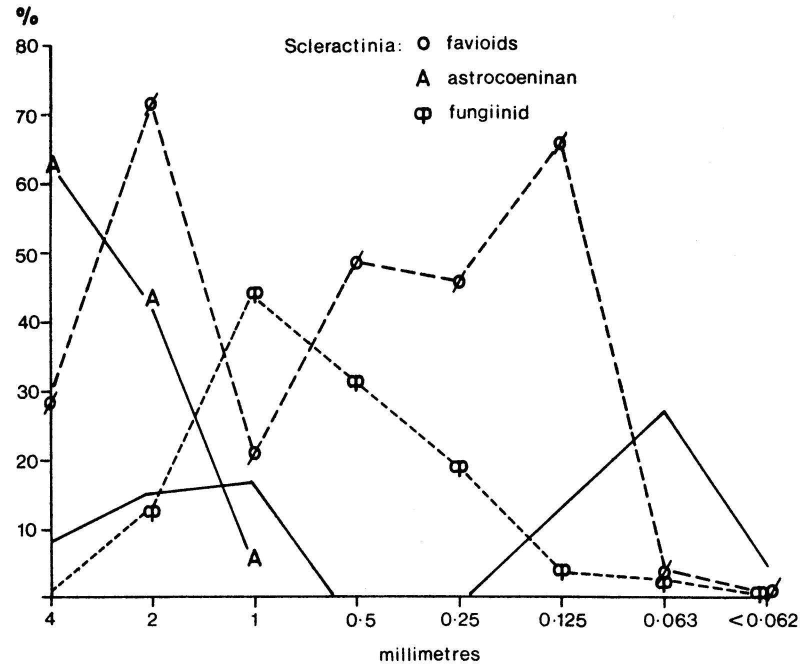
Text-fig. 24: Grain size analysis of constituent particle composition from a 250 cc sample taken from –10.219m at Ariadne, Zanzibar, to show that variations in in-put not only relate to the natural sizing differences of taxa and their component parts, as opposed to the gradational mineral in-put curve, but also to multiple in-put as shown by the bivalves and foraminiferans.



Text-fig. 25: Grain size analysis of constituent particle composition from a 250 cc sample taken from −1.524m at Murogo, Zanzibar, to show that variation in in-put is not only determined by taxonomic grading but by differences in community structure as compared with text-fig. 24.



Text-fig. 26: Grain size analysis of coral, mollusc and mineral constituents of a 250 cc sample of the reef-top sediments from Ariadne, Zanzibar, featured in text-fig. 24, to show increase in mineral and octocoral in-put amongst the fines, in reverse relation to the scleractinian in-put and in contrast to the even distribution of the molluscs.



Text-fig. 27: Grain size analysis of the scleractinian components of a 250 cc sediment sample from Ariadne, Zanzibar, featured in text-figs 24 & 26, to show that the variability of taxonomic in-put related to both the geometry of clast size and the durability of the material. The astrocoenians are the studies with pronounced bimodal distribution, and the fungiids most friable with most uniform geometric properties cluster unimodally in the middle.

recorded in the palaeoecological and palaeogeographical accounts of reefs or the analysis of their constituent particles. Furthermore when diagenetic effects are considered, as in the Canning Basin as interpreted by Logan & Semeniuk (1976), then the initial variabilities of reef facies are not considered fully.

