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Distribution of smaller benthic foraminifera in the Chagos Archipelago, Indian Ocean

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ABSTRACT - The Chagos Archipelago is a series of atolls situated in the centre of the Indian Ocean close to the equator. The area experiences small tides and periods of strong winds. The combined effects of these is to cause relatively high energy conditions to exist in the shallow waters around the reefs, therefore the bottom sediments are coarse grained and mobile. Although the coral faunas are diverse, seagrasses are rare. The total benthic foraminiferal assemblages have low to high species diversity and are dominated by hyaline taxa. On the oceanic side of the atoll reefs, the dominant foraminiferan is *Amphistegina lessonii*, with subsidiary miliolids. Planktonic tests form up to 20% of the combined benthic and planktonic component. In the lagoon, the assemblages are dominated by *Calcarina calcar*, with subsidiary miliolids. Planktonic tests are relatively uncommon. Some post-mortem transport and damage to tests has taken place but the distribution patterns are believed to be representative of the original living ones. *J. Micropalaeontol.* **13**(1): 47–53, September 1994.

INTRODUCTION

The Chagos Archipelago is the most remote Indian Ocean atoll (Fig. 1). It is situated within the gyre formed by the westward-flowing Equatorial Current to the south and the eastward-flowing Indian Counter Current to the north which effectively isolates it from the Maldive Islands. Because of its geographic isolation it is of particular biogeographic interest. The samples discussed here come from Peros Banhos atoll. The larger foraminifera are discussed in Murray (in press) who showed that the fauna is less diverse than that of the Mauritius and Comoro island groups.

The only previous study of smaller benthic foraminifera from an Indian Ocean atoll is that of Hottinger (1980) on the Maldive Islands and there have been few studies of oceanic island faunas: Comoro Islands (LeCalvez in Guilcher *et al.*, 1965), îles Glorieuses (Battistini *et al.*, 1976), Kerimba archipelago (Heron-Allen & Earland, 1914–1915), Mascarene Islands (Montaggioni, 1981). Murray (1991) summarized the distribution of smaller foraminifera from the Indian Ocean in general.

THE ENVIRONMENT

The Chagos bank is part of a lineament (Chagos–Laccadive Ridge) formed by volcanic activity along a north–south transform fault during the Teriary opening of the Indian Ocean (McKenzie & Sclater, 1971). On leg 115 of ODP, Site 713 was drilled on the northern edge of the bank. Forty-two metres of basalts were drilled and these give a weighted mean plateau age of 49.0 ± 1.0 Ma and a weighted mean isochron age of 49.6 ± 0.6 Ma (Duncan & Hargreaves, 1990). Interbedded baked sediments were assigned to calcareous nannofossil Subzone CP13b, early to middle Eocene, and were deposited in moderate water depths. The present depth of Site 713 is 2915 m (Backman, Duncan *et al.*, 1988).

The Chagos Archipelago is the surface expression of a thin limestone cap resting on the volcanic basement. During the Pleistocene lowstand of sea level, the area of land exposed was about 13 000 km^2 greater than now. Peros Banhos atoll lies to the north of the major Great Chagos Bank. The coral reefs are the largest area of undisturbed reefs in the Indian Ocean. The coral and mollusc faunas are diverse but this is not the case for fish or algae (Sheppard & Wells 1988). On the oceanward side, the reefs have a groove and spur structure extending down to 5 m but this dies out in the channels as the reefs pass into the lagoon (Sheppard, 1981).

Peros Banhos atoll is centred on 5° 20′ S, 71° 50′ E (Fig. 1). It has an area of 463 km^2, a maximum lagoon depth of 80 m and an average of 38 m. The atoll is rather square in shape and the channels between the numerous islands allow good exchange of water between the open sea and the lagoon. The total length of reef is 94.5 km and the total width of channels 30.5 km. The tidal range is normally <1 m. The waters are well oxygenated and have a temperature range of 25–30°C; the lagoon surface waters commonly exceed those of the open ocean by >2°C (Pugh & Rayner, 1981). Primary productivity off île du Coin is 15.7 μg C l^{-1} h^{-1} oceanwards and 11.8 μg C l^{-1} h^{-1} in the lagoon (Rayner & Drew 1984). On the outer reef slopes, the water has high clarity but this is reduced to around 30 m in the lagoon. South East Trade Winds blow strongly from May to September while from October to April there are light to moderate northwesterly winds. Severe storms are rare but even during calm weather there is a marked swell. Rainfall is 4000 mm per annum (Sheppard, 1981; Sheppard & Wells, 1988).

