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BY F.R. FOSBERG

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Articles submitted for publication in the Atoll Research Bulletin should be original papers in a format similar to that found in recent issues of the Bulletin. First drafts of manuscripts should be typewritten double spaced. After the manuscript has been reviewed and accepted, the author will be provided with a page format with which to prepare a single-spaced camera-ready copy of the manuscript.

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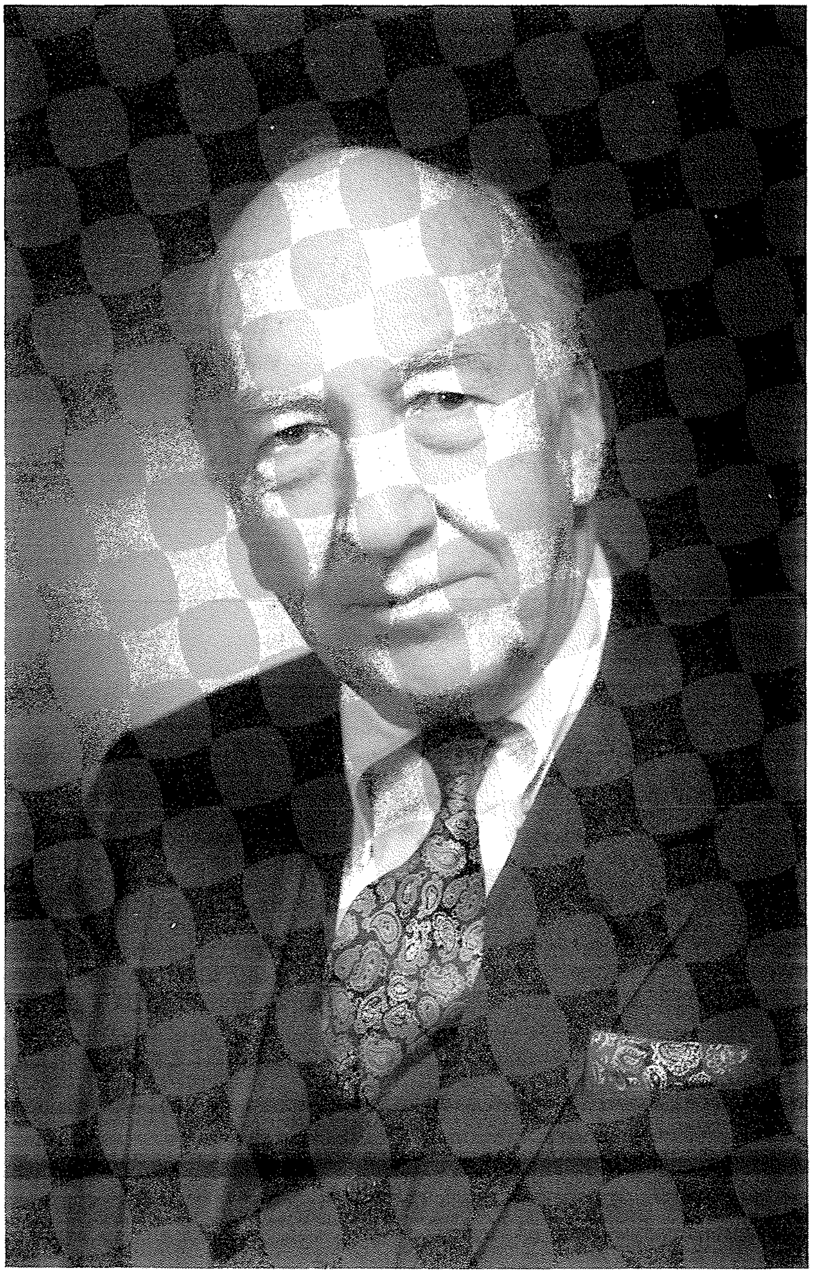

S. Dillon Ripley
March 1980

HENDERSON ISLAND

DEDICATION TO S. DILLON RIPLEY

We are happy to dedicate this issue, presenting the first scientific results of the Smithsonian 1987 Expedition to Henderson and Neighboring Islands, to S. Dillon Ripley. He is the author of a classic monograph on the rail family of birds and was particularly interested in an endemic flightless rail from Henderson and its island home. He has heartily supported our efforts to promote this expedition, and was instrumental in bringing it about. We only regret that he could not participate in it and study this pristine bird habitat.

Born in 1913, in New York City, Dr. Ripley has had a memorable career in science, especially ornithology, and in public life. His long series of scientific positions, expeditions, and major publications have been detailed elsewhere and are well known. His scientific stature as the world authority on the birds of South Asia and the Himalayas, and on several families of birds, is recognized world-wide. His crowning achievement has been, as its eighth Secretary, to guide the Smithsonian Institution to its present stature as the world's greatest, most widely known and respected, repository, promoter, and dispenser of human knowledge. His two decades at the helm of this Institution have seen unparalleled growth, increase in scope and effectiveness, and brightening of its public image. At present, in retirement, he continues to advise the Institution, and to carry on his scientific work. He will long be known and remembered as one of America's great scientific figures. May he have many more productive and satisfying years.

Results of the 1984 Smithsonian Henderson Island Expedition

Henderson island is a small elevated coral island in the south central Pacific Ocean, just south of the Tropic of Capricorn, longitude 128°20' W, latitude 24°20' S. It is one of a scattered group of four islands east of, or forming an eastern extension of, the vast Tuamotu Archipelago. They are, west to east, Oeno Atoll, Pitcairn Island, Henderson Island, and Ducie Atoll. They are among the most remote of all islands from continental land masses and remote, even, from groups of high islands, except for nearby Mangareva, the nearest being the Austral, Society and Marquesas groups. There is no suggestion that there has ever been any connection between them or with any other land. Only Pitcairn has had any human inhabitants in historic time. Archeologic traces of earlier temporary occupation by Polynesians have been found on Henderson. Lack of fresh water would have made lengthy habitation difficult or unlikely.

Previous exploration, and available natural history information, known to the authors up to 1983 was summarized by Fosberg, Sachet and Stoddart, Atoll Research Bulletin no. 272, 1983. Since then, a party of amateur explorers was brought to Henderson by "Operation Raleigh" in 1986. They hacked a trail from the North Beach southward for some distance, perhaps to the south end. No scientific results from this visit have come to our attention. One exotic plant, <u>Setaria verticilata</u>, found at North Beach by the Smithsonian party may have been accidentally introduced by the Raleigh group. One native herbaceous species, <u>Senecio stokesii</u>, apparently with some pioneer or weedy tendencies, has spread along the cut trail, reported by the Smithsonian party. Coconuts were planted along this trail, either by the Raleigh party or by possible visitors from Pitcairn. Small groves of coconut palms are found at North Beach and Northwest Beach, planted earlier by the Pitcairners. Otherwise the island appears to be in relatively undisturbed condition.

In the early 1980's an American millionaire proposed to build a home on Henderson and bulldoze the vegetation to make a cattle ranch. He had ample means to do this and was willing to pay for the privilege. A small group of scientists interested in island ecology and related disciplines, waged a campaign, ultimately successful, to prevent this destruction of one of the very few remaining pristine island ecosystems.

These, and associated scientists concerned with oceanic islands, then felt that, in the face of such threats, an "across the board" investigation of this uninhabited elevated coral-limestone island was a matter of highest priority. In order to protect it, we must know and understand the island in order to be able to demonstrate its uniqueness and scientific importance.

Plans for a lengthy, one to two months or more, visit were frustrated by lack of funds, budget cuts, as the expense involved would be major. This idea has not been given up, but meanwhile opportunities for a short, preliminary visit were sought. In 1987, through the interest and generosity of George and Ann Nichols, owners of R/V Rambler, a 100-foot three-masted staysail schooner, such an opportunity was offered and a small expedition of five scientists was able to spend nine days on Henderson and to have short visits to Pitcairn, Oeno, and Ducie, with stops also on Easter Island and the Marquesas.

The scientists included the leader, Wayne Mathis, Smithsonian entomologist; Thomas Spencer, then of Manchester University, now of Cambridge University, geomorphologist; Susan Schubel, of New York State Museum, avian paleontologist; Gary Graves, Smithsonian ornithologist; and Gustav Paulay, of University of Washington, zoologist and general naturalist. Prof. David R. Stoddart, then of Cambridge University, now of University of California, Berkeley, geographer and expert on islands extraordinary, was scheduled to participate, but delays in starting and conflicts with teaching duties made last-minute cancellation necessary.

From a base at Northwest Beach, the party was able to explore the north coast, the Northwest Beach area, and the northern third of the plateau and gain a reasonable view of the general geography, surficial geomorphology, vegetation, ornithology, fossil history, marine and insect fauna. Substantial collections of insects and other land invertebrates, marine invertebrates, vertebrate fossils, and land plant and bird specimens were collected.

The east, south and southwest coasts and the southern half of the plateau remain little-known, to even a reconnaissance extent. Much of the coast-line is of perpendicular or undercut limestone cliffs, and is very difficult and dangerous to work if the sea is at all rough. The east coast, exposed to the Southeast Trade Wind swells is especially difficult. Only a well-supported and well-equipped expedition with ample time will yield a thorough knowledge of Henderson Island. Visits at several seasons would be desireable, as the subtropical climate is surely seasonal.

Oeno and Ducie Atolls would also justify more time, though their terrestial biotas are meagre. This very fact might yield ecological insights obscured by the complexity of richer biotas and more complex environments.

The papers in this issue give valuable information from the results of the field observations. Critical study of material collected remains to be done, and other papers, in more specialized journals will appear in due course.

This expedition should be looked upon as a precursor to the planned comprehensive study mentioned above, with broader coverage and time available for study of ecological processes operating on this fascinating island.

Acknowledgments

Several people, especially the crew and owners of the R/V Rambler, provided direct assistance and greatly facilitated our work on the islands as well as on the ship. They include: George and Ann Nichols, the skipper and owners of the R/V Rambler, and their children Pierce and Dominica; Lawrence Schuster and his daughter Talilla; Buck Moravec; Jimmy and Cannan Hewson; and Margaret Wilmot. We note with sadness the passing of George Nichols, who suffered a heart attack while skiing this past spring. Marsha Sitnik and David Challinor helped immeasurably with finances, paper work, and the coordination of innumerable logistical matters. The Pitcairn Islanders extended gracious hospitality and complete access to their Island for the few days spent there. Their generosity will not be forgotten. Lastly we thank Mr. Terence D. O'Leary, then Governor of the Pitcairn Island Group, for permission to conduct the field work and to collect specimens.

F.R. Fosberg

ATOLL RESEARCH BULLETIN

NO. 322

TECTONIC AND ENVIRONMENTAL HISTORIES IN THE PITCAIRN GROUP, PALAEOGENE TO PRESENT: RECONSTRUCTIONS AND SPECULATIONS

BY

T. SPENCER

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October 1989

TECTONIC AND ENVIRONMENTAL HISTORIES IN THE PITCAIRN GROUP, PALAEOGENE TO PRESENT: RECONSTRUCTIONS AND SPECULATIONS

BY

T. SPENCER [1]

ABSTRACT

Interpretation of SEASAT geoid anomaly data and improved seafloor mapping of the south-central Pacific suggest a complex tectonic history for the islands of the Pitcairn group. While Oeno atoll formed at ~ 16m.y.BP at a 'hotspot' now south of the Easter microplate, subsequent progressive island development at Henderson (13m.y.), Ducie (8m.y.) and Crough seamount (4m.y.) resulted from the lateral leakage of magma from the Oeno lineation along an old fracture zone, itself originating during the Tertiary reorientation of the Pacific plate. At all four islands cessation of volcanism was followed by subsidence and the development of a carbonate cap. By comparison, Pitcairn has been the product of recent (<1m.y.) volcanic activity along an independent, subparallel hotspot lineation. Nevertheless, this activity has interacted with the older island chain by transforming Henderson Island, through the process of lithospheric flexure, into an uplifted atoll with ~ 30m of relief.

These tectonic processes have been accompanied by changes in sea level and oceanographic conditions. As the Holocene record shows, the deciphering of the sea level record at these islands is difficult; sea level change has been a response not only to glacio-eustatic processes but also to a range of isostatic, and possibly geoidal, effects. Although the Pitcairn group at ~24°S occupies a marginal position for reef growth and development, reconstructions of palaeoceanographic conditions for the Tertiary and Quaternary suggest that the tropical water masses were largely unaffected by either changes in ocean circulation systems or climatic cooling and that water temperatures in the past have been very similar to those experienced at the present time.

INTRODUCTION

Until recently the tectonic and environmental history of the south-central Pacific has been poorly understood. Previous reconstructions of ocean basin and island histories have had to rely upon the relative paucity of information supplied fron infrequent and low density bathymetric traverses of research vessels. However, within the last decade the application of new remote-sensing technologies, improved mapping of the sea floor and the transfer of deep-drilling techniques refined in more accessible oceans has vastly expanded the volume of information available from even the remotest parts of the south Pacific.

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Thus, for example, critical phases in the geological history of the oceanic lithosphere in this region took place in the early Miocene, a time period for which sea-floor magnetic anomalies are few and broadly separated in age, yielding more conjectural estimates for sea-floor spreading rates than at subsequent time periods. However, following the operation of the altimeter satellites GEOS-3 and more particularly SEASAT, variation in the height of the sea surface - the marine geoid - is now known throught the south Pacific (e.g. Sandwell 1984) to a height of accuracy of 10-30 cm and a horizontal resolution of 10-50 km. Geoidal signals have a high level of correlation with sea-floor topography and have thus been used to discover previously undetected bathymetric features (e.g. Sabers et al. 1988), precise seamount geometry then being determined by multi-beam sonar mapping (e.g. Pontaise et al. 1986).

As the following syntheses demonstrates, degree of detail of this kind has revolutionised the level of explanation of regional geodynamics and environmental change in the south-central Pacific. As a result, some preliminary reconstructions of tectonic and environmental histories for the Pitcairn group can be attempted.

PLATE-TECTONIC EVOLUTION OF THE SOUTH-CENTRAL PACIFIC

TERTIARY RE-ORIENTATION OF THE PACIFIC PLATE.

At the beginning of the Palaeogene (65 million years B.P.) the prototypes for all the major oceans were already in existence. The Pacific was a multi-plate ocean, separated by subduction zone margins from the Asian and, in all probability, the Australian plate and bounded to the east by a complex series of mid-ocean ridges and triple junctions from the Farallon, Kula and Phoenix plates (Williams 1986; Figure 1). Although the Pacific Ocean was gradually reduced in size during the Palaeogene, with rates of subduction exceeding those of seafloor spreading, the Pacific plate itself increased in size at the expense of the plates on its western margin. The re-orientation of the plate, from a NNW to WNW spreading direction at ~42 million years B.P., preserved in the hot-spot traces of intra-plate islands and seamounts, most notably by the 'bend' in the Hawaiian Islands - Emperor Seamounts chain, is well known. Of equal significance in the South Pacific, however, was the collision of the Pacific-Kula-Farallon boundary with the Farallon-Americas trench at ~26 million years B.P. This event stopped all seafloor spreading and subduction in this region and initiated direct coupling between the Pacific and Americas plate. This fusion created a major, progressive re-orientation of seafloor spreading patterns and plate geometries as follows: i) ~20 million years B.P.: clockwise rotation of the southern portion of the Pacific-Farallon ridge and the development of the Galapagos rift; ii) ~10 million years B.P.: break-up of ridge south of Baja California and ridge 'jumps' and iii) ~5 million years B.P.: development, from the north, of the Gorda-Juan de Fuca-San Andreas-Gulf of California spreading system with eastward ridge jump below Baja California and westward shift of the Galapagos triple junction (Herron 1972, Herron and Tucholke 1976, Handschumacher 1975).

These adjustments were echoed in progressive plate re-orientations between 15-30^0 which have been fully documented by Okal and Cazenave (1985) using a full SEASAT dataset. At 40 million years B.P., spreading was taking place along the Mendoza and Roggeveen ridges (terminology : Mammerickx et al. 1980), offset 500 km by the transform fault of the Austral Fracture Zone (Figure 2a). Between 36 and 25 million years B.P. the Mendoza ridge propagated south, causing ridge re-orientation and the development of two fracture zones : FZ1, a re-orientation and re-located version of the Austral Fracture Zone and FZ2, dividing the northern and southern sections of the Roggeveen ridge (Figure 2b); Okal and

Cazenave 1985, Sailor and Okal 1983, Okal and Bergeal 1983). Both these fracture zones are orientated N95°E, intermediate between the strike of the ancient Farallon ridge (N70°E) and the orientation of spreading of the present East Pacific rise (N110°E), are 400-500 km in length and may be associated with comtemporary seismic activity (Figure 3; Okal and Cazenave 1985, Okal et al. 1980).

The southern Roggeveen and the Mendoza ridges subsequently 'jumped' westwards at 20 and 18 million years B.P. respectively, completing the re-alignment of the Pacific plate boundary with a straightening of the spreading system, and perhaps providing the western boundaries of the present Easter micro-plate (Figure 2c) - f); Hey et al. 1985).

STRUCTURAL TRENDS AND ISLAND AGES : SOUTHERN TUAMOTU ARCHIPELAGO AND PITCAIRN ISLAND.