From the foregoing discussion it is evident that, as yet, there is not a single fossil reef which has undergone a sufficiently rigorous, all-round scientific dissection to cite as a classic example of reef analysis and reconstruction, but this does not mean to say that certain specific aspects have not been covered adequately. For example, despite the limitations of models in palaeogeographic reconstruction they have been used extensively (see Wilson, 1975, and Longman, 1981, and Smith, 1981); even the more refined reef models discussed at length in Hubbard & Swart (1982) have had their applications tested in the facies interpretation and reconstruction of the geological history of the well exposed Tertiary, Miocene, Pliocene, Pleistocene and Recent sediments of Bahrain (Hubbard, 1980). So a foundation exists, albeit crude, on which further reef analyses can be based. This can be used, together with the supplementary information on contrasting reef facies given in this account, to unravel other reefs to a higher level of sophistication. This means that more accurate reconstructions should result. These, in turn, should yield improved models for further facies prediction, palaeogeomorphological insight and seismic recognition of marginal areas thus aiding regional basin analysis. But throughout the analytical process the geologist has to think like a detective, linking seemingly random facts and fabrics to a three dimensional whole which often appears to defy the laws of gravity. Cavity systems abound as snares and delusions : some are post-depositional and of late diagenetic origin, having formed from palaeokarstic phenomena at subsequent sea level stands, but others are of contemporaneous origin as evidenced by their wall clinging coelobite communites. Not infrequently the two types of cavities are superposed upon one another and cut by yet another more geometric system, of subsequent origin which can be related to the brittle fracture affects of regional tectonics and their filling by migrating groundwaters. Thus the original framebuilding biota is readily obscured by subsequent events and its community structure is difficult to resolve. The associated sediments, which in themselves represent complex micro-ecosystems, are not much less difficult to analyse as they comprise a relic history of a compound series of both intra - and inter-particle porosities and cementation. When these facies are loaded further complexities arise as a result of a further loss of porosity by pressure solution. Thus the sum total of a reef fabric can range from the simple and readily recognisable to the very complex phenomenon whose origin is, indeed, obscure.

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Explanation of Plates 1 – 4

Plate 1

Plate 1 illustrates the complex inner world of three individual clasts (A - I; J - N; & O) which support diverse populations.

A is a critical point dried grain of *Seriatopora*, from -10.219m at Ariadne, off Zanzibar, showing corallites in various states of preservation.

B detail of sponge - bored apical area; C eleven dinoflagellates adhering to three sponge - pits.

D abraded top left corallite encrusted with a host of algae (E & F).

G detail of upper portion of C to illustrate endolithic boring of algal filaments (G & H) underlying residual dinoflagellate tests (I).

J is a close - up of a worm producing faecal pellets within an acroporid fragment from the intertidal storm shingle at Heron Island, Australia.

K & M show discrete pellets, which internally comprise dinoflagellate fragments (N) and coral clasts (M) organically bonded by fine threads (L).

O illustrates faecal matter containing ostracods from a similar acroporid clast from the reef crest at Heron Island. Bar scales in micrometres.

Plate 2

Plate 2 illustrates the mineralogy of preservation by reference to a dead specimen of the Codiacean green alga *Halimeda* (A - F) from -1.524m off Grave Island, Zanzibar, and a mouldic scleractinian coral, *Coeloria*, (G - P) and its associated endolithic alga (J), algal borings (K - M), and cement fillings after voids (N - Q) from the Pleistocene of Malindi, Kenya. The original aragonitic skeletal structure of *Halimeda* is most readily seen in detail (F) taken from the upper surface of (A) close to one of its utricles (C, D & E) which open to the surface from the twisted tubes seen in B. There is not a sign of the coral's original aragonite skeleton : vadose Low -Mg calcite both coats the septal surfaces as a cement and occupies the cores of septa which have subsequently been bored by algae (H - J), leaving permeable pathways where they are not fully cemented (K - M). Bar scales in micrometres.

Plate 3

Plate 3 is a further illustration of the mineralogy of preservation by reference to the living calcitic coralline alga *Lithothamnion* from -15m off Heron Island (A - C), to its quasi-fossil counterpart from the storm shingle of Heron Island (D - F) and associated quasi-fossil scleractinian corals *Porites* (I - J) and *Acropora* (I - O). A - C illustrate the relationship of the individual coralline cells to their adjacent cells (C), coralsubstrate (B) and whole algal crust (A).
D - C illustrates the cementation of the red algal cells, while G shows a general view of coral skeletal organisation with syntaxial aragonite cements in close detail (H). While J – L show internal filling of *Acropora* by aragonite cement, in depth, and by High-Mg calcite at the surface. Bar scales in micrometres.