The sediment is exclusively biogenic and calcareous being composed mainly of coral and algal bioclasts. Only in a few deeper lagoonal samples from off Petite île Coquillage is there any size fraction <63 μm. From visual examination,

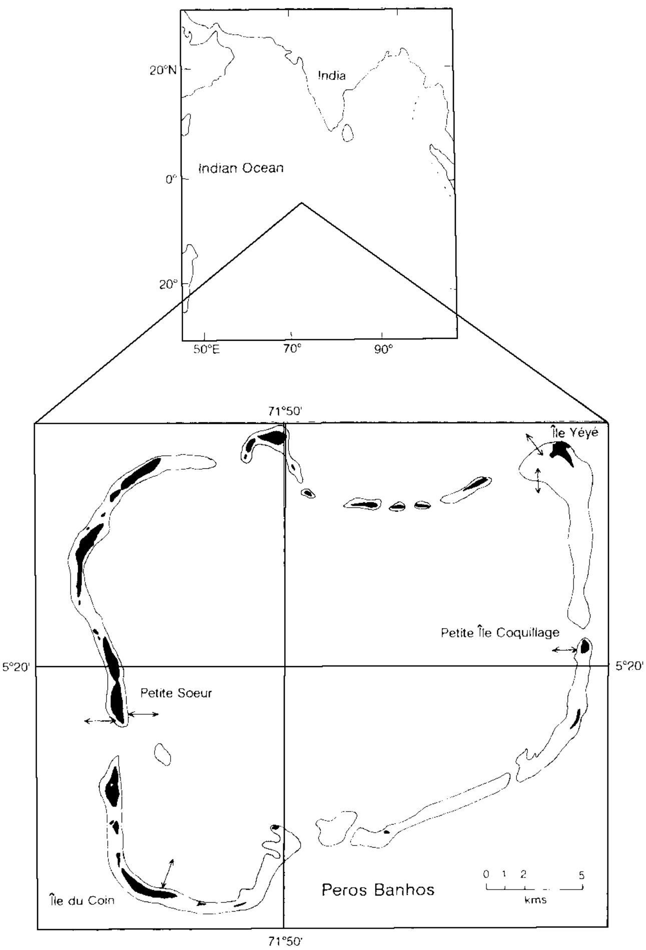

Fig. 1. Map of Peros Banhos atoll, Chagos Archipelago, Indian Ocean. Arrows indicate traverses studied.

most sediments are composed of fine, medium, coarse and very coarse sand with granule-sized gravel.

Sheppard (1980) used phototransects, particularly in the lagoon off île du Coin, to determine the proportions of bottom cover; from 3–30 m, 'sand', i.e. loose sediment, covers 15–35%, bare hard surfaces 15–20%, coral and soft coral 50–70%. He noted that '...much bare rock exists for no obvious reason' although heavy wave action and shifting sediment were mentioned as possible explanations. Drew (1980) observed that large areas of potentially suitable habitat for seagrasses remained uncolonized, perhaps due to 'geographical isolation, lack of appropriate substrates and an excessive exposure to wind and waves'. The virtual absence of seagrass has profound implications for availability of suitable substrates for phytal foraminifera. However, fragments of *Halimeda* are widespread, commonly abundant and may serve as substrates for some foraminifera.