The islands of the Pitcairn Group- Ducie and Oeno atolls, Henderson Island and Pitcairn Island itself - lie between 23.9°S - 24.7°S and 124.7°W - 130.7°W. The islands are both widely spaced and isolated from their nearest neighbouring groups : Ducie atoll is 1000 km west of the Easter micro-plate; Oeno atoll is 450 km east of the Minerve reefs and the Gambier Islands (Figure 3). Henderson Island rises from water depths of ~3,500 m; similarly, Pitcairn Island has been constructed from a sea floor at least 2,000 m and perhaps 3,500 m below the ocean surface. By comparision, Oeno atoll appears to rise from the southern side of a broad plateau at 1,600 m and Ducie atoll is probably not a simple feature (Mammerickx et al. 1975) but the surface expression of a complex collection of seamounts (Canadian Hydrographic Service 1982). Further to the east, clearly present in the SEASAT geoid but omitted from bathymetric charts, is a major structure topped by two seamounts reaching 1,000 m below present sea level at 25°S, 122.2°W and 24.8°S, 121.7°W; Okal (1984) has proposed that this feature be known as Crough Seamount. Geoidal signatures have revealed further seamounts around 25.6°S, 121.2°W and 26.2°S, 121.8°W (Okal and Cazenave 1985). Finally, the presence of several small seamounts near the East Pacific Rise is indicated by a cluster of geoidal anomalies. The regional synthesis of these recently-discovered submerged features indicates a much more complex and extensive island group lineation than has been apparent up to now from the disposition of islands above sea level. The alignment and spacing of the islands is strongly suggestive of an origin related to a relatively-fixed melting anomaly, or 'hotspot', to the east of the islands and seamounts.

Island chain hotspot traces should show a progressive increase in island age away from the hotspot itself in the direction of plate motion. However, given island morphologies in the Pitcairn Group, the only established dates for island genesis are from Pitcairn Island where potassium-argon dating of exposed volcanics has identified two phases of volcanism, at 0.46-0.63 and 0.76-0.93 million years B.P. The latter period probably represents the main phase of island construction (Duncan et al. 1974). Basaltic lavas which form the islands of Mangareva, Aukena and Makapu, Gambier Islands, cooled between 5.2 and 7.2 million years B.P. (Brousse et al. 1972) and recovered basalts from Fangataufa atoll and Mururoa atoll have been dated to 7.1-9.1 million years B.P. and 6.5 and 8.4 million years respectively (Brousse 1985), Duncan and Claque 1985). Volcanic migration rates have been calculated at 12.7 ± 15.5 cm yr^{-1} (Duncan and Claque 1985) for the Pitcairn-Gambier sequence and at 10.7-11.0 cm yr^{-1} (Brousse 1985) when extended to Mururoa atoll. These propagation rates are comparable to the values calculated for other S.

Pacific island chains (e.g. Austral-Cook Islands: 10.7 ± 1.6 cm yr^{-1}; Marquesas: 10.4 ± 1.8; Society Islands: 10.9 ± 1.0; Duncan and Claque 1985).

Unfortunately, however, Pitcairn Island's evolution throws little light on the origins of the other islands of the Pitcairn Group. Although almost certainly underlain by volcanics, none of the carbonate caps of Ducie, Oeno or Henderson have been deep-drilled to reach basement basalts. In the absence of such direct data, current reconstruction must be based upon the interpretation of the marine geoid.

SEASAT DATA AND ISLAND ORIGINS : OENO, HENDERSON, DUCIE AND CROUGH

Methodological comment

Fundamental to the concept of plate tectonics is the notion of a strong, rigid lithosphere overlying a weak, fluid asthenosphere. Lithospheric rigidity can be determined by studying the response of oceanic lithosphere to surface loads. By comparing calculated profiles of flexure, computed from known or assumed load shapes, with observed bathymetry, patterns of island uplift and subsidence, seismic refraction results and gravity and/or geoid anomlies, it appears that the most useful first-order model of oceanic plate behaviour is that in which the lithosphere is modelled as a thin elastic plate overlying weak substratum (e.g. McNutt and Menard 1978, Watts 1978). As oceanic lithosphere cools with age (e.g. Parsons and Sclater 1977) it thickens and becomes less responsive to surface loads. Not surprisingly, therefore, summaries of flexure studies (Figure 4) show that the elastic thickness of the lithosphere, T_e, increases with the age of the plate at the time of loading, estimated by subtracting the age of the load from the age of the seafloor (Watts et al. 1980, Watts and Ribe 1984). thus, for example, seamounts formed on young lithospheres are associated with low values of T_e (e.g. 5 km elastic thickness of age = 5 million years) whereas islands produced on old lithosphere are characterised by high values of T_e (e.g. 25 km elastic thickness of age = 80 million years). These differences are preserved through time and thus indicate whether islands were formed either at mid-ocean spreading ridges on thin oceanic plate or at mid-plate locations on much thicker lithosphere. This distinction is reflected in geoidal signature: on-ridge genesis is indicated by small amplitude (0.4-0.5m per km seamount height), short-wavelength geoidal anomalies whereas off-ridge origin is shown by large amplitude (1.4-1.5 m/km), large-wavelength perturbations (Watts and Ribe 1984; Figure 5).

Geodynamics and island ages in the Pitcairn Group

SEASAT geoid anomaly data in the south-central Pacific shows that the broad plateau of the Tuamotu Archipelago has no strong geoidal signature; furthermore, thick (27 km) oceanic lithosphere has been reported beneath the island of Rangiroa (Talandier, in Okal and Cazenave 1985). Both these lines of evidence suggest an on-ridge origin for the plateau and its islands. In the southern Tuamotus, the atolls of Tatakato, Pukaruha and probable Reao conform to this explanation and Okal and Cazenave (1985) have suggested that these islands formed at a hotspot near to, and then on, the junction of the Austral Fracture Zone and the Mendoza mid-ocean ridge (Figure 2a). It seems likely that the meeting of the hotspot and the Austral Facture Zone triggered the southerly propogation of the Mendoza ridge (see above) and the subsequent deactivation of the Austral Fracture Zone and concomitant initiation of the FZ1 fracture zone (Figure 2b). When the spreading system jumped westwards, the hotspot became an off-ridge melting anomaly on the Farallon plate, generating the seamount sequence on the Sal-y-Gomez ridge (Figure 2c) -f) and see Duncan and Hargraves 1984, Schilling et al. 1985). By comparison, the more southerly Tuamotu atolls, from Hao south-east to the Acteon group and Marutea, show strong geoidal signals, indicating that they must have formed off-ridge. Importantly, SEASAT date for Oeno, Ducie and Crough seamount also suggest an off-ridge origin. Unfortunately, no comparable data is available for Henderson Island but given its location it seems reasonable to assume an off-ridge origin for Henderson as well. The extension of the Hao-Marutea trace passes through the location of Oeno and predicts the present position of the hotspot to be ~300 km south of the south-western boundary of the Easter micro-plate (Figure 3). Henderson Island, Ducie and Crough seamount, however, do not fall on this alignment but form a linear chain at a 15^0 angle to it (Figure 3). Okal and Cazenave (1985) have suggested that this deviation has resulted from the interaction of the hotspot with the line of lithosperic weakness represented by the old fracture zone FZ2, with, following the theory of Morgan (1978), lateral leakage from the hotspot leading to the successive construction of Henderson, Ducie and Crough.

If such speculations on island origins are correct, then what ages can be assigned to the islands within the Pitcairn group, aside from Pitcairn Island itself? Okal and Cazenave (1985) give ocean floor age estimates of 10 million years for Crough Seamount, 14 million years for Ducie, 19 million years for Henderson and 27 million years for Oeno. In the vicinity of Pitcairn Island, Duncan et al. (1974) have suggested that the plate has an age of 30 million years. Using the methodology of Cazenave and Dominh (1984), where the comparison of observed and theoretical geoid heights is used to define a best fit of lithospheric flexural rigidity (D) and effective elastic thickness (T_e), Okal and Cazenave (1985) have calculated the age of the plate at the time of loading, or flexural age, as 5-7 million years. This would suggest the following island ages (±1 million years):- Crough Seamount : 4 million years; Ducie : 8 million years; Henderson : 13 million years; and Oeno : 16 million years. These dates, however, can only be seen as first approximations as the flexural age is not a true measure of the age of the plate at time of loading because of the likelihood of plate re-heating at the time of island emplacement (for theory : Detrick and Crough 1978, McNutt 1984). Interestingly, in the Central Pacific a range of geophysical anomalies indicate low elastic thickness over the region between - 10^oS to -30^oS and from 120^o to - 160^oW (Cochran 1986, McNutt and Fischer 1986, Calmant and Cazenave 1987). McNutt and Menard (1982) and Calmant and Cazenave (1986) have interpreted these low thicknesses as indicative of thermal rejuvenation.

Cessation of volcanic activity and island subsidence subsequently led to the development of carbonate caps, of unknown thickness, on the islands of Oeno, Henderson and Ducie (and Crough?). With the later, and independent, development of the Duke of Gloucester Islands - Pitcairn Island hotspot lineation, Henderson was affected by lithospheric flexure processes. On the relatively thin and deformable lithosphere of the South Pacific, the emplacement of relatively young (<2 million years) volcanoes, as a result of 'hotspot' activity, has produced a near-volcano moat and a peripheral bulge, or arch, at some distance from each load. The coincidence of sea-level coral reefs with this radius has resulted in the formation of raised reef islands (McNutt and Menard 1978). Flexural moats have been defined around some mid-plate volcanoes (e.g. Hawaii: Ten Brink and Watts 1985, Watts et al. 1985; Marquesas: Fischer et al. 1986) and reef limestone uplift, apparently associated with flexure, demonstrated from the Society Islands (Pirazzoli 1983), the N.W. Tuamotu Archipelago (Lambeck 1981a, Pirazzoli and Montaggioni 1985) and the southern Cook Islands (Lambeck 1981b, Stoddart et al. 1985, Spencer et al. 1987, Calmant and Cazenave 1986). In the Pitcairn group lithospheric flexure under the weight of the Pitcairn Island has resulted in - 30 m of uplift at Henderson. The raised reef topography of

Henderson, and estimates of the rate of flexure-controlled uplift, are considered in more detail by Spencer and Paulay (this volume).

In summary, therefore, the final patterning of the islands of the Pitcairn group appear to have been derived from three different tectonic settings: old hotspot (Oeno); leakage from old hotspot (Henderson-Crough); and young hotspot (Pitcairn Island), with further tectonic activity at Henderson. Thereafter, the development of island morphologies within the group has been a reaction to mid-latitude environmental change; this is considered in more detail below.

Geodynamics and island age: complications and speculations

Although the scenario outlined in some detail above is an attractive one, recent SEASAT studies in the area to the south-west of the Cook-Austral Islands archipelago have revealed, inportantly, the presence of further fracture/fault zones with the same alignment (N95°E) as FZ1 and FZ2 but extending linearly over much greater distances than Okal and Cazenave's (1985) fractures, in excess of 1000 km (Diament and Baudry 1987). Rather than regarding such lineations as the short-lived (~8million years; Okal and Cazenave 1985) product of mid-ocean ridge re-orientation, it has been suggested that these features indicate far more fundamental intra-plate deformations, being either the result of differential movement between the northern and southern sections of the Pacific plate or the consequence of changes in the absolute motion of the plate as a whole (Diament and Baudry 1987).

Such ideas have resurrected the notion of a south Pacific 'hotline', linking melting anomlies from the Tonga trench to the Nazca plate (Bonatti and Harrison 1976, Bonatti et al. 1976, Turner and Jarrard 1982). This hypothesis has found support from the detection of gravity undulations, of 150-200 km wavelength and trending WNW in the direction of plate motion, between the East Pacific Rise and French Polynesia by Haxby and Weissel (1986). They suggest that such features result from small-scale thermal instabilities beneath young lithosphere being organised into longitudinal rolls by the shear from fast-moving plates. Interestingly, such patterns are predicted by some convection models (e.g. Richter 1973). SEASAT altimeter data further suggests that such small-scale convection develops within 5 to 10 million years of the initiation of plate cooling (Haxby and Weissel 1986); thereafter this pattern is 'frozen in' to the lithosphere (Buck 1985, Buck and Parmentier 1986).

Finally, however, it should be noted that two further models have been proprosed to explain these undulations: compressive buckling (McAdoo and Sandwell 1985) and tensional cracking (Winterer and Sandwell 1987) of the lithosphere. Clearly, careful bathymetric work will be required to discriminate between these different explanations before a more conprehensive 'hot-line' hypothesis can be formulated.

ENVIRONMENTAL HISTORY OF THE SOUTH-CENTRAL PACIFIC

The growing inventory of high-quality deep-sea cores from the Deep Sea Drilling Project (DSDP) and the determination of fine resolution down-core environmental records from core lithology, stable isotopes and microfloral and microfaunal assemblages now permits the reconstruction of palaeoclimatic and palaeoceanographic conditions, for precise time slices, as far back as the beginning of the Palaeogene.

Clearly, however, such reconstructions are dependent upon the spatial coverage of deep-sea core sites. Unfortunately, the density of sites in the Pacific Ocean is poor by comparison with the Atlantic Ocean and biased towards the northern hemisphere and the eastern equatorial region. Thus, only broad inferences can be made, as yet, as to former circulation patterns and sea surface palaeotemperatures in the south-central Pacific.

Methodological comment

A key tool in environmental reconstruction of ancient oceans is oxygen isotope stratigraphy. $^{18}O/^{16}O$ ratios in foraminifera from deep-sea sediments have been used as indicators of past climates since it was demonstrated in the 1950s that ^{18}O enrichment ($\delta^{18}O$) in foraminifera varies with ^{18}O in the water from which their carbonate skeletons have been precipitated but differs from the water value by an amount determined by temperature (e.g. Epstein 1953, Emiliani 1955; but see also Shackleton 1984 for problems of temperature calibration and potential effects of within-sediment diagenesis of skeletal calcite). However, the deep-sea palaeotemperature record is complicated by historical fluctuations in ocean isotopic composition. It is generally agreed that there have been changes in isotopic composition of the order of 1.0-1.6 (180 per mil to PDB standard) resulting from the repeated growth and decay of isotopically light ice sheets on the Northern Hemisphere continents (Shackleton 1967, 1984) but the interpretation of the Tertiary record has proved more problematical. One hypothesis (Matthews and Poore 1980) suggests that there have been no significant changes in low latitude sea surface temperatures in the Cenozoic and, therefore, that the fluctuations in the oxygen isotope record only reflect changes in global ice volumes. This hypothesis, however, challenges the widely-held view (e.g. Shackleton and Kennett 1975, Savin 1977, Woodruff et al. 1981) that Antarctica was essentially ice-free until the middle Miocene and, therefore, that the Palaeogene isotopic record is one of temperature change in the deep ocean. Recently more accurate oxygen isotope measurements (Shackleton 1986), whilst providing general support for this second model, have shown the interpretation to be too simplistic, and it now seems likely that ice was present in Antarctica in the early (Shackleton et al. 1984b), middle (Keigwin and Keller 1984) and latest (Miller and Fairbanks 1985) Oligocene. These arguments need to be borne in mind when interpreting the oxygen isotope record of the past 70 million years.

TERTIARY PALAEOGEOGRAPHY AND PALAEOCEANOGRAPHY

Shackleton's (1984) compilation of oxygen isotope data (Figure 6) shows that the early Cenozoic was characterised by high temperatures at both low- and mid-latitudes and thus relatively small equator-to-pole and surface-to-bottom temperature gradients. Dramatic cooling of both mid-latitude and deep-ocean waters occurred at the Eocene-Oligocene boundary (Figure 6; Keigwin 1980) and there was a further divergence, of mid-latitude and deep-ocean water temperatures, in the middle Miocene (Savin et al. 1981, Shackleton and Kennett 1975, Woodruff et al. 1981). Evidence for increasingly vigorous atmospheric-oceanic circulation, at both 15-16 myr B.P. and 9-5 myr B.P., associated with climatic deterioration, is provided by the appearance of diatomites in Pacific rim sedimentary sequences (Ingle 1981), increasing biogenic silica accumlation (from 16 myr B.P., peak at 8 myr B.P.: Leinen 1097) and rising calcium carbonate supply rates (peaking 14-15 myr B.P.: Van Andel et al. 1975) in the equatorial Pacific. Changes towards large grain sizes in the particle-size distribution of aeolian dust from 11.8 myr B.P. imply a significant intensification of the southern hemisphere tradewinds (Rea and Bloomstine 1986); this mirrors the better-known North Pacific record (e.g. Rea and Janecek 1982, Rea et al. 1985).

It has been suggested that these events in the Pacific Ocean were indirectly driven by palaeogeographic changes, themselves the result of the re-arrangement of plate boundaries; thus an attractive scenario argues that the Oligocene development of the Circum-Antarctic Current, as Australia and, later, South America, became detached from Antarctica, progressively isolated the Antarctic from lower latitude influences and resulted in cooler, polar temperatures, increased presence of sea-ice, cooler bottom water temperatures and, ultimately, the development of a major continental ice sheet on East Antarctica (Kennett 1977, 1982). Allied to the establishment of this high-latitude, circum-global circulation was the modification and ultimate loss of the circum-equatorial Tethys seaway, firstly by the mid- to early late-Miocene closure of the Indo-Pacific passage in the Indonesian region as a result of the continued northward migration of Australia/New Guinea (Edwards 1975, Hamilton 1979), and secondly by the late Miocene constriction - Pliocene closure of the Atlantic-Pacific connection through the isthmus of Panama (Keigwin 1978).

These palaeogeographic changes both steepened pole-to-equator temperature gradients and altered the pattern of atmospheric and oceanic circulation towards their present arrangement. In the equatorial region these changes enhanced surface productivity of ocean waters by diverting large volumes of water into westerly boundary currents which were then returned as an intensified surface circulation and by the development of an equatorial undercurrent (Figure 7). As a result, east v. west Pacific biogeographic differences were reduced and replaced by a latitudinal provincialism (Kennett et al. 1985). However, and importantly, these changes took place around the largely unaffected subtropical gyres.

