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APPENDIX: FORAMINIFERAL COMPOSITION OF HENDERSON ISLAND BEACH SAND

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ABSTRACT

Sediment samples from fore-reef, beach face and incipient sand dune/sand sheet environments on Henderson Island show a wide range of sediment sizes and a restricted composition dominated by coral debris, molluscan fragments and, in certain size bands, benthic foraminifera. These characteristics reflect regional biogeographical gradients and local reef structure and development.

INTRODUCTION: SEDIMENTARY ENVIRONMENTS

The contemporary fringing reef at Henderson Island is restricted to a narrow reef flat, which lacks a well defined seaward margin, and a fore-reef which slopes steeply offshore.

There is no algal ridge margin to the reef edge at Henderson; rather, waves break on a series of seaward-sloping coral ledges which remain shallowly submerged at low tide. Natural breaks in these ledges provide rudimentary passages onto, rather than through, the lagoons of the north, and more particularly the north-west, beaches. The reef lagoon at Henderson varies in width from 20-50m at the north-west beach to 40-75m at the north beach. Estimates from aerial photography suggest maximum lagoon widths of closer to 100m offshore from the east beach. The reef flat consists of a smoothed reef plate, runnelled and potholed in places, largely devoid of sediment except for local aggregations around the few reef flat rocks. Large blocks on the reef flat between the north and north-west beaches are the product of limestone cliff retreat rather than storm coral blocks removed from the fore-reef slope.

The early bathymetric observations made in 1825 by H.M.S <u>Blossom</u> under the captaincy of F.W. Beechey (see Fosberg et al. 1983) reported that the shallowest coral ledge terminates 46m (= 50 yards) from the north beach at a water depth of 5.5m (= 3 fathoms). This surface is followed by a second ledge reaching a depth of 46m (= 25 fathoms) 183m (= 200 yards) from the beach slope - lagoon margin. To seaward of this second terrace water depths in excess of 366m (= 200 fathoms) are encountered. SCUBA observations by G Paulay (pers. comm., 1988) indicates a steeply-sloping uninterrupted fore-reef slope grading into a mobile slope of sand and coral rubble at ~ 40m. Sand channels, between reef spurs, form about half of the bottom cover on the north-west shore at -10 to -15m but they are much less prevalent off the north shore. Coral cover is low; about 6 per cent at 10m depth offshore from the north beach, and live corals are almost entirely restricted to the outer reef slope. Most of the reef surface is covered by an algal turf with living corals accounting for less than 10 per cent of the surface cover. To date, 36 species of scleractinians have been identified (G. -

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Paulay pers. comm., 1988): *Millepora* sp. dominates shallow water environments to depths of -5 to -10m, while deep water zones are characterised by an abundance of *Pocillopora* spp., especially *P. meandrina* and *P. eydouxi*.

The beaches of Henderson can be divided into the long, relatively broad beaches of open aspect on the central northern and eastern shores and the small pocket beaches, backed and flanked by low limestone outcrops, of the north-west coast and the eastern sections of the north beach. On the central north shore, the beach can be divided into a lower foreshore dominated by beachrock and poorly sorted sands and an upper, planar beach, 10-17m in width, characteristically with a 6^{0} slope and backed by a beachridge, presumably the result of storm washover processes. At the eastern end of the central north beach, where the reef edge is closest to the shoreline, and the beach is composed of broken beachrock flags and coarse coral rubble banked up against low limestone outcrops (Plate 1). At the western end of the same beach, incipient sand dunes or low sand sheets are found between the limestone cliffs and the beach sands.

Beachrock is present on the landward reef flat margin of both the north and north-west beaches. It is particularly extensive, however, on the north beach where massive and runnelled seaward-dipping plates may reach 0.5m in height and 10m in width. The presence of this beachrock zone on the north beach suggests widespread contemporary beach retreat (Plate 2).

Fore-reef, beach and incipient sand dune/sand sheet environments can thus be provisionally identified at Henderson Island. This paper pursues the quantitative description, in terms of both grain-size distribution and compostion, of sediments from these three sedimentary environments.

METHODS

Nine surface sand samples were collected from the north and north-west beaches and two samples were collected from the north beach on SCUBA dives; sample locations are shown in Figure 1.

Following Stoddart (1978), grain size analyses of each pre-treated, split sample were made using standard sieves, a mechanical shaker and a sieving time of 15 minutes. The results, expressed as percentages by mass in each phi (ϕ; $-\log_2$ particle diameter in millimetres transformation) interval of the size range, were used to construct cumulative sediment-size curves and from these curves general statistics of sediment characteristics were derived.