Plate 4

Plate 4 illustrates mouldic preservation of *Acropora* from the Pleistocene of Malindi, Kenya.
A shows partial preservation of the septa by vadose cements which are even more distinct in the areas between the septa. The related threads are algal filaments.
B shows the internal mouldic axial corallite, to the right of the field of view, and associated cement external mould forming a chamber to the left, the coral, in between, having been dissolved away.
C is a detail from B illustrating the relationship of the calcitic internal mould to the external mould separated by a space which is being filled by yet another generation of fine rhombic Low-Mg calcite cement. While D – F, which are enlargements from Plate 3, I of a recent acroporid from the storm shingle follows the early development of syntaxial aragonite cement (E) on the acroporid coral (D) which is closely in contact with the later High-Mg calcite rhombic cement (F). Bar scales in micrometres.

Plate 1

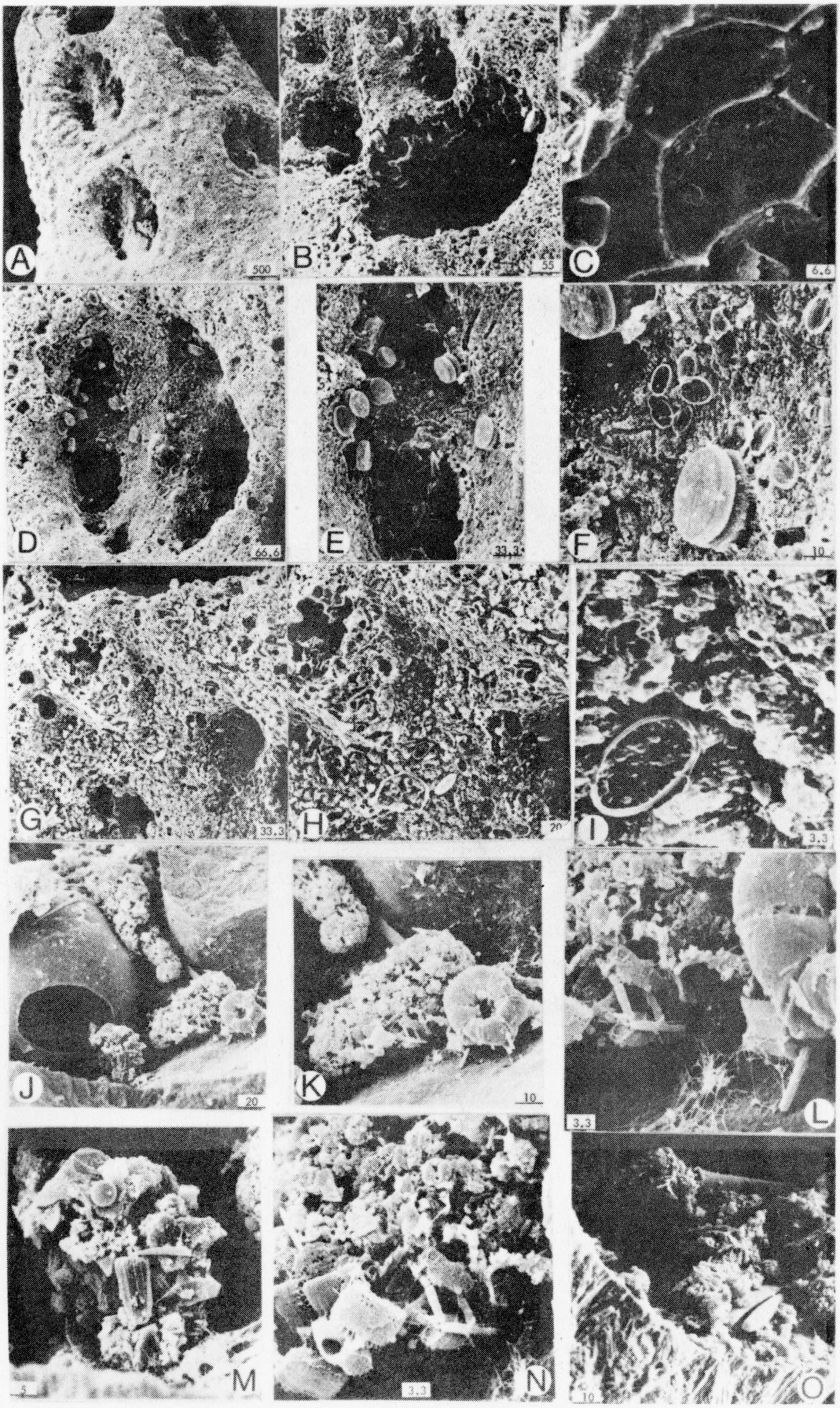
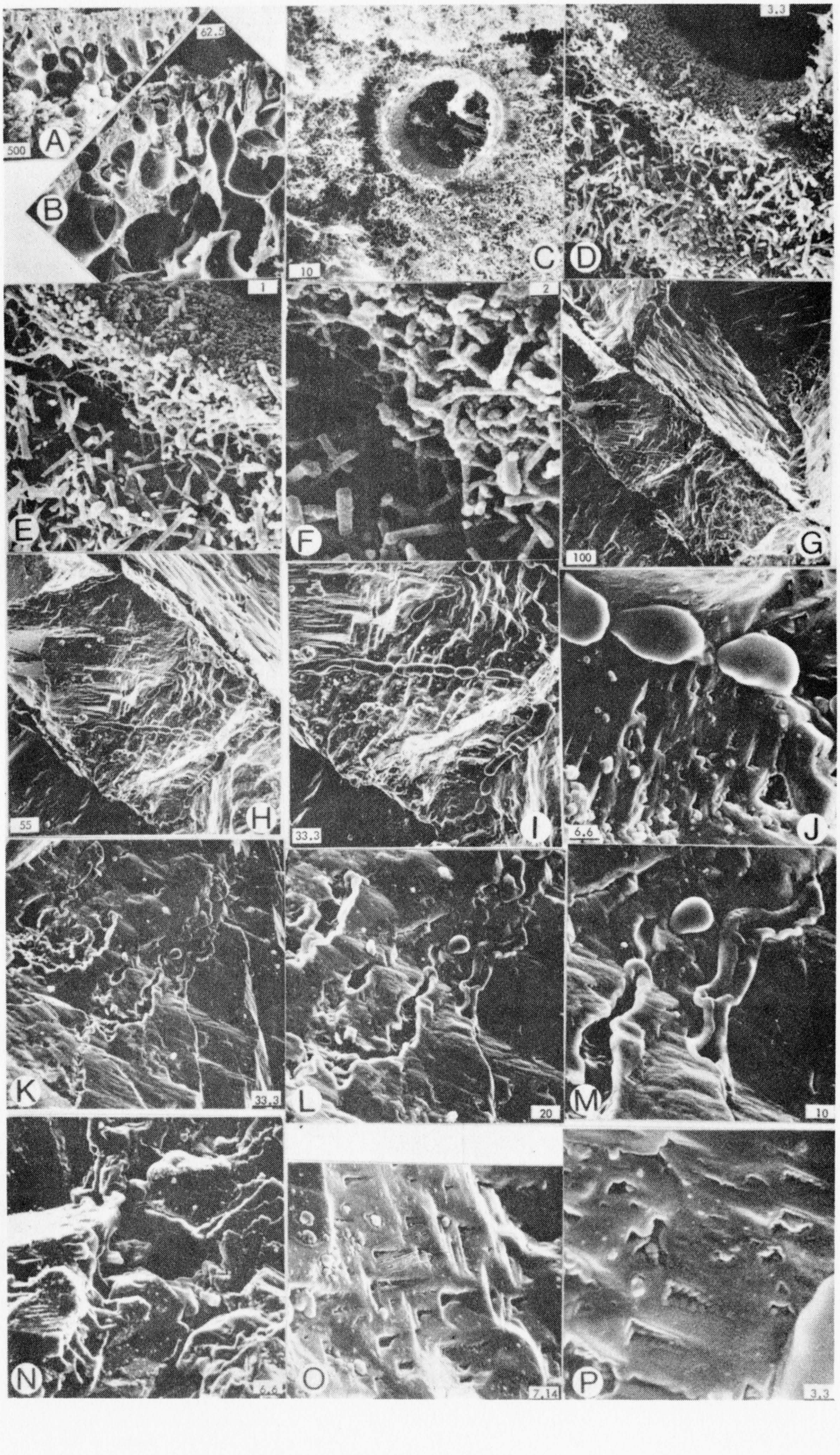