QUATERNARY ENVIRONMENTS: SEA LEVEL CHANGE IN THE PLEISTOCENE

The oxygen isotope record from deep-sea cores (Figure 8) indicates strong climatic fluctuations from ~ 3.2 myr B.P. (Shackleton and Opdyke 1977, Shackleton et al. 1984a). There have been 10 completed glacial-interglacial cycles in the last one million years, with 8 cycles, at approximately 100,000 yr intervals, since 0.73 myr B.P. (Shackleton and Opdyke 1973). Each cycle shows a characteristically 'saw-toothed' pattern of slow, progressive ice build-up and rapid de-glaciation (Broecker and Van Donk 1970; Figure 8).

The mass and melting history of contential ice sheets can also be derived from radiometrically-dated coral reef sequences preserved by uplift on tectonically active coasts. The difference between the altitude of a reef of known age and the present sea level provides a precise measure of the past sea level if the tectonic component can be estimated and substracted (e.g. Haiti: Dodge et al. 1983; Barbados: Matthews 1973). Using these principles, a particular fine record of sea level change has been constructed from the Huon Peninsula, New Guinea (Chappell 1974), Bloom et al. 1974, Chappell 1983) where coral reef terraces have been preserved along a rapidly rising (0.9-3.5 m kyr^{-1}) coastline. The sea-level curve from this locality has been recently refined, following comparison with the deep-sea core oxygen isotope record (Chappell and Shackleton 1986; Figure 9). The curve shows, for the last glacial-interglacial cycle fast rising sea levels (up to 8m kyr^{-1}) during the major post-glacial transgressions, culminating in interglacial high sea level stands between 118-138,000 yr B.P. (reef complex VII) and from 8,200 yr B.P. (reef I). The Last Interglacial sealevel on the Huon Peninsula (124,000 yr B.P.; reef VIIa) is assumed to have reached ~ 6.0 m above present sea level, as elsewhere around the globe (Moore 1982). Estimates for low sea levels prior to these transgressions, determined by maximum ice volumes, have been set at -130 m, less that the levels of -135 to -165 m suggested by evidence from northern Australia but in excess of the values of -90 to 110 m reported from the eastern seaboard and Gulf of Mexico coasts of the USA (Chappell and Shackleton 1986). Such differences are to be expected as they relate not only to the record of sea level change but also to the behaviour of the continental margins. Slower rising sea levels (up to 2.5 m kyr^{-1}) were recorded by Huon fringing reef development at 100,00 (reef VIa), 81,000 (Va), 59,000 (IVa), 45-40,000 (IIIa-IIIb) and 28,000 (II) yr B.P. (Figure 9). These reefs represent a series of high sea level interstadials falling progressively further below present sea level at -9±3m, -19±5m, -28±3m, -41±4m and -44±2m respectively (Figures 9, 10). Low sea levels between interstadials have proved difficult to define in the absence of dateable reef deposits but inference suggests a range of 37 to 55 m below present sea level (Aharon and Chappell 1986).

In the South Pacific, presumed Last Interglacial (i.e. reef complex VII) reef limestones reach 3.48 m above present sea level at Ngatangiia and 2.2 m at Nikao, Rarotonga, Southern Cook Islands, and have been attributed to glacio-eustatic fluctuations in sea level (Stoddart et al. 1985). At Makatea Island, NW Tuamotu Archipelago, cliff-veneering apron reefs, bounded at their upper margin by notch lines and caves 5-8 m above present sea level (Montaggoni et al. 1985) have been assigned to the time interval 100-140,000 yr B.P. on the basis of limited uranium-series age determinations (Veeh 1966). In the Southern Cook Islands, Last Interglacial reef limestones on Mangaia (101-135,000 yr B.P.: Veeh 1966, Spencer et al. 1987) reach 14.5 m above present sea level; raised reefs presumed to be contemporaneous with the Mangaian deposits attain heights of ~10 m or more on Atiu, Mauke and Mitiaro. Finally, at Henderson Island, presumed Last Interglacial reef units also reach ~10 m above present sea level (Spencer and Paulay, this volume). Apart from Rarotonga, all these reef limiestones exhibit upper altitudinal limits considerably above characterstic Last Interglacial elevations, they must, therefore, indicate an additional component of tectonic uplift superimposed upon the sea levels associated with glacio-eustatic sea level changes. For all these localities it has been argued that uplift has resulted from the up-arching of oceanic lithosphere under loading from neighbouring volcanoes of Pleistocene age (McNutt and Menard 1978, Lambeck 1981a, 1981b, Spencer and Paulay this volume). However, it is difficult to apply this explanation to Rurutu, Austral Islands, where Last Interglacial (188-126,00 yr B.P.) limestones reach 8-10 m above present sea level and mid-plate thermal rejuvenation, in association with mid-plate hotspots, may also have been involved (Pirazzoli and Veeh 1987).

In spite of these tectonic processes, uplift rates have not been sufficient at these mid-ocean settings to raise interstadial reefs above present sea level (see Figure 9). Thus at Henderson Island where the uplift rate over the last 125,000 years has been estimated at between 0.04 and 0.09 m/1000 yr (Spencer and Paulay, this volume), deposits equivalent to New Guinea reef complex VIa should be found at ~0 to -5 m; thus they may floor the contemporary reef flat and form the shallow terrace offshore. By extension, reef complexes Va and IVa should be found in water depths of ~ -11 to 16 m and -20 to -25 m respectively; they may, at least in part, from the second, deeper coral ledge at Henderson and the broad offshore shelves, with their shelf breaks at 25-30 m, seen at Ducie atoll.

QUATERNARY ENVIRONMENTS: PALAEOCLIMATOLOGY AND PALAEOCEANOGRAPHY

As well as adapted to relatively rapid fluctuations in sea level, Pleistocene coral reefs in the Pitcairn Group must also have been subjected to a varying climatic and oceanographic environment.

It is possible to successfully reconstruct palaeoceanographic conditions by the application of biological transfer function techniques, orignally devised by Imbrie and Kipp (1971), to micropalaeontological data. When mapped over the ocean floor, mathematically-defined micro-faunal assemblages from surface sediments show a close fit to water mass and current distributions. Thus changes in assemblages within cores indicates different oceanographic conditions. It is further possible to express assemblage information in terms of physical or ecological variables; in particular, equations which express sea surface temperature as a function of various assemblage have been derived using regression analysis. The down-core application of such transfer functions permits estimates of past temperatures to be made (e.g. CLIMAP Project Members 1976, 1984).

Reconstruction of sea surface temperatures for the Last Interglacial ocean suggests little change from present conditions: 60 per cent of the estimates from deep-sea cores differ from today's values by amounts less than the typical ±1.0 to 1.5°C standard error of estimate (CLIMAP Project Members 1984). However, within the southern hemisphere sub-tropical gyre palaeotemperature estimates from core V19-53 (17°S; 113°W) suggest a southern summer (February) mean sea surface temperature of 29.3°C and a souther winter (August) temperature of 27.°C, in each case 3.9°C warmer than the equivalent present sea surface temperature at that latitude (Table 1). Were such changes to have extended south they would have had important implications for the maintenance of reef growth at Henderson, Oeno and Ducie. However, not all the deep-sea core evidence suggests such changes in temperature (Table 1).

For the last glacial maximum, at 18,000 yr B.P., deep-sea core evidence suggests that the Southern Ocean as a whole was cooler by 2°C (CLIMAP Project Members 1976). Similar reconstruction from $^{18}O/^{16}O$ ratios in reef molluscs (Konishi et al. 1974, Fairbanks and Matthews 1978, Shackleton and Matthews 1977), allowing for global ice volume effects, have given comparable results. In particular, careful studies using specimens of the giant clam *Tridacna gigas* from the Huon terrace sequences by Aharon and Chappell (1986) have suggested a cooling of 2-3°C in surface ocean temperature from early (reef complexes VI-V) to late (IV-V) interstadials in the last glacial-interglacial cycle. However, as with the pre-Pleistocene and Last Interglacial record, little temperature change appears to have affected the mid-latitude gyre of the south-central Pacific (CLIMAP Project Members 1976), a pattern repeated for the Indian and S. Atlantic Oceans (Moore et al. 1981). In the north Pacific, ocean surface temperatures have been reconstructed as similar to those at present (Thompson 1981) or, for the vicinity of Hawaii, perhaps up to 2°C warmer (Rind and Peteet 1985). Rather than temperature change, the northern hemisphere glaciations led to further intensification of the atmospheric-oceanic circulation.

The south-east Trades are the driving force of surface currents in the eastern equatorial Pacific. Studies of quartz abundance distribution in core V19-29 (3°'S, 83°56'W) have suggested that the tradewinds were more intense during the glacial phases, in particular between 73-61 x 10^3 yr B.P. and 43-16 x 10^3 yr B.P. (Figure 11; Molina-Cruz 1977). Changing distributions of radiolarian assemblages in deep-sea core (Moore et al. 1981) indicate that the strengthing of the glacial trades was accompanied by a more meridional pattern of wind stress and an intensification of the equatorial surface circulation, with increased equatorial countercurrent and decreased equatorial undercurrent (Romine 1982). The eastern boundary flows showed greater westward penetration with Peru Current upwelling reaching its most westerly at the glacial maximum (Romine and Moore 1981).

Stoddart's (1973) calculation of the effect of glacial sea surface temperatures on the extent of the reef seas suggests a simple, latitudinal shift towards the equator of the area of the south Pacific able to support coral growth (Figure 12). However, from the more comprehensive deep-sea core coverage now available it is clear that the major glacial to inter-glacial changes in climatic and oceanographic conditions produced variations in the intensity of circulation not latitudinal migrations of the climatic belts (Figure 12). The expansion of the polar seas at high latitudes resulted in the compression of the areas occupied by the sub-polar and subtropical-transitional water masses and left the tropical water masses largely intact. Whilst the islands of the Pitcairn Group may have been subjected to a windier and perhaps stormier glacial climate, with greater contrasts between windward and leeward shores, it is unlikely that water temperatures were appreciably cooler or more inimical to coral growth than at the present time (Figure 12).

HOLOCENE SEA LEVEL CHANGE IN THE SOUTH-CENTRAL PACIFIC

The explanation of global Holocene sea level changes lies in the interaction between the volume, melting history and location of sources of meltwater from the decay of ice sheets and deformation of the earth's crust due to both the unloading of continental ice (glacio-isostasy) and the loading of the oceans by meltwater (hydro-isostasy) (Farrell and Clark 1976). Both these sets of controls have varied considerably in their magnitude at-a-point in time over the globe and at-a-point in space during the Holocene transgression, thus giving rise to a range of Holocene sea level curves not only between different oceanic areas (e.g. Peltier et al. 1978) but also between continental margins and oceanic islands (Walcott 1972) and within ocean basins (e.g. Nakiboglu et al. 1983, Lambeck and Nakada 1985).

There is widespread evidence through the south-central Pacific for a higher-than-present Holocene sea level of ~±1.0m between ~6,000 years B.P. and ~2,000 years B.P. (Figure 13). Field observations suggest that this event is represented on at least some of the islands of the Pitcairn Group.

At Ducie atoll, the lagoon shore of the largest *motu,* Acadia Island (Rehder and Randall 1975), is characterised by superficially cemented sheets and slabs of coral rubble, estimated to be 0.30-0.45 m above present mean sea level at the lagoon edge. The morphology of these deposits varies along the lagoon shore: at the eastern extremity of the island the deposits appear to represent lithified, coalescing washover fans (Plate 1) whereas on the central lagoon shore extensive areas of exfoliating sheets, comparable to the Holocene conglomerates described from French Polynesia by Montaggioni and Pirazzoli (1984) are characteristic (Plate 2). Towards the western end of the *motu* these sheets are replace by boulder streams of uncemented coral heads, separated by areas of coral stick gravel (Plate 3).

On the south-western margin of the main wooded island at Oeno atoll (Figure 14) a lower beachrock unit with locally abundant acroporids appears bevelled and overlain by an upper beachrock unit containing corals and *Tridacna* Plate 4). Massive beachrocks also locally overlie the bevelled beachrock and on the north-west coast appear to provide the basement for island sediments (Figure 14).

By comparison with the atolls, however, there is less evidence for a Holocene high stand on Henderson Island. The reasons for this are partly topographical: the presumed high stand deposits on Ducie and Oeno have accumulated, and subsequently been preserved, on lagoon shores whereas the inner reef environment on Henderson offers no such protection (and see Spencer and Paulay this volume). However, additional tectonic and tectonically-related factors must also be considered.

Attempts to model Holocene sea level change in the Pacific basin have been complicated by the presence of two unknowns: the melting histories of the Late Pleistocene ice sheets (and specifically the relative contributions of Arctic and Antartic ice) and the flow in the lower mantle, or mantle viscosity. In addition, local hydro-isostatic adjustments take place around islands (Nakada 1986) and on continental shelves (Chappell et al. 1982) because of the differential loading between island interiors and outer margins and inner and outer continental shelves respectively; fortunately, however, such effects are unimportant at scales of 10 km or less. Finally, however, the possible role of migratory geoidal highs in determining the sea level record, first postulated by Mörner (1976), also needs to be evaluated in reef environments (Nunn 1986).

The sea level record can in turn be masked by non-related tectonic processes. One such process is the subsidence of young volcanic islands; subsidence rates of 1-2 mm yr^{-1}, over 8,000 years, and 0.14-0.15 mm yr^{-1}, over 5,000 years, have been suggested for Oahu, Hawaiin Islands (Nakiboglu et al. 1983) and Moorea-Tahiti, Society Islands (Pirazzoli and Montaggioni 1985) respectively. Furthermore, Pirazzoli and Montaggioni (1985) have argued that regional variations in Holocene sea level curves between the Society Islands and the N.W. Tuamotu atolls (and perhaps within the Societies themselves (Pirazzoli 1983)) have resulted from lithospheric flexure around the Tahiti-Moorea volcanic load. Presumably such arguments might be used to differentiate sea level histories between flexure-affected Henderson on the one hand and Ducie and Oeno atolls on the other.

Taking these complications into account, and using constrained values for mantle viscosity and favoured melting models from the comparison of model sea level curves with observed records from N. Australia and New Zealand (Lambeck and Nakada 1985, Lambeck and Nakiboglu 1986), it is clear that the Pacific high stand at ~6,000 years B.P. was largely due to the control of mantle viscosity, with the potential contribution of Antartic ice controlling the 'peakedness' of the event (Lambeck and Nakada 1985, Nakada and Lambeck 19867). The model fit to observed values provides a useful first approximation, although high sea levels appear to have been sustained into a period when model predictions suggest a gradual fall in sea level (Figure 15). Clearly more detailed observations, with radio-carbon dating control, from the Pitcairn group would be useful in the refining of sea level models for this period.

CONCLUSIONS

This review has shown that while our knowledge of the genesis and evolution of the south-central Pacific, and of the Pitcairn group of islands within this region, has been considerably increased on the last decade, large gaps still remain in our understanding of volcanic island development and attendant coral reef construction.

While remarkable progress has been made through the use of remotely-sensed data many of the research questions which have been generated by these studies now require direct field-testing. This might be achieved by programmes of deep-drilling, to both ocean floor and island basements, and by more comprehensive geological and geomorphological surveys than have hitherto been achieved.

Although there have been noteable exceptions, mid-plate, mid-latitude locations have been relatively neglected in scientific terms by comparison with plate-marginal settings and both high and low latitude environments. However, a much greater knowledge of the processes active at intra-plate settings at intermediate latitudes will be required for forthcoming reconstructions of global tectonic and environmental histories and the predictions at and around remote islands such as those of the Pitcairn group are of significance, both to answer specific research hypotheses and in much broader contexts.

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			SST_W (°C)^1			SST_S(°C)^1	
Core	Location	5e^2	Atlas^3	Core Top^4	5e^2	Atlas^3	Core Top^4
V19-53 (Moore et al. 1980)	17°01'S 113°31'W	27.0 ±3.0	23.1	23.9	29.3 ± 1.5	25.4	28.3
V32-126 (Thompson 1981)	35°19'N 117°55'E	18.9 ±1.5	16.0	16.8	27.0 ±1.5	24.6	25.2
V21-146 (Moore et al. 1980)	37°41'N 163°02'E	17.3 ±2.4	14.5	13.5	24.8 ±1.8	24.0	22.0

[1] SST_W = winter sea surface temperature in February (N. Hemisphere) or August (S. Hemisphere).
SST_S = summer sea surface temperature in August (N. Hemisphere) or February (S. Hemisphere).

[2] Last Interglacial seasonal sea surface temperature (with standard error of estimate) from transfer functions applied to deep sea core.

[3] Modern SST from atlas values.