MATERIAL AND METHODS

The samples were collected from Peros Banhos by the late Dr Paul Morris in April–May 1979 on the Joint Services Chagos Research Expedition. Sampling was carried out by SCUBA diving and was generally limited to depths ≤43 m. Material was preferentially collected from bare sediment surfaces. Each of the 47 samples had a volume of 85 cm^3 and was preserved in formalin or alcohol. In most cases the preservative had dried out but, nevertheless, a few tests had observable cytoplasm coloured by the symbionts. Seven samples were processed with rose Bengal but yielded few red stained individuals. It was decided not to stain the bulk of the samples because of the uncertainty of preservation. In addition, since bare sediment was collected, it was considered unlikely that the living habitat of most of the foraminifera had been sampled. Thus, the assemblages described here are total, i.e., living plus dead.

In the laboratory, the samples were washed over a 63 μm sieve and dried. They were then dry sieved on a 1.4 mm sieve to remove the coarse fraction which was studied separately for larger foraminifera (Murray, in press). The foraminifera were picked from the 63 μm–1.4 mm size fraction and mounted on slides. At least 250 benthic individuals were picked to give the total benthic assemblage. Species diversity has been expressed as the alpha index of Fisher *et al.* (1943). In addition, the planktonic:benthic ratio was determined and expressed as percentage planktonic of benthic plus planktonic.

No attempt has been made to identify all the benthic taxa because most are rare. A partial faunal reference list is given in Appendix 1 and most taxa are illustrated in Fig. 6.

RESULTS

The results are presented as traverses from the reef barrier both into the lagoon and seawards into the open ocean (Figs 1–5). Although there are similarities in the assemblages, there are also some major differences. Species diversity in the lagoon ranges from α 2–21 (average 12), with exceptional values of α 27–33 on very fine sediment, to α 8–21 (average 14) in the open sea. The assemblages have high faunal dominance with the most abundant species usually making up >30% and commonly >50% of the total. In terms of wall structure, hyaline ranges from 61–96%, porcellaneous from 4–30% and agglutinated from 0–13%. All the agglutinated taxa have a calcareous cement and all the detrital particles are calcareous (and biogenic) because there are no non-carbonate rocks exposed on the atoll.

The seaward profiles off Yéyé and Petite Soeur (Figs 2,3) are dominated by *Amphistegina lessonii* (25–56%), with modest numbers of miliolids (0–21%) and *Calcarina calcar* (1–20%). No other taxa are present in >10% abundance except for *Heterostegina depressa* in the shallowest samples off Petite Soeur. The abundance of planktonic tests ranges from 2 to 20% and shows a general seaward increase.

The four lagoon profiles are from Yéyé, Petite Soeur, île du Coin and Petite île Coquillage (Figs 2–5). *Calcarina calcar* is the dominant species: 65–90% off Petite Soeur, 12–84% off Yéyé and île du Coin. The only other abundant group is the miliolids but these are very variable (<1–30%). *Amphistegina lessonii* is <5% off YéYé and Petite Soeur, but off île du Coin it ranges from 1–20%. Off Petite île