Plate 2


A
500
B
62.5
C
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D
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Plate 3

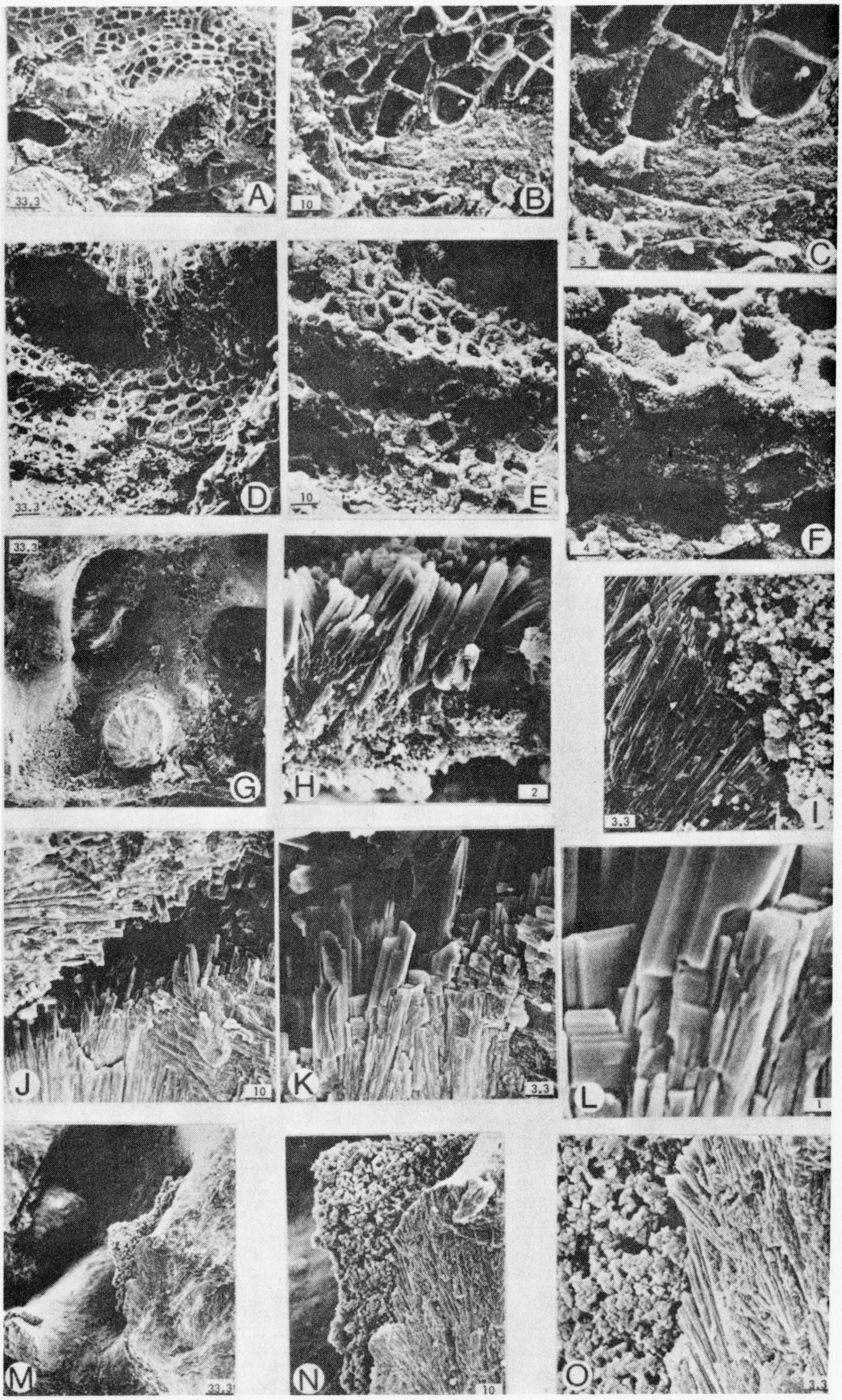

Plate 4