[4] Holocene SST from core top sediments

TABLE 1 SEA SURFACE TEMPERATURES IN SELECTED MID-LATITUDE DEEP-SEA CORES: ISOTOPIC STAGE 5e COMPARED TO MODERN ESTIMATES

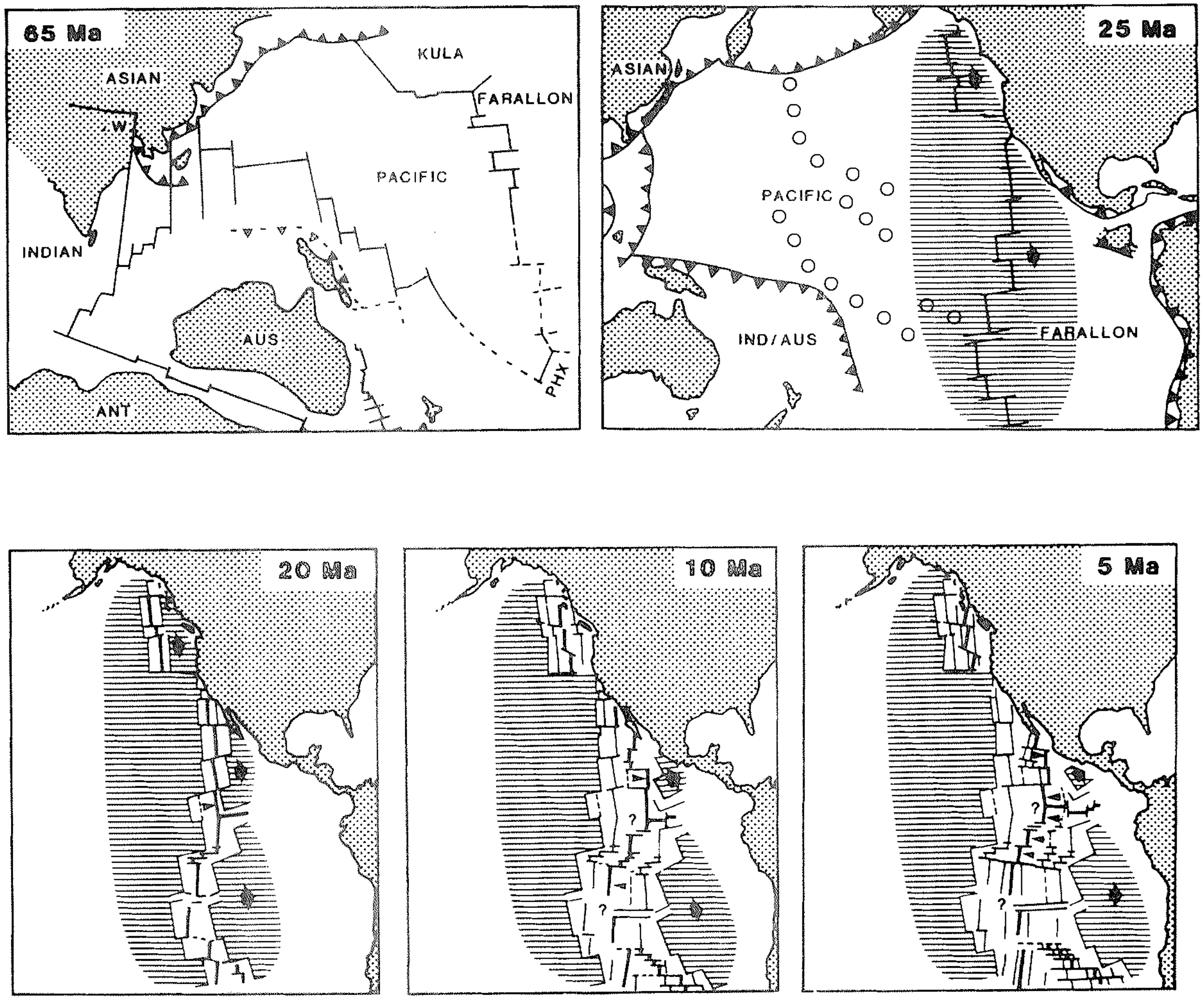


Figure 1. The Pacific at the beginning (65 million years B.P.) and end (25 million years B.P.) of the Palaeogene (after Williams 1986) and subsequent plate boundary reorganisation 20 to 50 million years B.P. (after Handschumacher 1975 and other sources). Open circles indicate island chains of volcanoes and seamounts.

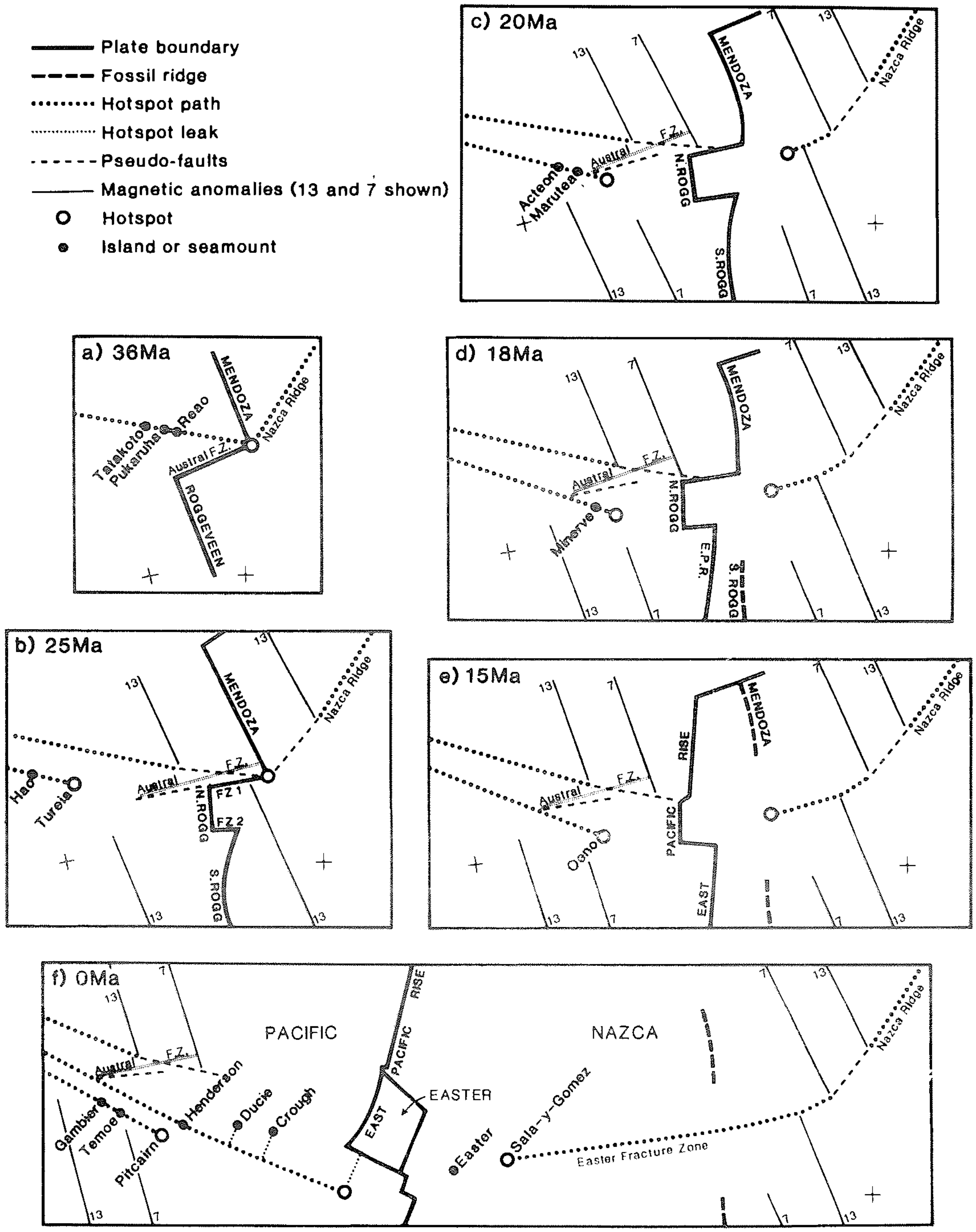


Figure 2. Plate tectonic evolution of the south-central Pacific 36 millions years B.P. to present (after Okal and Cazenave 1985). Island/Seamount names noted only on first time-frame appearance.

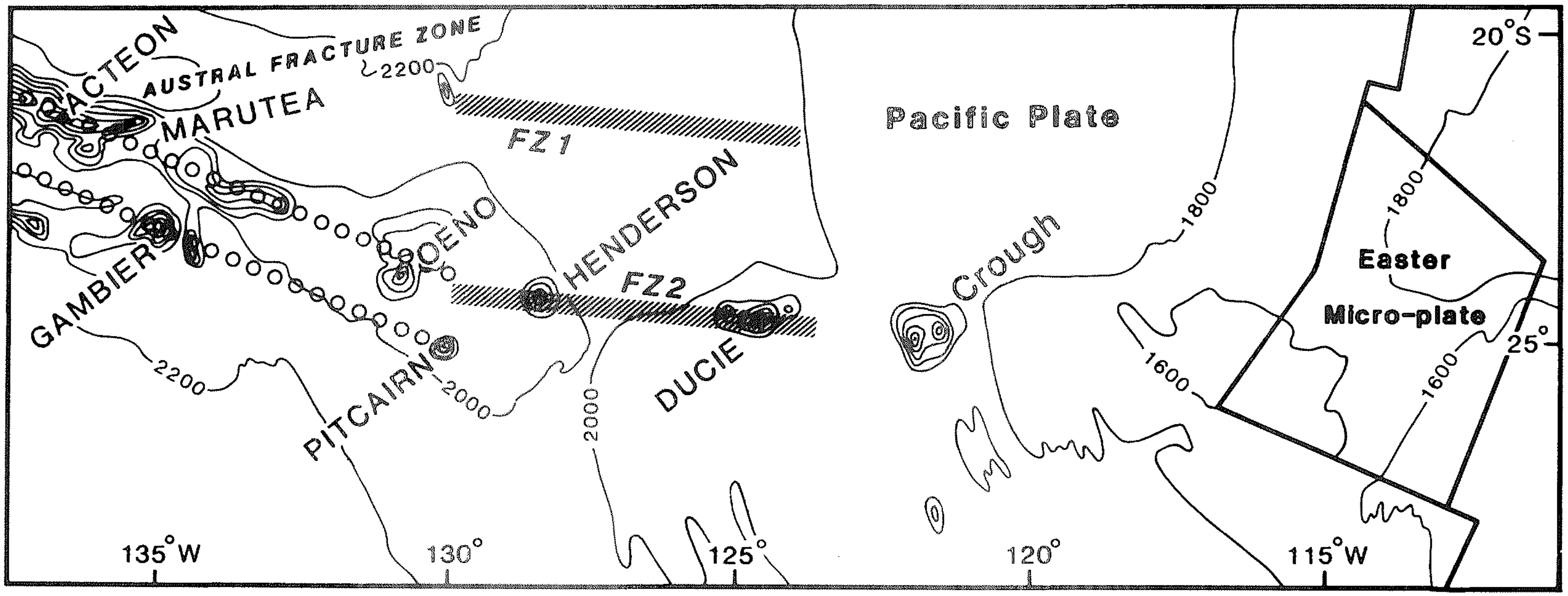


Figure 3. Regional bathymetry; and principal tectonic features and lineations (after Okal and Cazenave 1985).

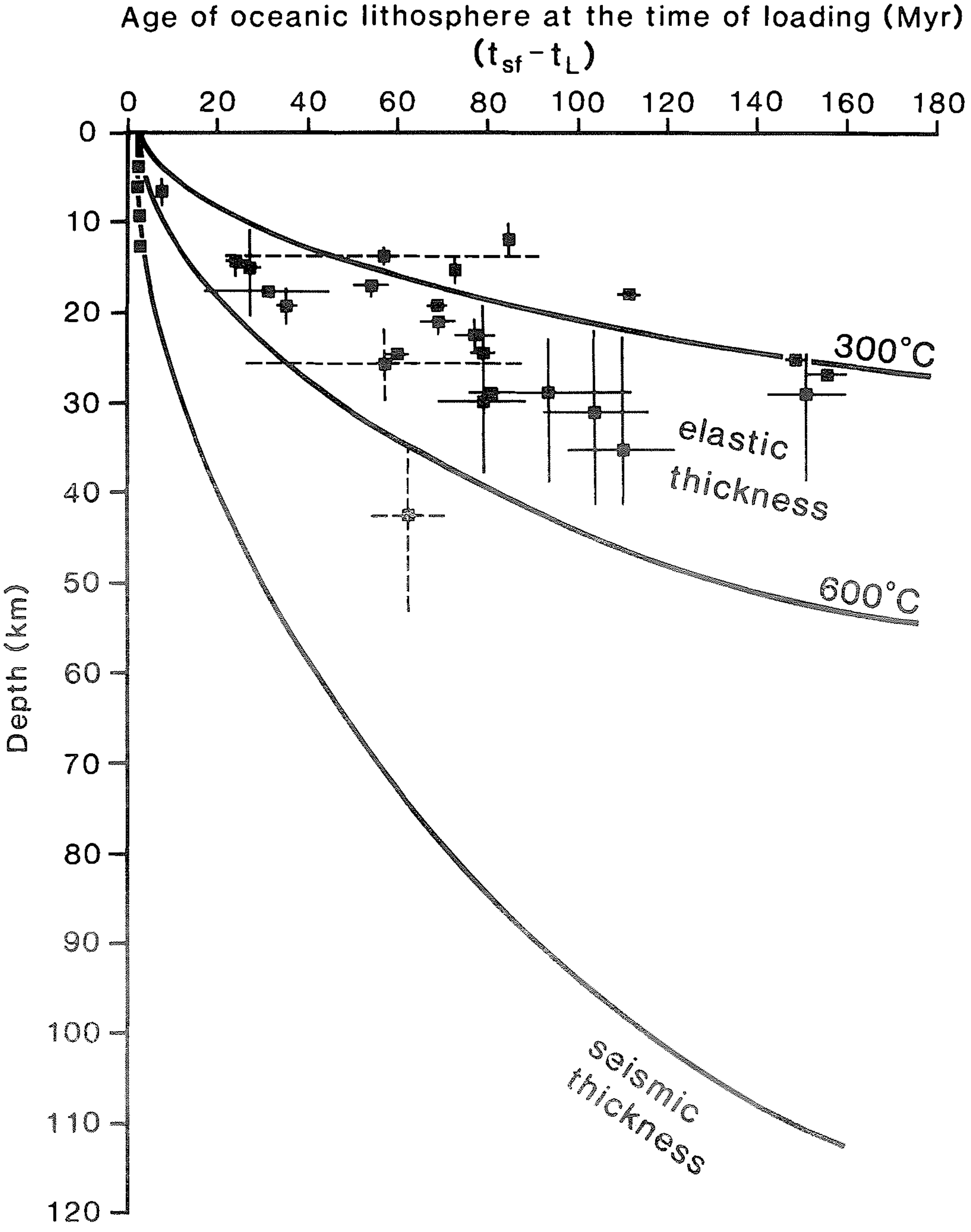


Figure 4. Elastic thickness of oceanic lithosphere, T_e, as a function of the age of lithosphere at time of loading t_{sf} = age of seafloor; t_L = age of load (after Watts and Ribe 1984). 300° and 600° isotherms from cooling plate model of Parsons and Sclater (1977).

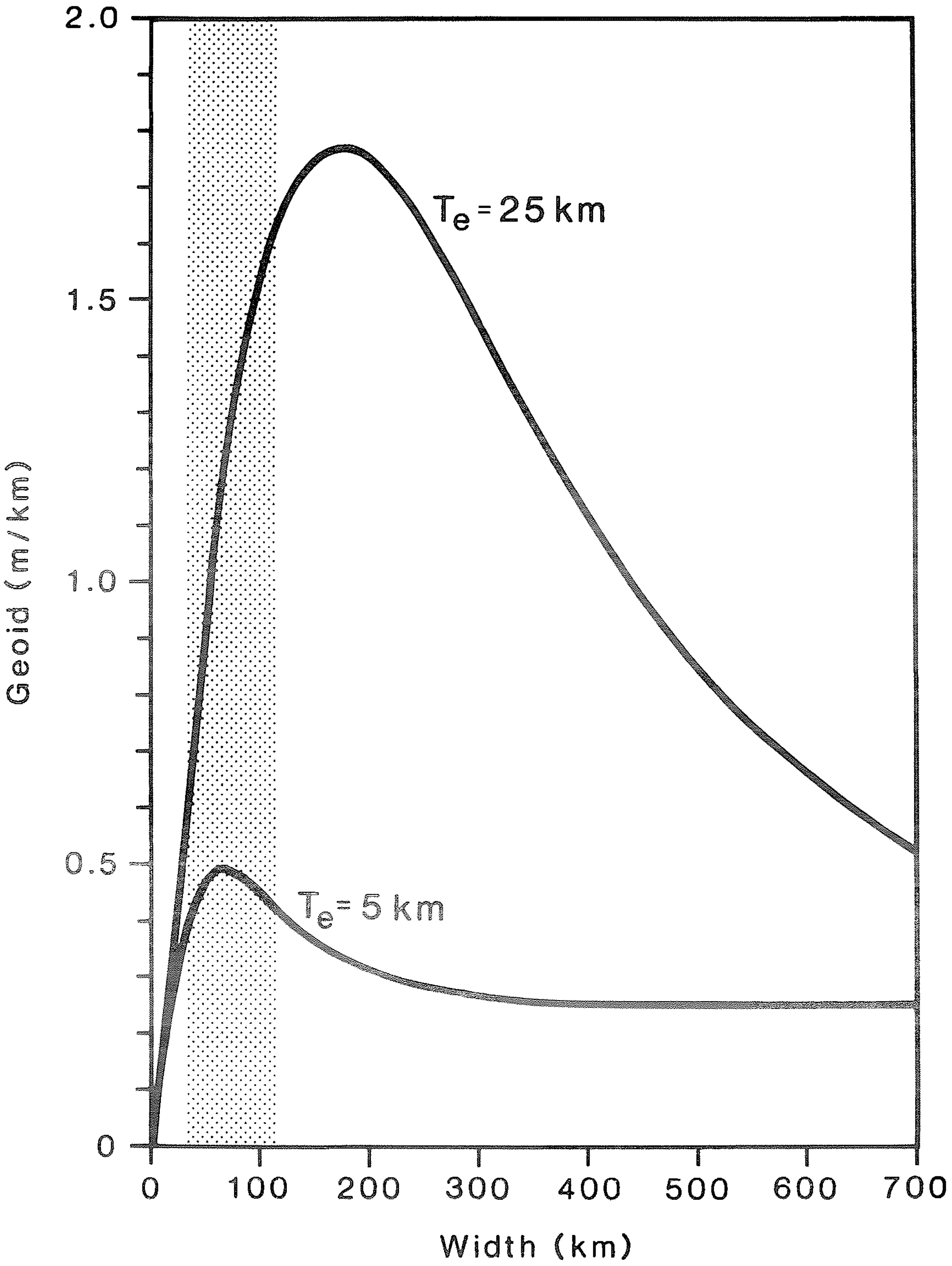


Figure 5. Maximum amplitude of geoid anomaly associated with two-dimensional seamount model. Upper curve for emplacement off-ridge (T_e = 25 km), lower curve for on-ridge origin (T_e = 5 km). Abscissa represents e^{-1} width of Gaussian seamount topography and vertical band indicates range of widths for typical oceanic seamount. Ordinate shows maximum geoid anomaly amplitude over feature 1 km high (after Watts and Ribe 1984).