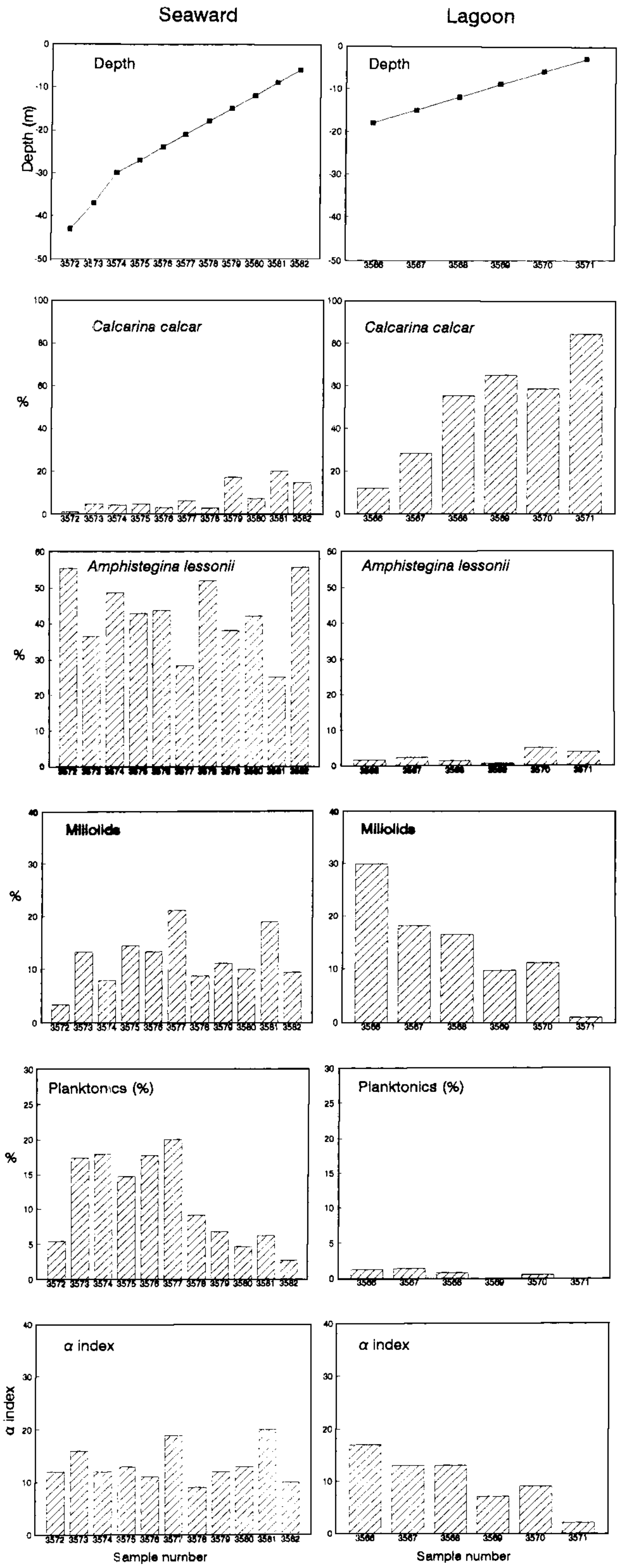

Fig. 2. Frequency distribution of *Calcarina calcar*, *Amphistegina lessonii*, miliolids, α index and % planktonic foraminifera in depth traverses off île Yéyé.