The samples were subsequently amalgamated to half phi (ϕ) intervals for the determination of component composition by point counting on a binocular microscope stage. 200-300 grains were counted per size fraction, in excess of 9500 grains being enumerated in total for all eleven samples. All constituents were assigned to component classes down to a grain-size diameter of $+1.0\phi$ (0.50mm); the abundance of easily-identifiable components were counted as a percentage of the total sample to a grain-size diameter of $+2.0\phi$ (0.25mm).

SEDIMENT SIZE DISTRIBUTION

Table 1 lists the standard Folk and Ward statistics (Stoddart 1978) for mean size, sorting, skewness and kurtosis (M_Z, σ_I, Sk_I, K_G) from the fore-reef, beach and incipient dune environments. The cumulative frequency curves from which these statistics were derived are shown in Figures 2-3.

The fore-reef sediments exhibit a wide range of sediment sizes, indicating little post-production transport of a wide variety of source materials (Figure 2). The beach sediments are variable in composition and are comprised of coarse sands, coral shingle and admixtures of these two sediment types. Both environments show similar grain-size distributions, with a range in mean size from the Wentworth class of pebble (>2.0ϕ) to that of coarse sand (>+1.0ϕ). Neither environment contains sediment in the silt/clay classes and, in all cases, less than 0.1 per cent of the total sample mass can be attributed to sediment sizes finer than +2.75ϕ (0.15mm). This observation supports McLean and Stoddart's (1978) assertion, from the northern Great Barrier Reef, that +3.0ϕ (0.125mm) rather than the usual +4.0ϕ (0.063mm) is a more appropriate division between sands and fines in reef island sediments. Either fines are not produced in abundance at Henderson or they are efficiently transported seawards out of the fringing reef system. In spite of this truncation of the grain-size distribution, the range of sediment sizes leads to very poorly to only moderately well sorted fore-reef and beach deposits (Table 1). The very coarse sands generally show the poorest sorting as their mean size reflects the admixture of a particular wide range of particles size and sorting (Figure 4). Both the fore-reef and the majority of beach sediments exhibit a coarse tail to their grain size distributions; in the absence of fines, negatively-skewed samples are, therefore, most characteristic. By comparison, the incipient small sand dunes and sand sheets on the north beach are chiefly distinguished by the lack of such a coarse tail to their particle size distribution (Figure 3) and are thus composed of well-sorted, weakly-skewed medium sands (Table 1). The lack of both coarse and fine sediments and the predominance of medium sands supports an aeolian origin for these deposits.

SEDIMENT COMPOSITION

The coarse nature of the Henderson Island sediments is reflected in the dominance of coral blocks and sticks, and smaller fragments, in all sedimentary environments. The other important consituents are the tests of benthic foraminiferans and molluscan whole shells and fragments, with algal constituents, including *Halimeda*, forming a component of lesser significance. Echinoid debris, coralline red algae and lithoclasts are of minor importance. The gross composition of the Henderson Island sediments is compared to compositional characteristics from some Indo-Pacific atolls and the Great Barrier Reef in Table 2.

DISTRIBUTION OF SEDIMENT COMPONENTS

CORAL: Coral debris is of particular importance in the larger >0ϕ (>0.1mm) size fractions where it accounts for over 50 per cent of sediment volume in the shallow (-12m) fore-reef and beach environments (Figure 5). It is also a significant component at finer grades and it is only on the deep (-30m) fore-reef, in the 0ϕ - +1.0ϕ (1.00 - 0.50mm) particle size range, that it ceases to be the major sediment constituent.

MOLLUSC: Molluscan fragments invariably account for in excess of 10 per cent of the sediment composition by volume (Figure 5). There appears to be an approximately even distribution of gastropod and bivalve debris, although with a greater preponderance of fractured bivalve shells in the larger size fractions. Small yet intact turreted gastropods are characteristic of -0.5ϕ - 0ϕ (1.41 -1.00mm) fore-reef sediments at -12m.

BENTHIC FORAMINIFERA: The tests of these organisms account for between 12 and 31 per cent of the overall sediment composition by volume at Henderson; they are particularly important in the 0ϕ - +1.0ϕ size fractions (Figure 5). Certain tests show little breakage by comparision with other constituents and thus the foraminiferal contribution often mirrors the relatively narrrow size distribution of the original, living population. Although 25 species of foraminifera have been described from Henderson (see Appendix) only 4 of these species have been found to be volumetrically important. The whole tests of the discoid *Marginopora vertebralis* (Quoy and Gaimard) are characteristic of the -2ϕ to -1.5ϕ (4.0 - 2.83mm) size fraction on the island fore-reef where they may account for over 60 per cent of the sediment volume in narrow, dune-rippled sand channels (e.g. sample H10, -12m). In addition, broken *Marginopora* plates locally form an important component of the total composition at grain sizes of +1.0ϕ diameter and the species is found in +2.0ϕ sediments (Figure 5). The yellow-brown *Amphistegina lessonii* (d'Orbigny) is an important contributor to sediment composition in the 0ϕ - +1.0ϕ size range where it forms never less than 20, and frequently more than 40, per cent of the sediment volume. Fractured tests of *Amphistegina* are not common in, but nevertheless do contribute to, the finer size fractions (Figure 5). A quantitatively less important foraminiferan, but one which is frequently found in association with *Amphistegina* and mirrors its patterns of abundance, is *Asterigerina carinata* (d'Orbigny). The distinctive red foraminiferan *Homotrema rubrum* (Lamarck) is particularly abundant at site 1 (see Appendix) but a less important sediment component in the larger size fractions elsewhere. It is present in both discrete and encrusting forms. Other benthic foraminifera noted as being of occasional abundance include *Heterostegina depressa* (d'Orbigny), *Trioculina* sp. (d'Orbigny), *Quinqueloculina* sp. (d'Orbigny) and *Amphisorus* sp. (Ehrenberg).