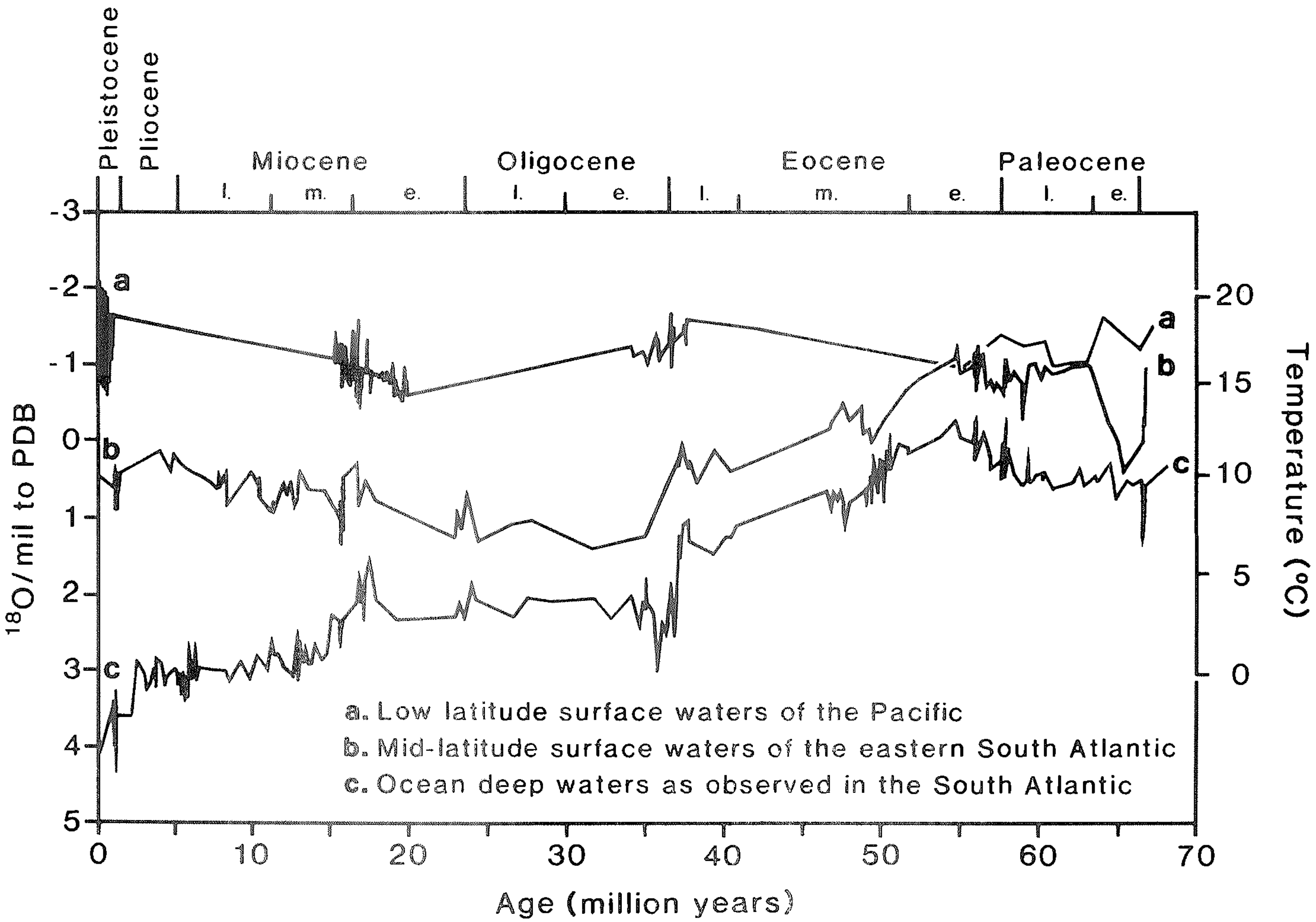
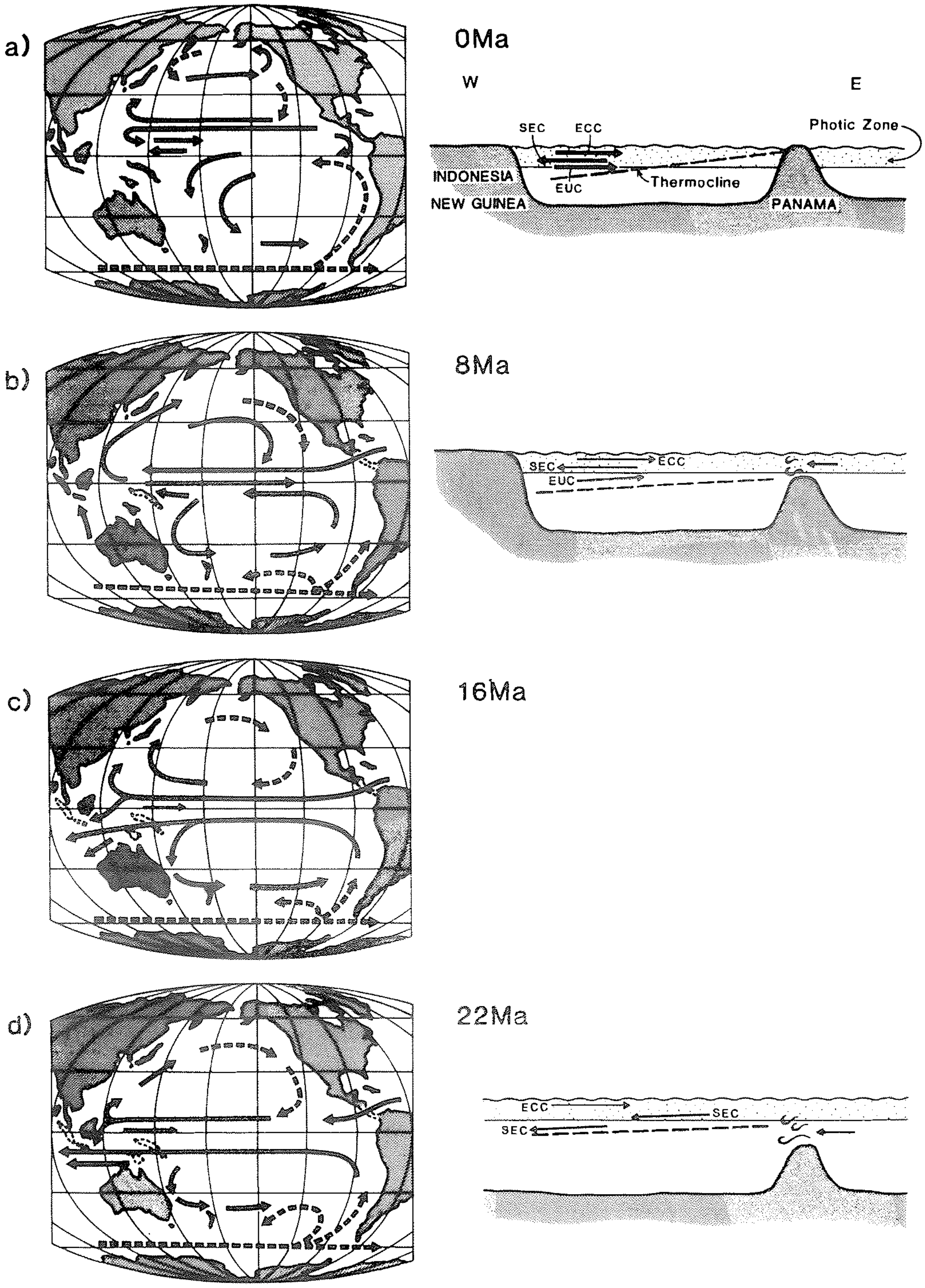


Figure 6. Oxygen isotope records for the last 70 million years (after Shackleton 1984). Temperature scale applicable only in the absence of Antarctic ice sheet before Middle Miocene; presence of Antarctic ice prior to this period would yield temperatures slightly higher than indicated on the temperature scale.


a)
0Ma
W
E
SEC
ECC
Photic Zone
INDONESIA
NEW GUINEA
EUC
Thermocline
PANAMA
b)
8Ma
SEC
ECC
EUC
c)
16Ma
d)
22Ma
ECC
SEC
SEC

SEE PRECEDING PAGE

Figure 7. Inferred circulation patterns of surface and near surface waters in the Pacific Ocean at 22, 26 and 8 million years B.P. and suggested changes in surface water-mass structure in the equatorial Pacific, early Miocene to present (after Kennett et al. 1985).

On maps: broken arrows indicate cold currents; solid arrows indicate warm currents.
On sections: SEC South Equatorial Current; ECC Equatorial Countercurrent; EUC Equatorial Undercurrent.

22-16 million years B.P.: Both Indonesian and C. American seaways open to surface waters; thermocline relatively deep in absence of undercurrent; ECC weak.
8 million years B.P.: Indonesian seaway closed and formation of EUC; thermocline shallower; ECC moderately strong.
Modern ocean: C.American seaway closed; all surface water circulation more vigorous; further raising of thermocline into photic zone, particularly in E. Pacific.

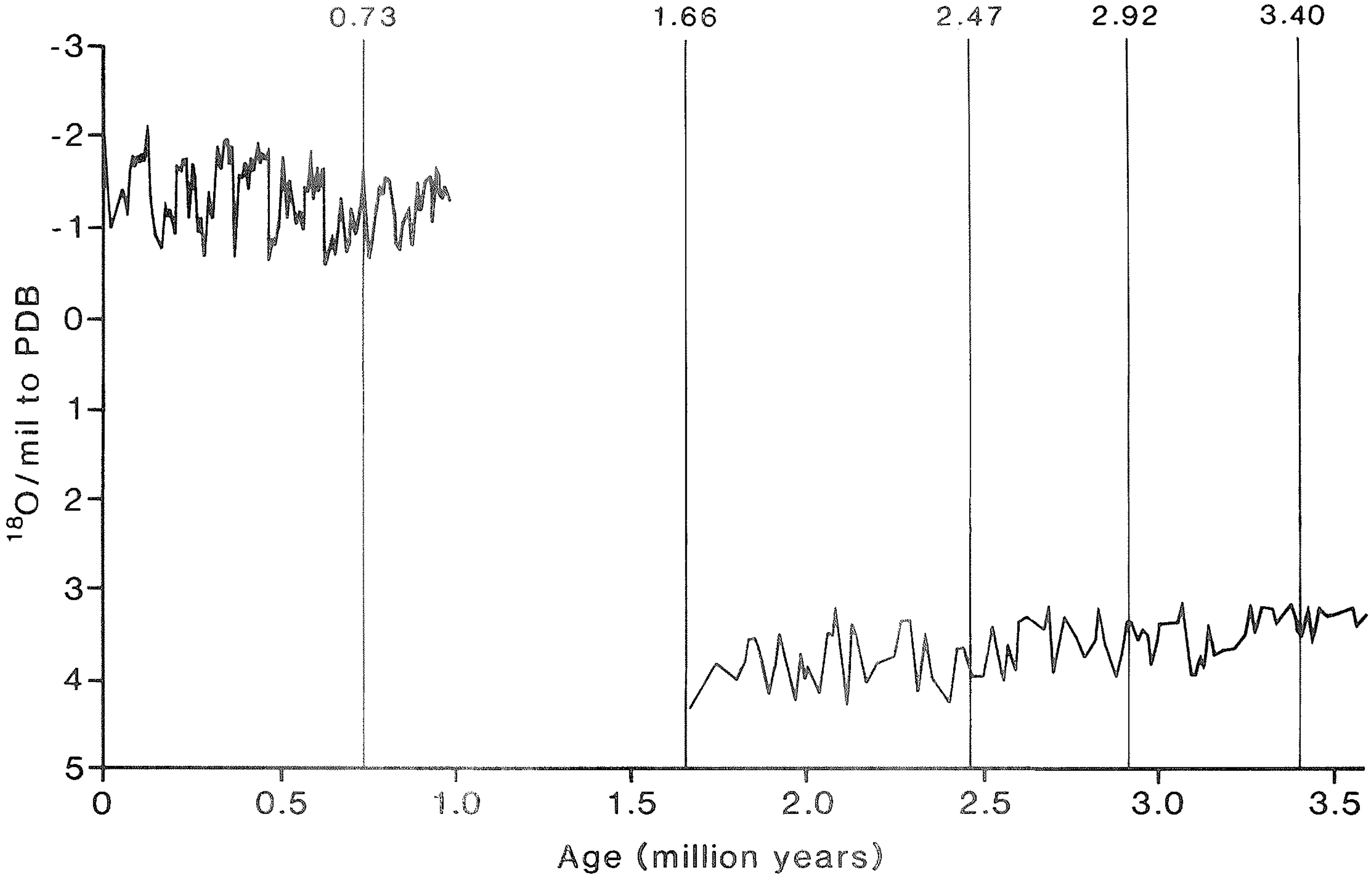


Figure 8. Oxygen isotope records from the Pacific Ocean. Top left: Pacific deep-sea core V28-238 (after Shackleton and Opdyke 1973). Bottom right; core V28-179 (after Shackleton et al. 1984a). Time control horizons: Brunhes normal chron (0.73 Myr), Olduvai normal subchron (1.66 Myr), Matuyama reveresed chron (2.47 Myr), Kaena reversed subchron (2.92 Myr) and Gauss chron (3.40 Myr).

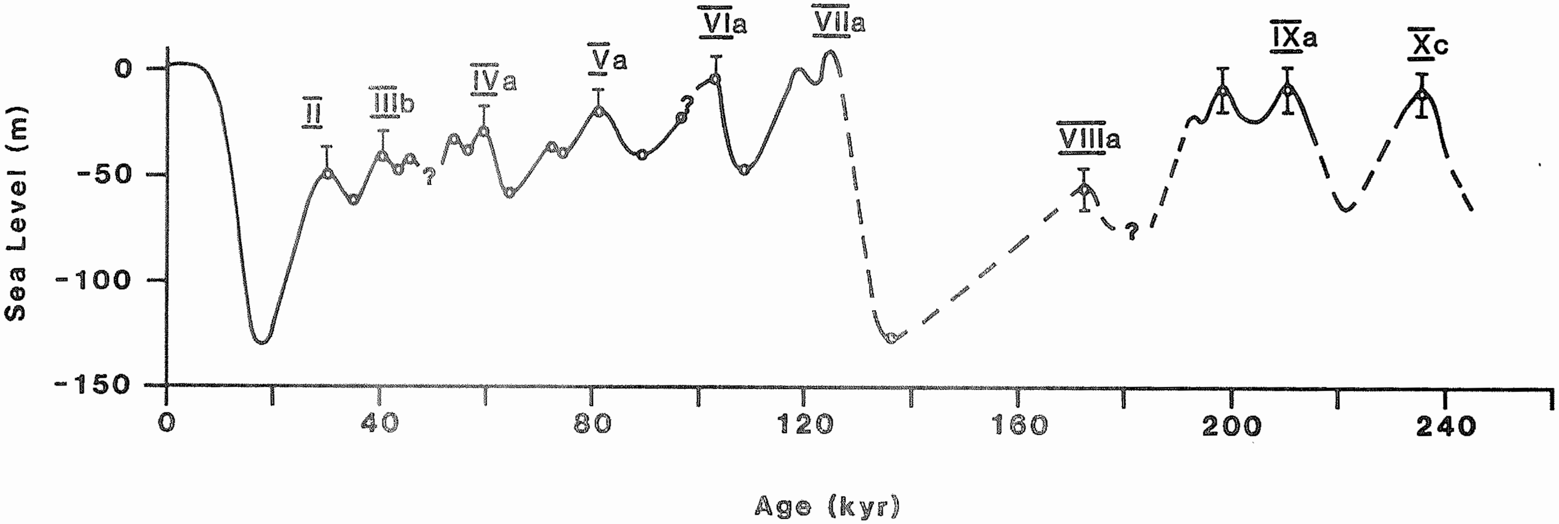


Figure 9. Latest sea-level curve for Huon Peninsula, New Guinea, with re-calculations after detailed correlation with ^{18}O record of Pacific core V19-30 (after Chappell and Shackleton 1986).