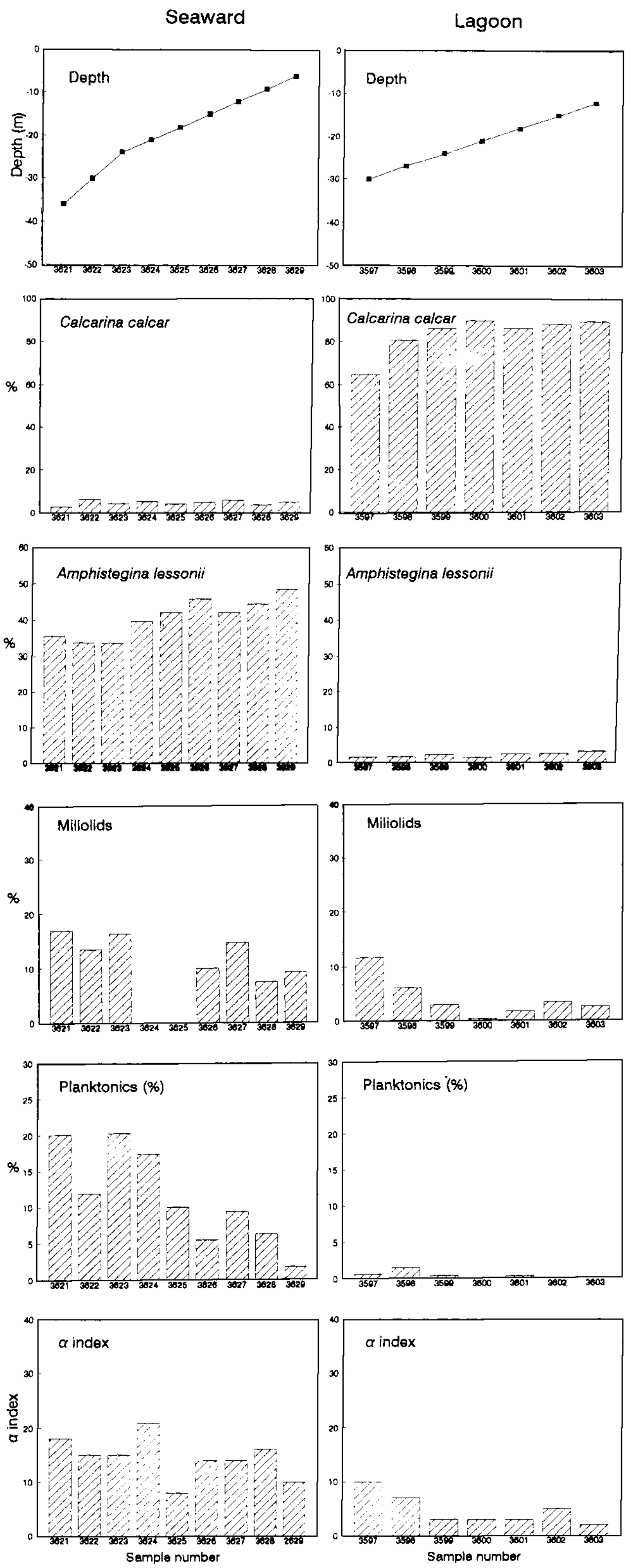

Fig. 3. Frequency distribution of *Calcarina calcar*, *Amphistegina lessonii*, miliolids, α index and % planktonic foraminifera in depth traverses off Petite Soeur.

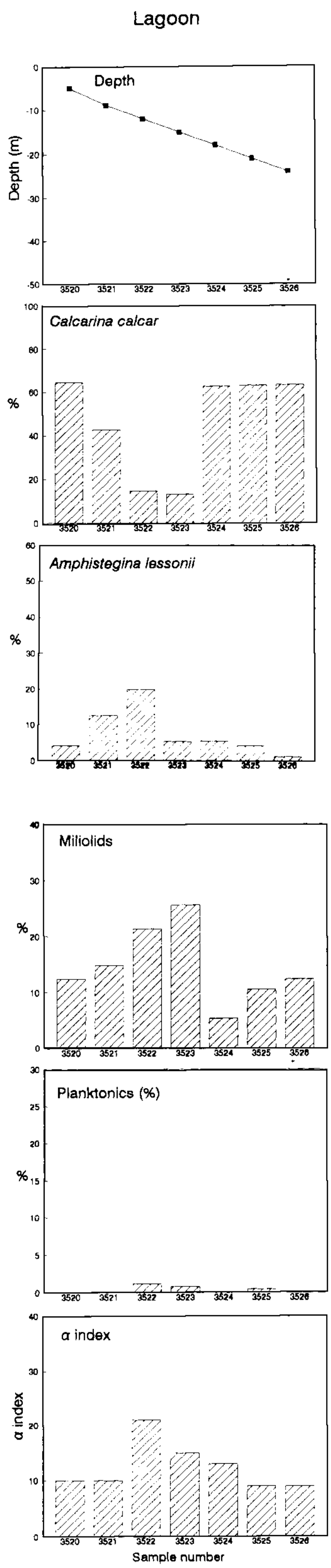

Fig. 4. Frequency distribution of *Calcarina calcar*, *Amphistegina lessonii*, miliolids, α index and % planktonic foraminifera in depth traverses in the lagoon off île du Coin.