CORALLINE RED ALGAE: In the absence of a true 'algal ridge' margin to the Henderson reef, the percentage of coralline red algae within the sediments is always less than 5 per cent. Nearly all the red algal sediment consists of encrustations on carbonate grains; free, articulated coralline red algae are rare. It seems likely that coralline algae are competitively smothered by the abundant fleshy algae of the algal turf, this abundance in turn being explained by low levels of herbivory (G. Paulay, pers. comm.).

HALIMEDA: The lack of a substantial contribution to sediment composition by *Halimeda* is worthy of comment. Hillis-Colinvaux (1980) has suggested, contentiously, that *Halimeda* both avoids subtropical water temperatures and is a poor dispersalist to remote areas, factors which would explain its rarity at Henderson. In biogeographic terms, it is difficult to predict the expected diversity of *Halimeda* at Henderson: Easter Island has one reported species (Hillis-Colinvaux 1980) whereas Moorea, Society Islands supports at least seven species in the lagoon alone (Payri 1988). If *Halimeda* is not excluded from Henderson by temperature or isolation, then the thick algal turf may limit its abundance through competition (G. Paulay pers. comm).

LITHOCLASTS: Grey lithoclasts derived from the erosion of the limestone cliffs of the island are found in small proportions within all three sedimentary environments and across the range of sediment sizes.

ENVIRONMENTAL DISCRIMINATION AND SEDIMENT COMPOSITION

In terms of overall sediment composition there is little variation between the fore-reef, beach and incipient dune environments (Table 3), apart from the differing relative contribution of the coral and, to a lesser extent, the benthic foraminiferan components; they form volumetrically more important components in the beach environment. In the $>0\phi$ size fraction, coral fragments are of lesser importance in the incipient dune environment than on the fore-reef and beach, probably because the relatively large size and high bulk density of this component is not conducive to aeolian transport. In the $+0.5\phi$ - $+1.0\phi$ size range, the major contribution of benthic foraminifera, largely a function of the abundance of *Amphistegina*, distinguishes the beach environment. In addition a carfeul study of the fore-reef statistics reveals that bentic foraminifera in total, and *Amphistegina* alone, account for 42.7 and 27.9 per cent respectively of sediment volume at shallow (-12m) depths. Field studies elsewhere have shown that large foraminifera are characteristically associated with shallow reef-front and reef flat algal meadows and that the distribution of foraminiferal detritus closely follows that of the living fauna (e.g. Heron Island, Great Barrier Reef: Jell et al. 1965). It seems likely that the foraminiferal sediment component at Henderson is derived from similar algal bed source areas, the relatively small and low bulk density test (Maiklem, 1970) being easily transported to the beach and locally concentrated at the swash line (Stoddart and Steers 1977). Environmental discimination is difficult in the $+1.5\phi$ - $+2.0\phi$ size fraction. However, it is clear that while benthic foraminifera contribute to sediment composition in the fore-reef and beach environments in these finer grades they are absent from the incipient dune sediments, probably because the tests are more suited to wave rather than aeolian transport.

CONCLUSIONS

Carbonate sediments in reef environments are derived almost entirely from reef organisms. The characteristics of these sediments reflect i) the availability of source organisms, which are controlled locally by ecological, and regionally by biogeographical, constraints, and ii) the subsequent breakdown patterns of these organisms which are determined by skeletal durability and micro-architecture. Actual sedimentary environments further reflect the interaction of these species - specific attributes with modes of transportation and local energy conditions. The combination of low biotic diversity, from a province-marginal location in the Indo-West Pacific province, and a simple reef structure yields a relatively restricted range of source materials for sediments at Henderson Island. Furthermore, the narrowness of the reef flats does not allow for great differentation of sediment sizes and components by the sorting action of transport processes. The net result at Henderson is a suite of locally-derived, poorly-sorted, wide size-range sediments, with relatively few components.

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