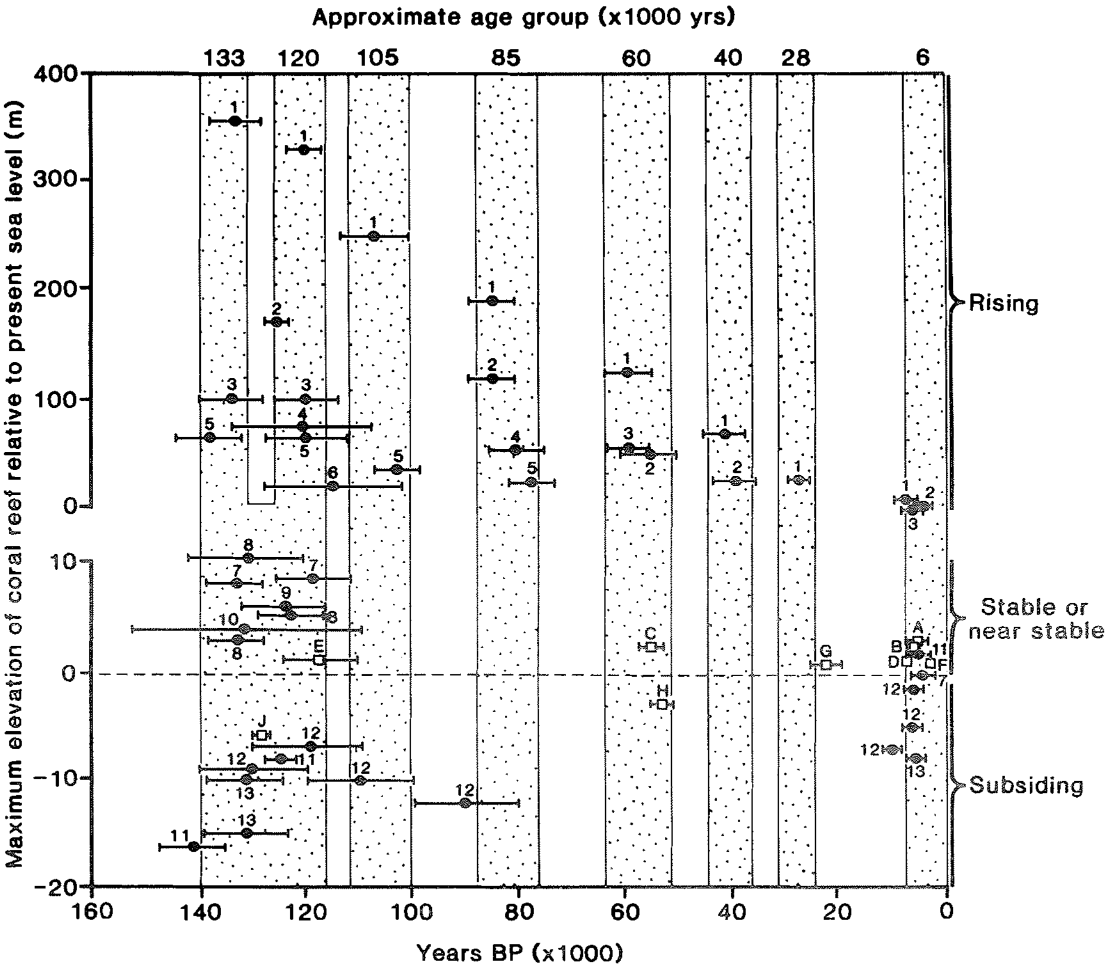


Figure 10. Chronology of late Quaternary coral reef occurrences (closed circles; after Aharon and Chappell 1986) and island phosphates (open squares; after Roe and Burnett 1985) from the Indo-Pacific biogeographical province plotted against the present position relative to mean sea level. Bars represent 1 S.D error of multiple dates.

Coral reef database: 1. Huon/New Guinea; 2. Ryukyu/Minami Daito; 3. Efate/Vanuatu; 4. Torres Island/Vanuatu; 5. Atauro/Timor; 7. Oahu/Hawaii; 8. Rottnest/W. Australia; 9. Aldabra; 10. Tuamotu Archipelago; 11. Great Barrier Reef; 12. Mururoa; 13. Enewetak.

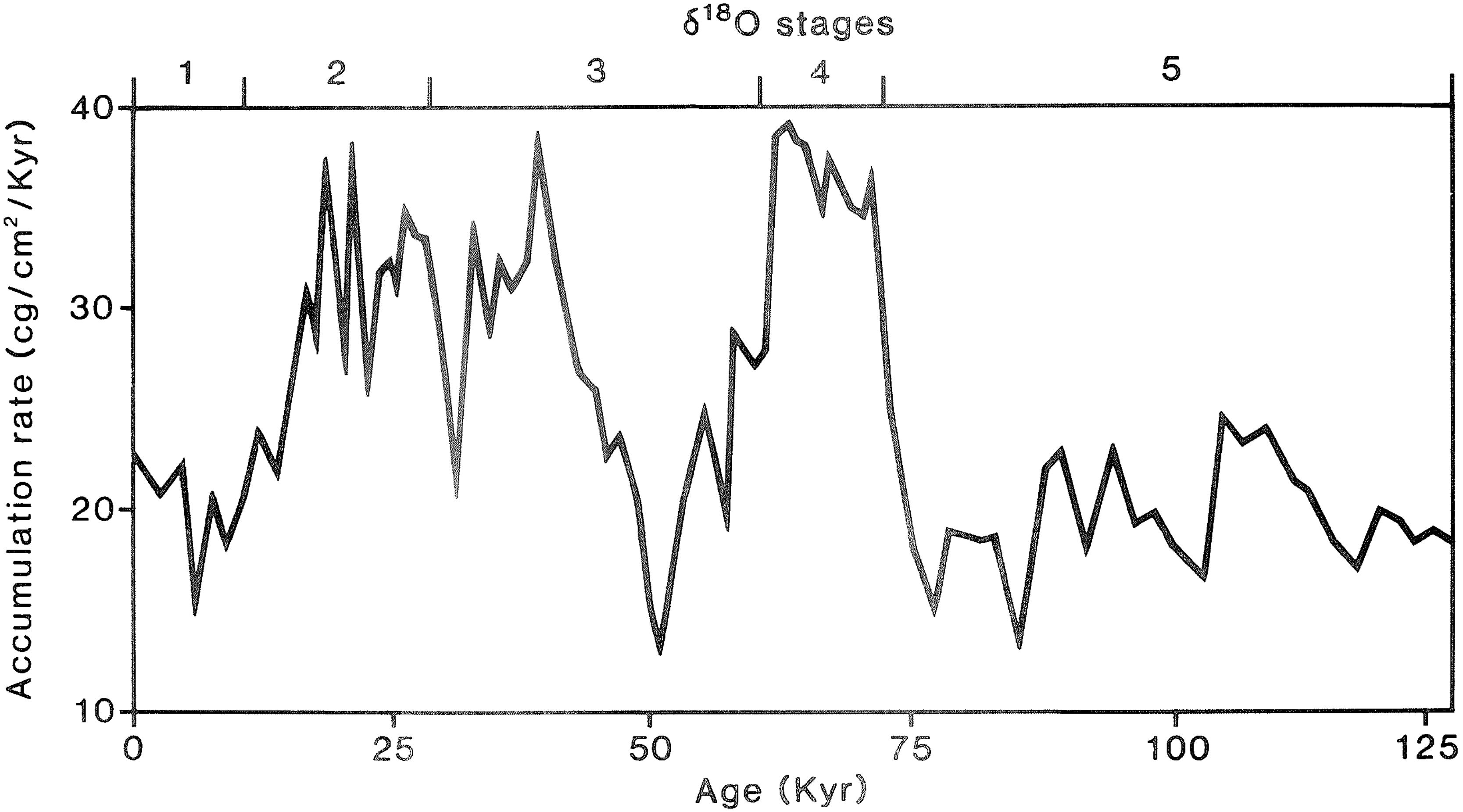


Figure 11. Downcore record of quartz accumulation in Pacific core V19-29 (3°35'S 83°56'W). (After Molina-Cruz 1977 and Romine and Moore 1981).

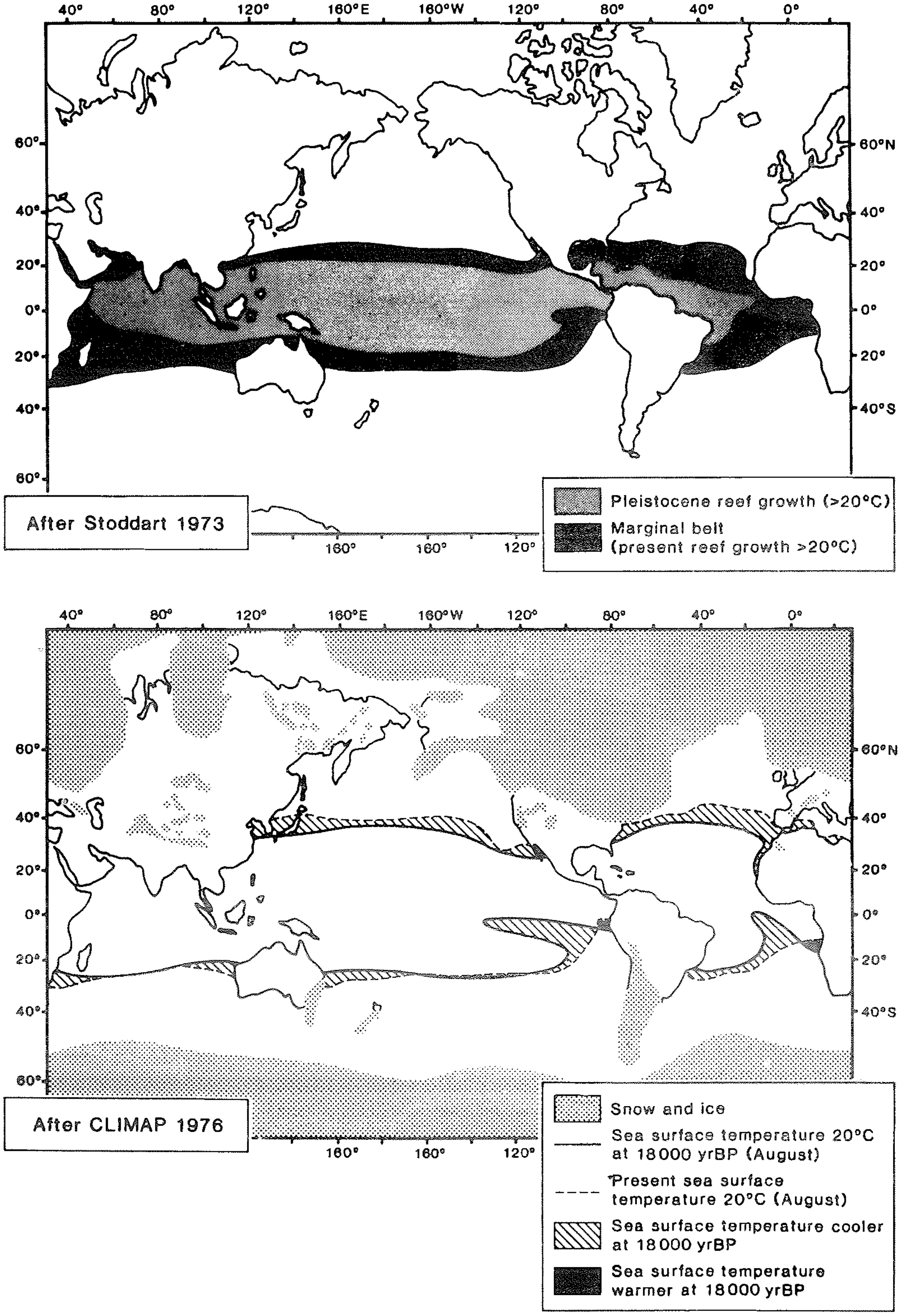


Figure 12. Possible changes in the extent of the reef seas, 18 x 10^3 yr B.P. v. present. In each case the isotherm of 20°C is taken as the effective limit of reef formation (Stoddart 1973. CLIMAP Project Members 1976).

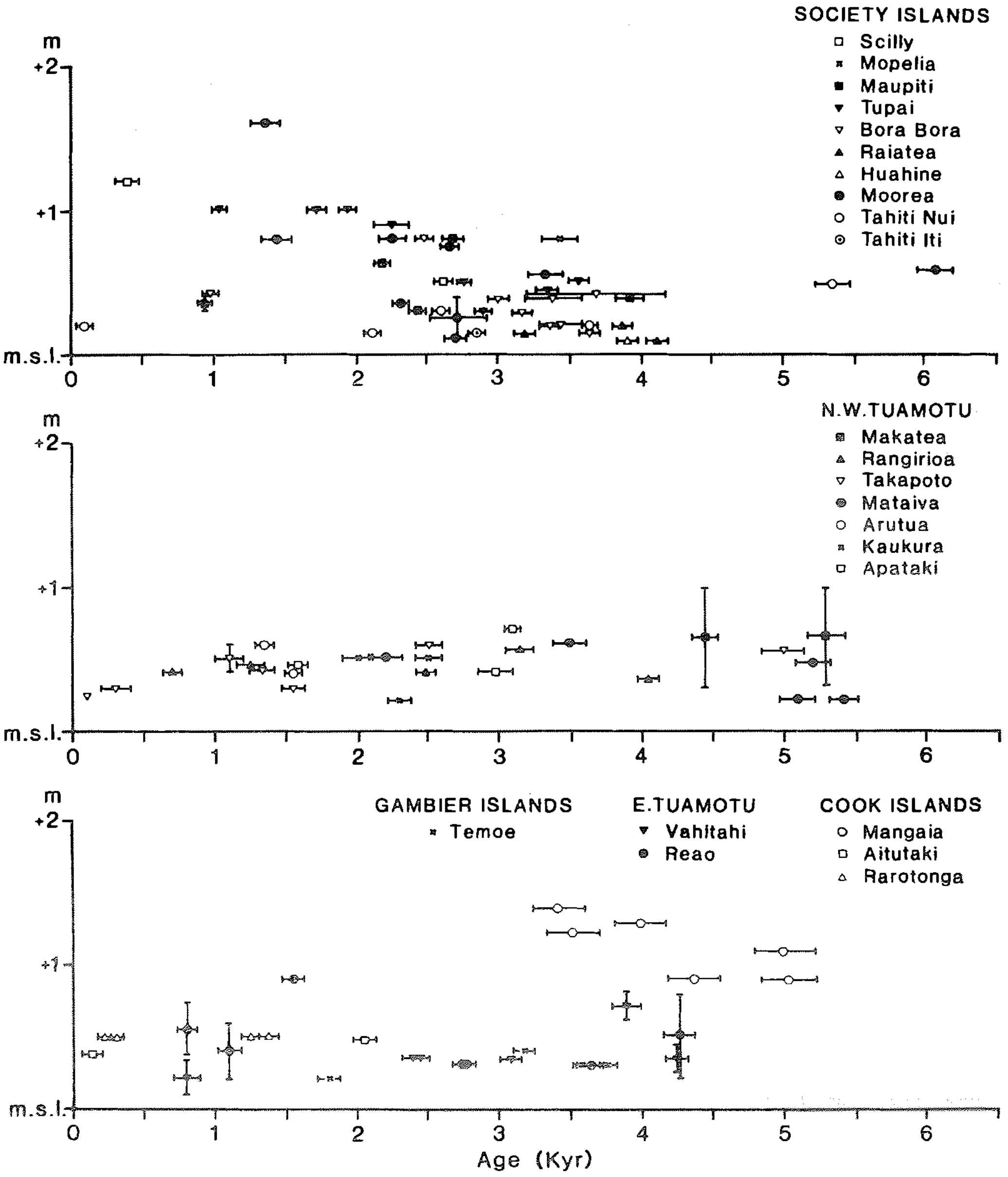


Figure 13. Time - elevation plot of sea levels in Polynesian archipelagoes, 6 x 10^3 yr B.P. to present.
Society Islands : Delibrias and Pirazzoli 1985; N.W. Tuamotu Pirazzoli 1985, Montaggioni et al. 1985, Pirazzoli and Montaggioni 1986; Gambier Islands: Pirazzoli 1987a, 1987b; E. Tuamotu: Pirazzoli et al. 1987a, 1987b; Cook Islands: Schofield 1970, Yonekura et al. 1984, 1985. Austral Islands: Pirazzoli 1987b.