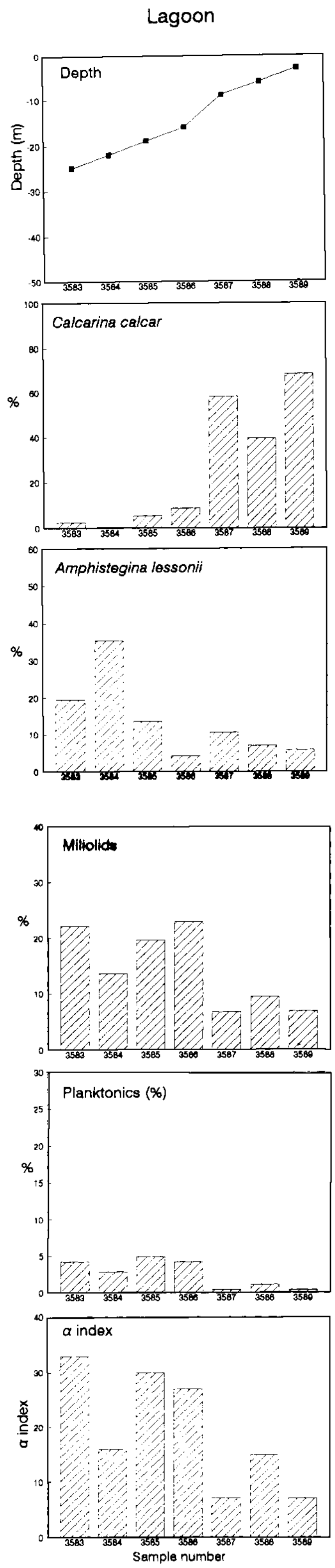

Fig. 5. Frequency distribution of *Calcarina calcar*, *Amphistegina lessonii*, miliolids, α index and % planktonic foraminifera in depth traverses in the lagoon off Petite île Coquillage.