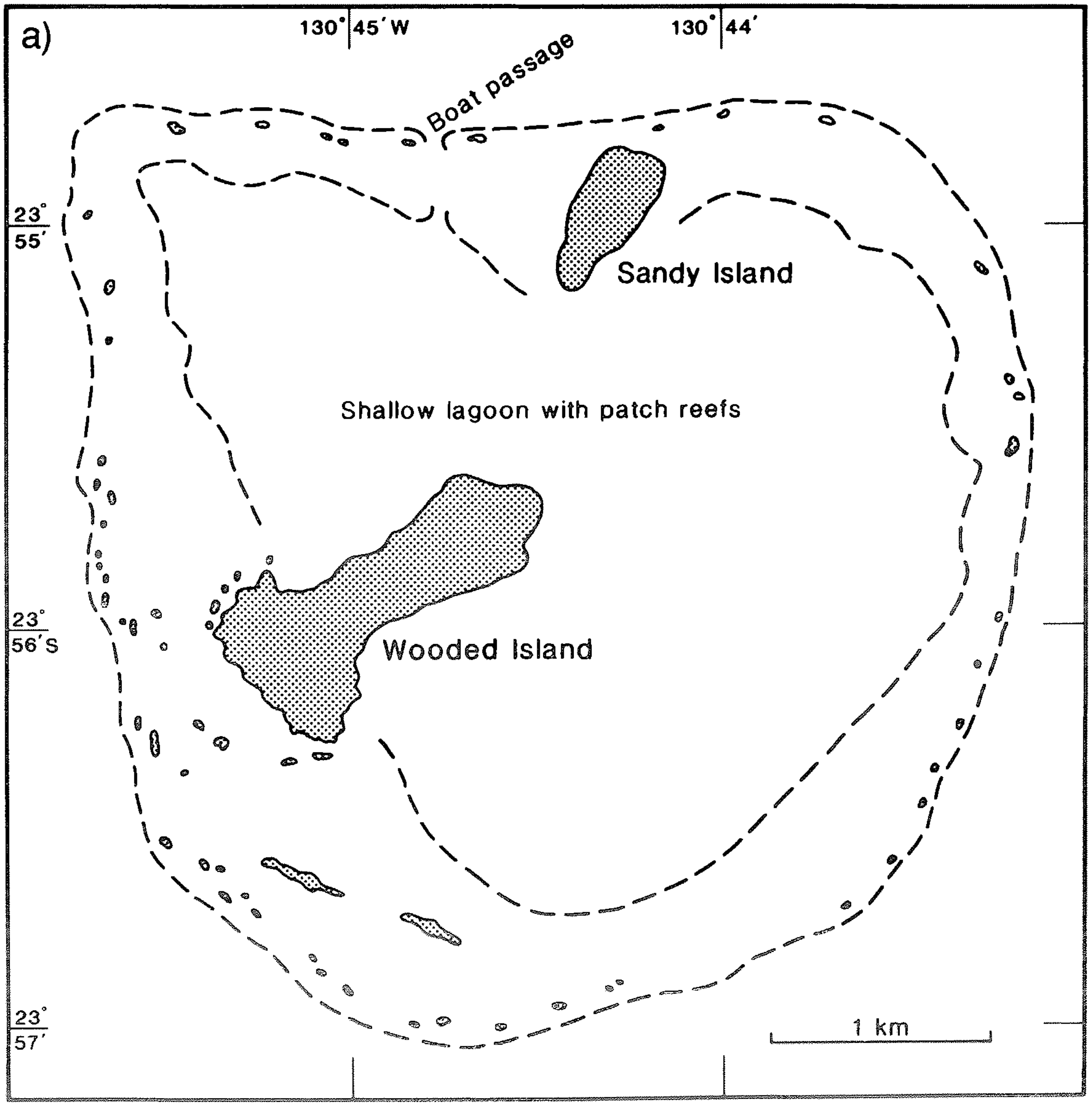
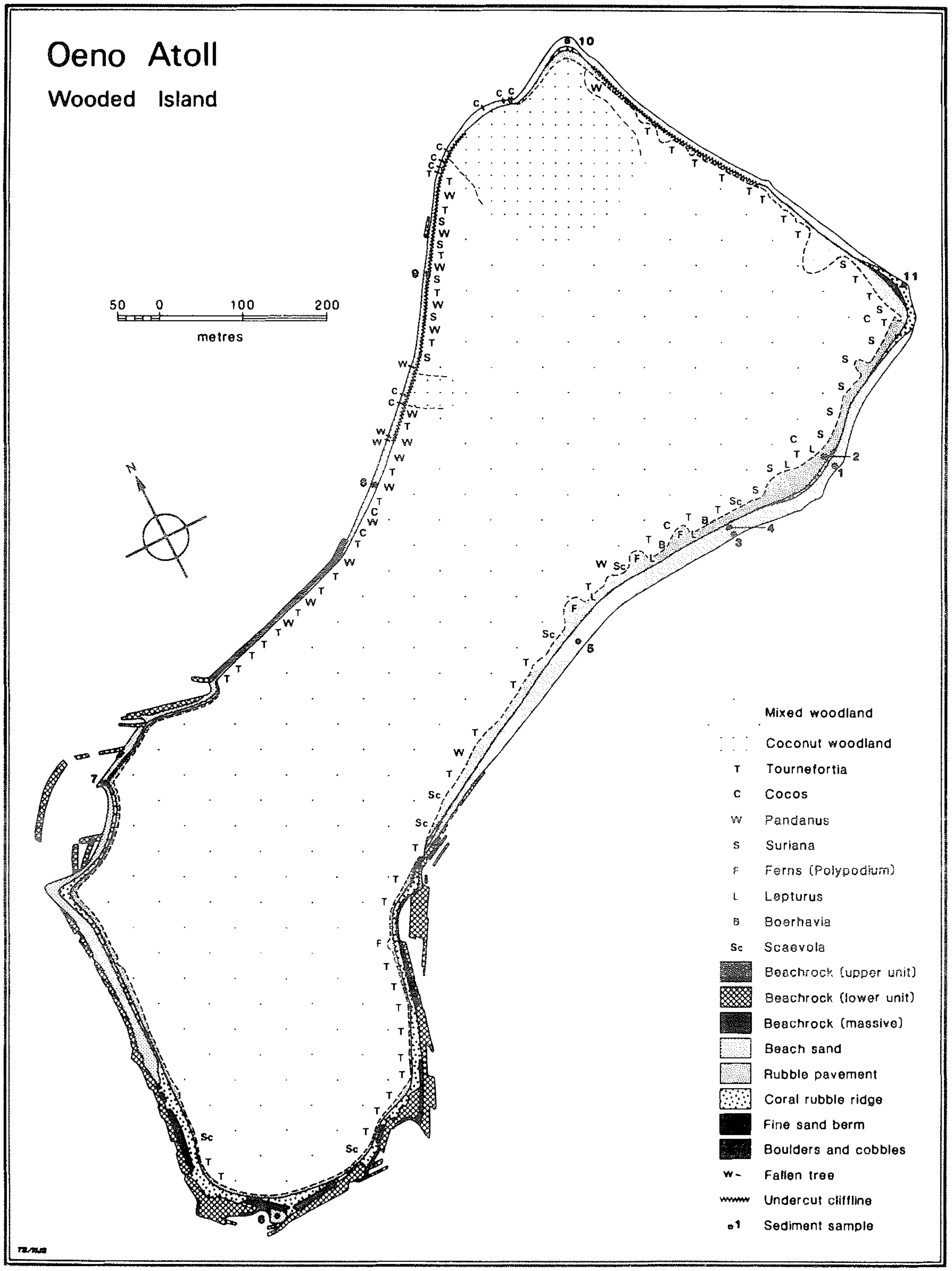


Figure 14. Geomorphology of Oeno Atoll, Pitcairn Islands. a) General plan form (after Admiralty Chart) b) Geomorphological map of wooded island. (see next page)


Oeno Atoll
Wooded Island
50 0 100 200
metres
N
1
2
3
4
5
6
7
8
9
10
11
Mixed woodland
Coconut woodland
T Tournefortia
C Cocos
W Pandanus
S Suriana
F Ferns (Polypodium)
L Lepturus
B Boerhavia
Sc Scaevola
Beachrock (upper unit)
Beachrock (lower unit)
Beachrock (massive)
Beach sand
Rubble pavement
Coral rubble ridge
Fine sand berm
Boulders and cobbles
W~ Fallen tree
Undercut cliffline
1 Sediment sample

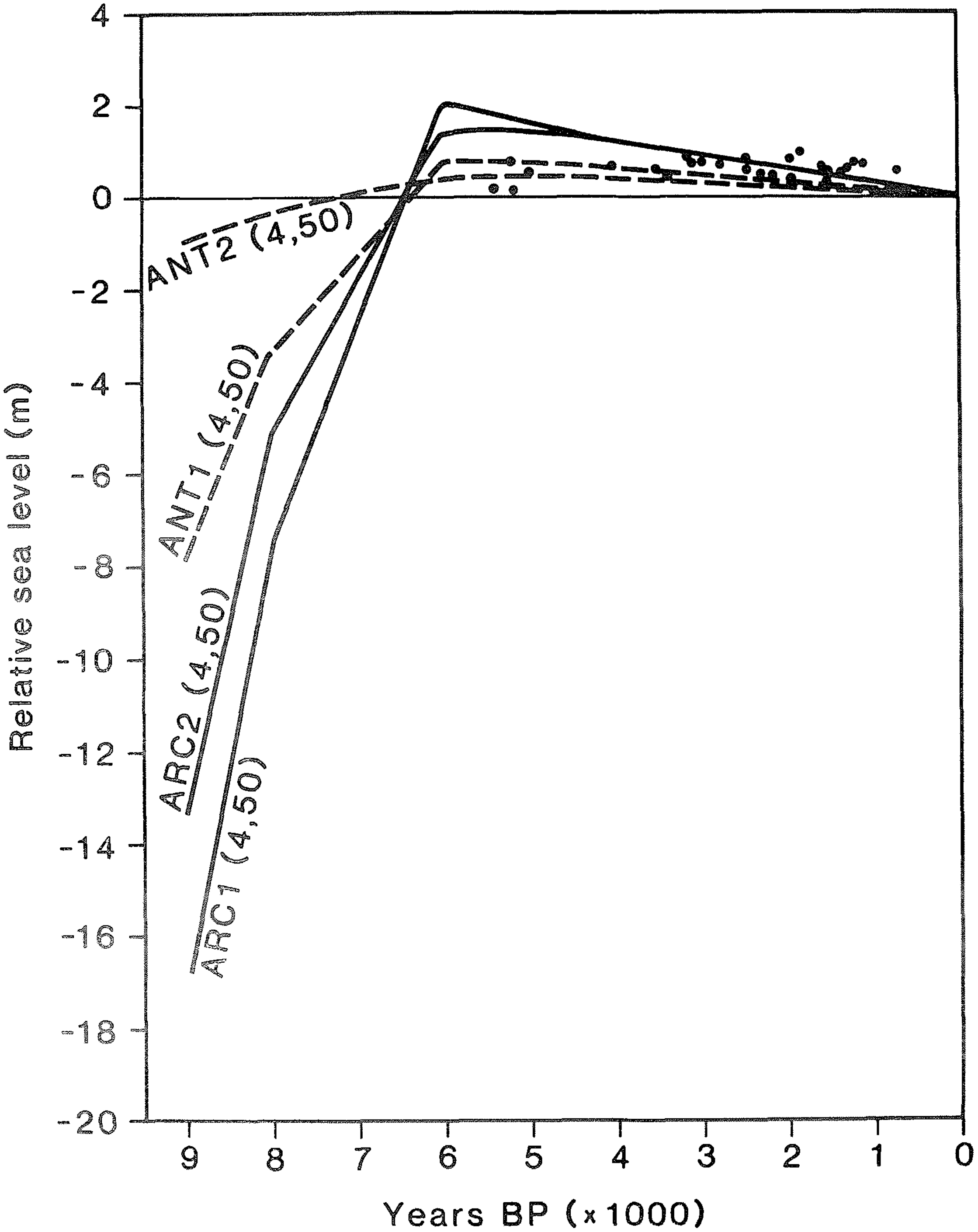


Figure 15. Relative sea-level models for the 'far field' as a function of ice load, mantle viscosity and lithospheric thickness (after Nakada and Lambeck 1987). Ice-melt models: ARC1,2: Arctic ice only; ANT1,2: Arctic and Antarctic ice. (4, 50): Upper mantle viscosity = 10^{21} Pa, lower (>670 km) mantle viscosity = 10^{23} Pa; 50 km thick lithosphere. Observed sea levels (closed circles) = N.W. Tuamotu archipelago (Pirazzoli and Montaggioni 1986).

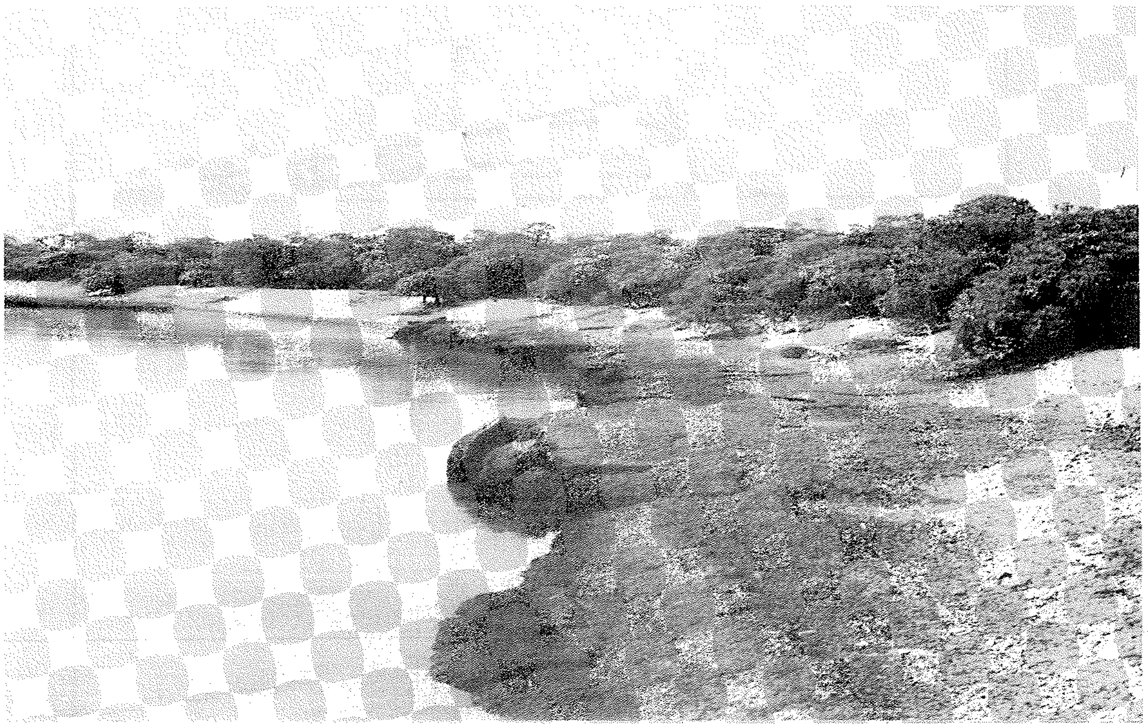


Plate 1. Cemented washover fans of coral stick rubble, eastern end of lagoon shore, Acadia Island, Ducie atoll.

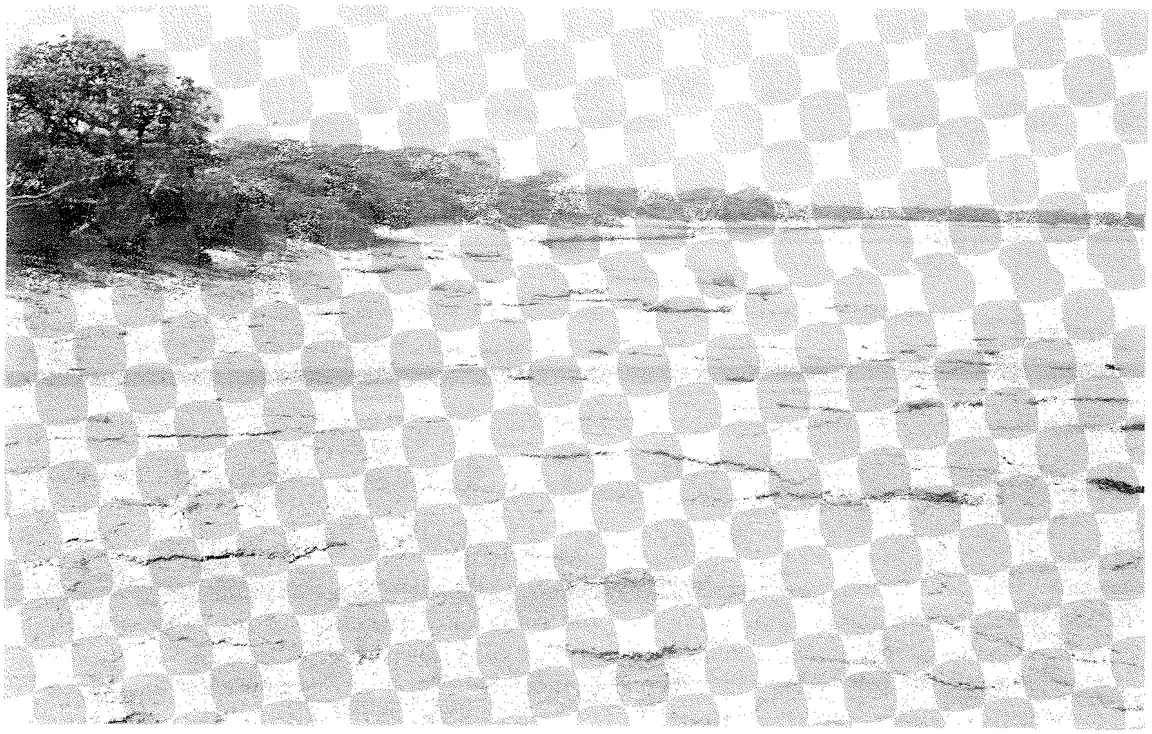


Plate 2. Pitted sheets of lagoon conglomerate spreads, central section of lagoon shore, Acadia Island, Ducie atoll. Lagoon margin at +0.30 - +0.45 m above mean sea level.

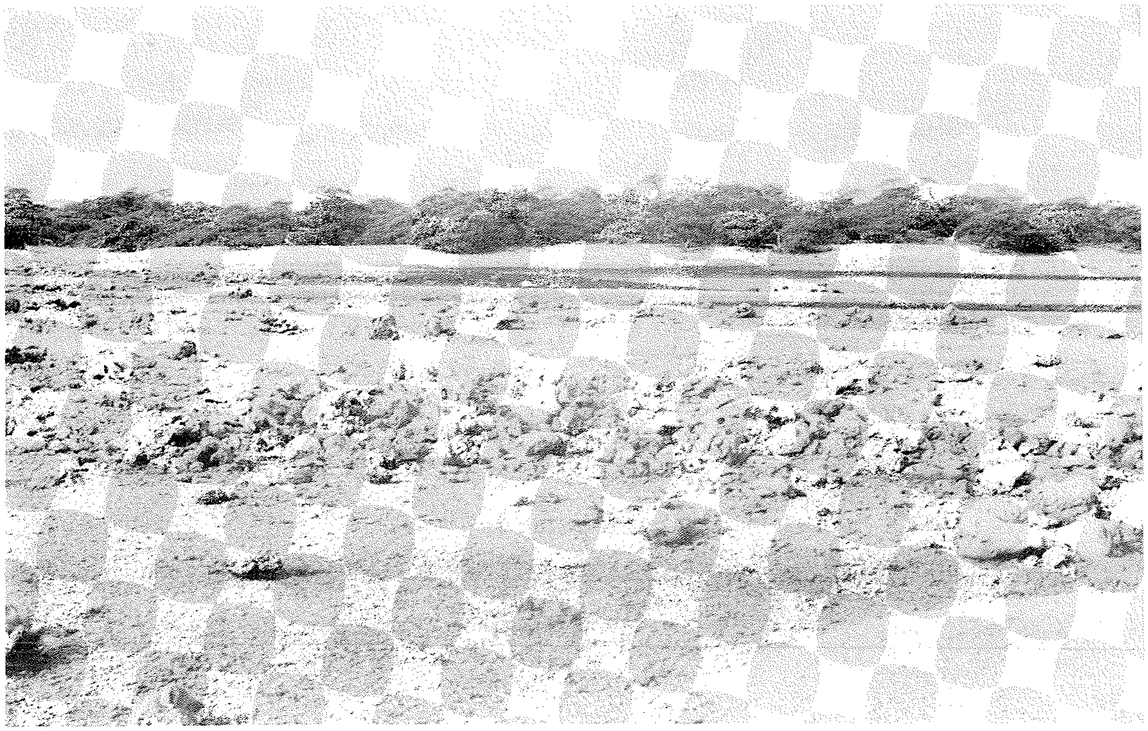


Plate 3. Boulder streams of coral heads with intervening flats of coral sticks, western end of lagoon shore, Acadia Island, Ducie atoll.