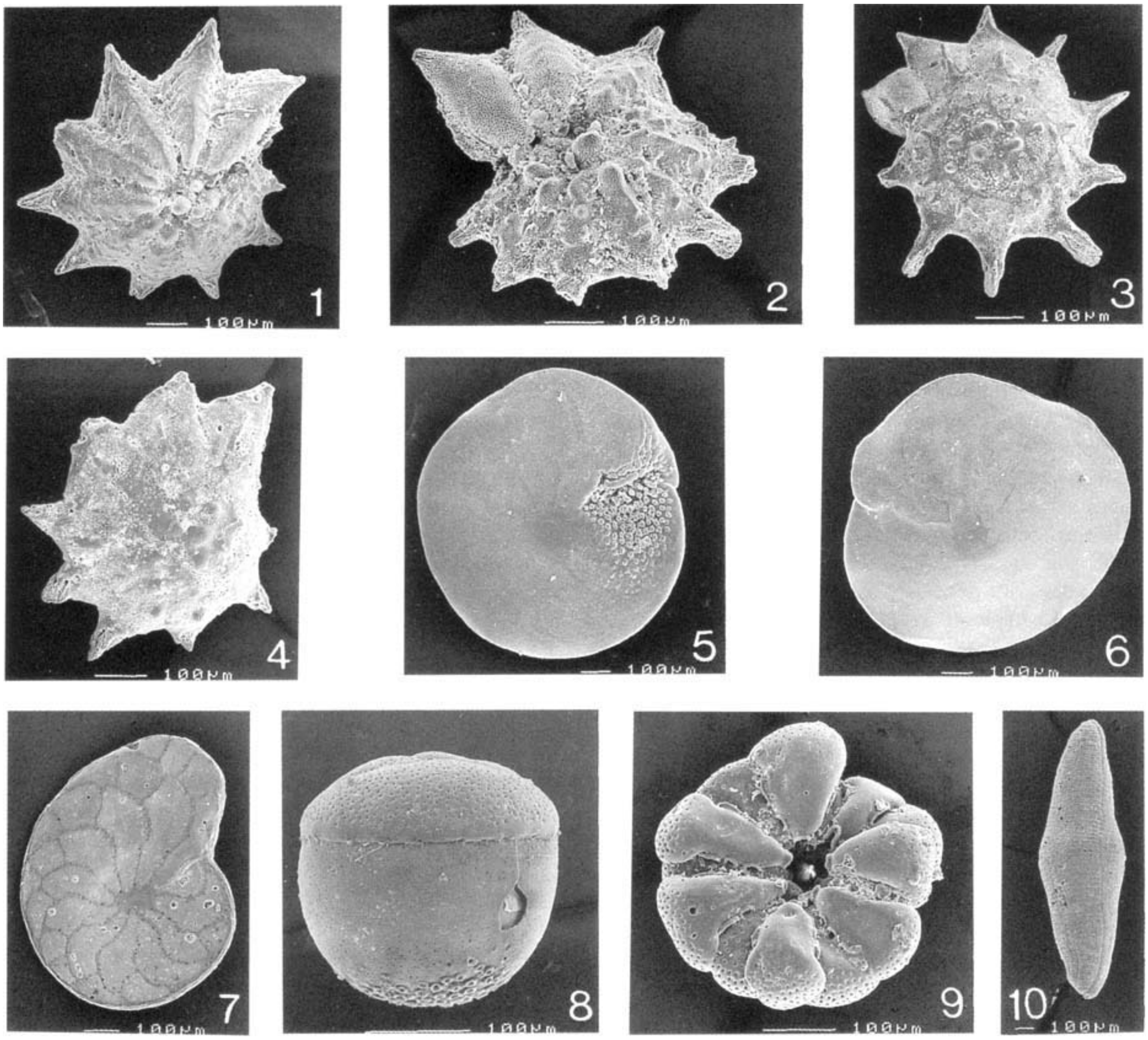

Fig. 6. SEM micrographs: figs 6.1–6.4, *Calcarina calcar* Deshayes; figs 6.5–6.6, *Amphistegina lessonii* d'Orbigny; fig. 6.7, *Heterostegina depressa* d'Orbigny, juvenile individual. fig. 6.8, *Tretomphalus* sp; fig. 6.9; *Cymbaloporetta* sp; fig. 6.10, *Borelis schlumbergeri* (Reichel).

Coquillage, *C. calcar* is abundant on the coarse shallow water sediments but has low abundance (<9%) on the fine-grained sediment at 16–25 m. The miliolids are variable as elsewhere and *Amphistegina lessonii* is generally more abundant on the fine sediment (up to 35%). Locally the *Cymbaloporetta*/ *Tretomphalus* group reach abundances of >10%. Planktonic foraminifera are rare throughout the lagoon sediments.

The miliolid group includes *Quinqueloculina, Triloculina, Spiroloculina, Miliolinella*, and *Pyrgo*. All other benthic taxa occur in small numbers and no attempt has been made to identify every species. They include planorbulinids, discorbids, rosalinids, cibicidids, bolivinids, eponidids, juvenile nummulitids, soritids, peneroplids and textulariids.

DISCUSSION

The most obvious contrast between the seaward and lagoon assemblages is in the dominant species: *Amphistegina lessonii* and *Calcarina calcar* respectively. Miliolids are more abundant in the lagoon, while planktonic tests are typical of the seaward profiles. The differences in diversity and wall structure group abundance are minor.

The substrates are generally coarse both seaward and in the lagoon: fine sand to granule-sized gravel. The environment is of moderate to high energy due to the combined effects of oceanic swell waves, tidal exchange and persistent winds (Pugh & Rayner, 1981). Most of the foraminiferal tests show abrasion damage and it is doubtful whether they are preserved exactly where they lived. The only fine-grained sediment is in the deeper lagoon off Petite île Coquillage and here the assemblages include many juvenile tests which are well preserved. These samples also have anomalously high species diversity values probably due to the post-mortem concentration of juvenile tests derived in part from adjacent environments.

Calcarina calcar is rare in the Kerimba archipelago (Heron-Allen & Earland, 1914–15), in the Mascarene Islands (Réunion, Mauritius, Rodriquez; Montaggioni, 1981), and somewhat more abundant in shallow waters in the Comoro Islands (LeCalvez in Guilcher *et al.*, 1965). In the Indian Ocean, only in the îles Glorieuses (Battistini *et al.*, 1976) and the Maldive Islands (0–20 m, Hottinger, 1980), have associations dominated by this species been recorded. In the Pacific Ocean, they are known from Palau (Hallock 1984) and New Caledonia (Lessard 1980, as *Tinoporus*) in water 0–3 m deep. In each case, the area is sheltered by a reef barrier.

There is considerable taxonomic confusion surrounding species of the genus *Amphistegina* (Larsen, 1976). *Amphistegina* spp. are generally abundant in shallow water carbonate reefal sediments in the Indian and Pacific oceans (Murray, 1991). *A. lessonii* and *A. lobifera* are abundant in fore- and back-reef sediments between meadows of brown algae in fairly high energy areas at depths <30 m (Montaggioni 1981). LeCalvez (in Guilcher *et al.*, 1965) recorded 8 species in the Comoro Islands and 5 of these (including *A. lessonii*) were abundant. In the Red Sea, *A. lessonii* lives in large numbers between 10 and 20 m, on the lower, shaded surface of boulders or within the coarse sediment. It contains diatom algal symbionts (*Fragilaria shiloi* Lee) and the habitats are occupied because of their needs (Reiss & Hottinger, 1984). In this study, *A. lessonii* is the sole species and it is abundant mainly seaward of the reef.

The abundance of miliolids is variable and does not generally exceed 30%. Similar abundances are known from Réunion and leeward reefs of Mauritius, but the back-reef muddy sediments of windward reefs on Mauritius and on Rodrigues have 60–90% miliolids (Montaggioni, 1981). Peneroplids are generally rare in the Chagos samples and this is also the case in the Mascarene Islands (Montaggioni 1981).

The suborder Miliolina is generally most abundant in subtropical–tropical shallow water environments, in normal marine or hypersaline waters, and commonly in association with seagrasses or other submarine vegetation (Murray, 1987, 1991). They are particularly abundant in such environments in the Arabian Gulf (see Murray (1991) for references) and in the Gulf of Suez (Azazi, 1992). Their modest abundance in the Chagos sediments may be attributed to the lack of suitable phytal and fine grained sedimentary substrates, which in turn are largely due to the high energy setting.

Alveolinids are rare in the Chagos sediments and their tests are small (*Borelis schlumbergeri*). With the exception of muddy sediments in the lagoon off Petite île Coquillage, *B. schlumbergeri* is restricted to the seaward side of the reefs. Using published data, Murray (1991, fig. 18.6) summarized the distribution of alveolinids in the world oceans and showed that both *Alveolinella* and *Borelis* are present in the western Indian Ocean. Only *Borelis* is present in the Red Sea as *B. schlumbergeri* (diatom symbionts) (Hottinger, 1977; Reiss & Hottinger, 1984).

The remainder of the fauna is similar to that listed from other Indian Ocean reefal areas and includes a number of attached morphotypes such as planorbulinids, cibicidids, rosalinids and discorbids. This is to be expected in such high energy environments.

As total assemblages have been studied, because the samples were inadequately preserved to distinguish living and dead, it is unlikely that they give a completely true picture of the distribution of taxa. Many of the tests are broken and abraded due to the high energy of the environment. It is probable that some transport has taken place with movement of individuals into shallower or deeper water than they occupied during life. Nevertheless, the broad distribution patterns are considered to be valid and the distinctive differences between the seaward and lagoon assemblages are believed to be real.

CONCLUSIONS

The Peros Banhos atoll is a moderately high energy environment because of the tidal exchange of water between the lagoon and the open sea, the oceanic swell waves and the influence of winds. Submarine vegetation is sparsely present. The samples examined were all from bare sediments, and most are mixtures of fine to coarse sands and gravels made entirely of calcareous bioclasts.

The benthic foraminiferal total assemblages from the seaward side of the reefs are dominated by *Amphistegina lessonii* while those of the lagoon have a predominance of *Calcarina calcar*. Miliolids vary in abundance and generally make up <30% of the total. In this respect, the Chagos assemblages differ from those of more sheltered carbonate environments with muddy substrates and seagrasses where miliolids commonly constitute 50–90% of the assemblages. Notwithstanding some post-mortem transport and damage to tests, it is considered that the distribution patterns are broadly representative of the living distributions.

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APPENDIX 1: PARTIAL FAUNAL REFERENCE LIST

The name used in this paper is followed by the original name, author and date.

Amphistegina lessonii d'Orbigny, 1826

Borelis schlumbergeri (Reichel) = *Neoalveolina schlumbergeri* Reichel, 1937

Calcarina calcar Deshayes, 1830
Heterostegina depressa d'Orbigny, 1826

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