Plate 4. Lower bevelled beachrock unit overlain by more massive upper beachrock unit at S.W. point of wooded island, Oeno atoll.

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GEOLOGY AND GEOMORPHOLOGY OF HENDERSON ISLAND

BY

T. SPENCER AND GUSTAV PAULAY

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GEOLOGY AND GEOMORPHOLOGY OF HENDERSON ISLAND

BY

T. SPENCER[1] AND GUSTAV PAULAY[2]

ABSTRACT

The 1987 expedition to the Pitcairn group was able to perform a spatially-limited reconnaissance of the structure and topography of Henderson Island and of the more common elements of its fossil fauna; this paper presents a number of observations and hypotheses which need to be tested by further work. Henderson is an uplifted atoll with a large fossil lagoon that preserves many depositional features. The entire lagoon basin surveyed iscovered with pebble sized or larger coral debris, finer sediments being largely absent. The fossil coral fauna is well preserved and diverse, and the old lagoon probably had excellent communication with the surrounding ocean. The rate of uplift, excellent preservation and predominance of recent species among the fossils, abundant depositional features in the interior basin, and limited extent of erosional features all point to the recency of uplift, supporting the hypothesis that hotspot volcanism at Pitcairn Island has been responsible for the regional flexure of the Pacific plate with up-arching and uplift at Henderson. We provisionally assign a Pleistocene age to all exposed deposits. Embayments within the 30m cliffs which encircle Henderson are characterised by core reef buttresses and two apron reefs: an upper fossiliferous reef unit and a lower low limestone unit which we tentatively assign to the Penultimate and Last Interglacial periods respectively.

INTRODUCTION

Raised reef limestone islands provide, generally, an indication of the thermal processes associated with oceanic lithosphere (e.g. Detrick and Crough 1978, Crough 1984, Menard 1986) and, specifically, important observational data to test models of crustal loading by relatively young (<2 m.y.) mid-plate volcanoes (e.g. McNutt and Menard 1978, Lambeck 1981a, 1981b, Pirazzoli and Montaggioni 1985). A comparison of theoretical models and field observations in the south Pacific has demonstrated the need for both the careful determination of raised reef altitudes and the geomorphological evaluation of the significance of such features (Spencer et al. 1987). Raised limestone sequences also provide important locations for the study of carbonate diagenesis (e.g. Schroeder and Purser 1986), including dolomitization (Schlanger 1981, Schofield and Nelson 1978, Bourrouilh-Le Jan 1982), and the genesis of island phosphorites (Hutchinson 1950). Related to these studies, the radiometric dating of emergent fossil corals, allied to a knowledge of the environment of

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deposition from diagnostic coral and molluscan assemblages, allows for the reconstruction of regional sea level histories and the determination of rates of tectonically-determined uplift in varied settings (e.g. plate margin: Huon Peninsula, New Guinea, Chappell and Veeh 1978; mid-plate: Bourrouilh-Le Jan 1985). Raised reef islands thus provide the opportunity to study the interplay between these tectonic, geochemical and environmental processes; they supply input for modelling and simulation exercises (Chappell 1980, Paulay and McEdward in prep.) on reef growth and island morphology; and they occupy an important position in the establishment of general theory on volcanic island development and attendant reef construction.

Of the raised limestone islands found on the Pacific plate (for distribution: Bourrouilh-Le Jan 1977) Henderson Island (Figure 1) falls within the category of raised atoll with preserved lagoon (Fosberg 1985; for the range of island-atoll types: Scott and Rotondo 1983). As such it can be broadly compared, at least in terms of gross appearance, to Nauru and Banaba in the Central Pacific, to Rennell (Taylor 1973), the Loyalty Islands (Bourrouilh-Le Jan 1977) and islands of the Lau Ridge, eastern Fiji (Nunn 1987) in the western Pacific and to Makatea (Montaggioni et al. 1985a, 1985b) and Niue (Schofield 1959) in the south-west Pacific. Some comparisons can also be made with the 'makatea' islands of the Southern Cook Islands (Marshall 1927, Wood and Hay 1970, Stoddart et al. 1985, Stoddart and Spencer 1987, Spencer et al. 1989).

In this paper we consider first, the contemporary sedimentary environments of Henderson Island; secondly, the environmental record preserved in the littoral margin and cliff face sequences; and thirdly, the topography and palaeo-environments of the central depression. These descriptions allow for a preliminary reconstruction of the island's genesis and history.

METHODS

The 1987 expedition concentrated upon (i) topographic levelling, (ii) observations of the morphology and stratigraphy of limestones with sampling for subsequent petrological examination and (iii) collections of fossil corals for both environmental reconstruction and dating purposes. Fieldwork, which was largely restricted to the north-west and north beaches and the areas inland from these coasts, was supplemented by the study of available aerial photographic cover (flown 3 May 1985).

The geomorphological data are summarized in a series of topographic profiles (Figures 2-8) surveyed by 'Abney' clinometer and graduated tape from sea level. Unfortunately, the tidal regime at Henderson has yet to be accurately determined. It is clear, however, that the island experiences a semidiurnal tidal rhythm, as at Ducie Atoll, 360 km to the east (Rehder and Randall 1975). Field observations would seem to agree with Fosberg et al.'s (1983) statement that Henderson's tidal range is probably similar to that of the Gambier Islands and the eastern Tuamotu Archipelago where the range at spring tide is 1.0m. With a knowledge of tidal stage at time of survey, individual profiles were adjusted to a common datum of mean sea level. It is important to stress that local micro-topography on Henderson is often severe, with the amplitude of upstanding pinnacles and erosional clefts often in excess of 1.0m. The compromises which such terrain introduces into field survey are further exacerbated by the density of vegetation cover. This not only impedes forward progress but also dangerously hides from view deeply dissected substrates. We estimate that errors involved in the establishment of a common datum and in ground survey require established altitudes to carry error terms of ±70 cm. Horizontal survey errors were not determined.

Exhaustive sampling for fossil corals and molluscs was undertaken at known locations on the surveyed profiles and also within the central depression along trails mapped by compass bearing and ground distance measurements. These sample locations were supplemented by collections from near the seaward margins of the cliff limestones.

CONTEMPORARY ENVIRONMENTS

The plan form of Henderson Island is shown in Figure 1. According to Fosberg et al. (1983), Henderson has a greatest length of 9.6 km, a maximum width of 5.1 km and an area of 36 km^2. Comparison of the Admiralty Chart, on which these measurements were based, with recent aerial photographyconfirms these general statistics. The only region where there appears to be a potential discrepancy between the chart and the photographic cover is in the area of the North-east Point but, most unfortunately, the Point itself was obscured by cloud cover when the aerial photographs were taken.

The island's perimeter has been calculated at 26.4 km; of this, 16.5km (63 per cent) is encircled by a fringing reef, principally along the entire length of the east coast (and not just the east beach: compare with the Admiralty chart), the north coast, and to just south of the north-west cove. The south-west coast and the south point area of the island are characterised by vertical cliffs undercut at sea level to give a cavernous coastline. Wave attack, even under moderate sea conditions, frequently throws spray to over 30m, above the height of the cliff margin (Plate 1). Fallen blocks, some of considerable dimensions, attest to the process of cliff retreat by undermining marine erosion. Indeed, a comparison of Figure 3 in St. John and Philipson (1962) with Plate 4 in Paulay and Spencer (this volume), photographs of the northern section of the north-west coast taken 53 years apart, shows an additional blockfall over this period.

There is no algal ridge margin to the reef edge at Henderson Island; rather the reef is a gently-sloping limestone platform that remains shallowly submerged and constantly inundated by the surf, even at low tide. The reef platform was investigated at the north beach. It consists of a smoothed reef plate, runnelled and dotted by small (<1cm) holes and covered by a thin algal turf. The seaward end of the platform has many large, deep (0.5m), well-scoured potholes that frequently coalesce to form shallow channels. A few loose or slightly cemented rocks on the reef lie near the landward margin with the limited loose sand found on the reef flat concentrated under them. The reef platform 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 platform terminates seaward at a line of breakers in a rugged, dissected reef front of vertical to undercut reef promontories separated by a maze of channels. Due to the lack of a protecting algal ridge, water is continuously piled onto the reef flat by surf and drains through larger grooves that extend onto, rather than through, the reef. These grooves provide the best landing sites, and are better developed on the the north-west rather than the north beach. Field observations, including by SCUBA, by the 1987 expedition showed that the jagged reef front gives way to a typical spur-and-groove topography at 3-5m water depth. Thereafter, the fore-reef slopes rapidly and without interruption to at least 50m off the north-west shore. The north-west fore-reef is dominated by reef spurs to 15m, but in deeper water the widening sand and rubble chanels that separate the spurs become dominant, and by 40m coalesce to form a wasting slope. The north beach outer slope has only limited sand channels dissecting the reef front and slopes gently to ~ 30m where it steepens and continues uninterrupted to at least 75m. An algal turf with trapped sand dominates the fore-reef surface and living corals usually account for less than 10 per cent of the cover (measured at 6% at 10.5m off the north shore).

Millepora dominates the coral fauna to a depth of 5-10m, while *Pocillopora* species (especially *Pocillopora* sp. 1 and *P. woodjonesi*) are the most common corals in deeper water. The rarity of *Acropora* on the present reef contrasts markedly with its abundance in the ancient fossil lagoon, as well as on nearby Ducie.

Both the fore-reef and reef platform are wider off the north than off the north-west beach, correlating with the pronounced embayment on the north coast. Shallow but wide embayments, as off the north of Henderson, are often associated with wider reefs on other Polynesian islands e.g. on Niue or Rurutu (Austral Islands).

THE MARGINAL CLIFFS: STRUCTURE, STRATIGRAPHY AND ENVIRONMENTAL HISTORY

The cavernous and undermined cliffs of the south coast are impossible of access from the sea. Furthermore, it seems likely that depositional units of relatively young age accreted to the island core will have been, at best, severely modified and, at worst, removed by wave attack and cliff collapse. The most complete stratigraphic sequences on Henderson are, therefore, preserved in the broad embayments within the main marginal cliffs. In this paper we consider the north-west (Figures 9, 13, Plate 2) and north beach (Figures 10, 14, Plate 3) areas but it seems likely that a similar stratigraphy is preserved in the eastern embayment; reconnaissance shows the presence of limestone units and abundant caves (Plate 4).

Ground survey has established that the marginal cliffs on the northern and north-western shores reach heights of 30.7m and 30.2m respectively. Whereas the cliffs of the south-west coast and the south point appear to be relatively unbroken, the north-western and, particularly, the northern embayments are backed by cliffs which are composed of a series of discrete limestone buttresses, with vertical or even overhanging slopes, separated by slopes of 25-30°. Where buttresses are encountered the cliff margin lies at between 26 and 27m above present sea level (Plate 5). The prominent buttress above the central north beach contains large colonies of *Lobophyllia corymbosa*, *Montastrea curta*, *Favia rotumana*, *Leptoria phrygia*, *Pocillopora eydouxi* (Plate 6), an abundant plate coral (likely *Montipora aequituberculata*), *Fungia scutaria* and a large (3m+) massive *Porites* colony (coral sample: FHEN-23).

Multiple levels of former sea level notches are preserved within the buttresses. The highest of these features is best seen at profile 4, north-west beach where a prominent notch is preserved at 24.8m above present sea level (Figure 5). This notch may correspond to a small bench at 24.5-25.1m on profile 5 (Figure 6) and to notches seen at the tops of limestone buttresses between the north and north-western embayments and at Awahou Point. On profile 4, this notch is a well-developed, laterally extensive feature, 1.44m high and 0.6m deep with a sand fill to the rear of the notch (Figure 5). The notch (coral collecting station FHEN-3) is filled with coarse sand and well rounded cobbles of coralline origin, suggestive of a high energy, beach deposit. Shells of two gastropods, the intertidal limpet *Patella flexuosa* and the intertidal to shallow subtidal *Turbo argyrostomus*, are commonly cemented in the notch, together with large, intact branches of *Pocillopora eydouxi* and *Acropora* colonies (Plate 7). The excellent preservation of the branching corals contrasts strongly with the polished, rounded coral cobbles and worn intertidal shells, and suggests that they were deposited during a second, low energy phase that post-dated notch formation. A much more pronounced notch characterises the limestone buttress in the central section of the north beach (profile 1, Figure 2). The broad notch floor commences at 19.7m above sea level and slopes upwards over ~4m to the rear of the notch; over a 35m-long section this varies in height between 21.0 and 21.6m. The notch roof intersects the buttress at 2.5-3.0m above the notch floor. It is surprising, however, that this well-developed and unambiguous sea level feature is not found elsewhere on the north and north-western coasts (except perhaps at 21.2m on profile 7: Figure 8) and even appears restricted to the central section of the north beach. It would be interesting to know whether or not this level is represented on the east coast.

Below the major constructional buttresses, and forming a veneer on the outer slope of the island, is a fossiliferous reef unit of generally limited width but considerable vertical extent (Figures 13, 14). The contact of this unit with the main cliff face is marked by a break of slope at 16.0m (profile 3: Figure 4) to 16.9m (profile 1: Figure 2) or, in the case of profile 7 (Figure 8) a notch at 16.2m above present sea level. Associated with this contact are caves (cave entrance, profile 2: 18.0m (Figure 3) cave floor, profile 3: 17.3m (Figure 4) and, possibly, a cliff shelf (base of shelf, profile 4: 17.9m (Figure 5)). The cave on profile 2 is ~20m in length behind a hemispherical entrance 2.2m in height. The main passageway varies in width from 1.4-4.1m but a low chamber to the north of the main conduit increases the overall cave width to over 9m (Figure 11; and see Schubel this volume for cave floor sediment characteristics). It is suggested that the cave/shelf level (Plate 9) relates to a sea level stillstand and erosion level associated with the deposition of the fossiliferous reef unit. At 9.6-11.4m on profile 2 (Figure 3; coral collecting station FHEN-11) the fossiliferous reef unit is exposed as a rich coral conglomerate, terminated to the south by a mostly featureless limestone. The deposit is dominated by *Pocillopora* sp(p)., *Astreopora* cf. *moretonensis*, massive *Porites* sp(p)., *Porites* cf. *mordax*, *Psammocora ?obtusangula*, *Coscinaraea columna*, *Acropora* sp., and *Plesiastrea* cf. *versipora*. About 50m to the south, the fossiliferous reef unit is well exposed between 7.6-11.1m on profile 7 (Figure 8; HW4-11) and contains a similar fossil assemblage: *Pocillopora eydouxi*, *Pocillopora* sp(p)., *Pavona* sp. 1 and *Montastrea* sp. 1. Additional exposures are found at the eastern end of the central section of the north beach. Here the fossiliferous reef unit is exposed in a 3-5m high cliff, its base at ~ 2.0m above mean sea level (Figure 10; coral collecting stations FHEN-20/22). At this locality the unit is composed of two facies. The lower facies (FHEN-20/21) exhibits abundant *Pavona* sp. 1, *Astreopora moretonensis* and *Pocillopora* sp(p)., as well as specimens of *?Pocillopora eydouxi*, *Fungia scutaria*, *Plesiastrea* cf. *versipora* and massive *Porites* sp(p). The upper facies is ~1m in thickness and composed of coral stick rubble (Plate 9) in a poorly cemented sand matrix (FHEN-22). Embedded corals include *Pocillopora* sp. 1, *Astreopora* cf. *moretonensis*, massive *Porites* sp(p). and *Porites* cf. *mordax*.

There are several topographic breaks and sea level features within the fossiliferous reef unit. These include a notch at 14.3-15.1m (profile 2; Figure 3), which is also reflected in a shelf at 15.0m on profile 7 (Figure 8), and a range of cliffed sections and slope inflections, with breaks of slope at between 12.5-14.0m for the top, and 11.6-11.9m for the base, of these slope elements. Erosion within this height band may have been related to the deposition of the low limestone unit which fronts the fossiliferous reef unit. On profile 7, north-west beach (Figure 8) an erosional embayment reveals the fossiliferous reef unit behind the low limestone unit (and see Figure 13). The contact between these two units, marked variously by either a change in slope angle, or a notch or a small cliff, has been established at 8.7m on profile 2 (Figure 3) and at between 9.4 and 10.6m on profiles 2-6 (Figures 3-7). This contact is marked, easily seen and shows considerable lateral continuity. It is possible to trace the junction between the north beach and the north-west embayment (Plates 11, 12); estimates from ship survey and photographic record suggest that in this region the contact varies in height between 7.6-11.9m, with an average altitude of 10.0m. The low limestone unit is also well seen at the southern end of the north-west beach (Plate 12) where the upper limit appears to fall between 8.4-10.5m, with a mean height of 9.7m above sea level.

The low limestone unit is represented by a thin deposit plastered onto the cliffed headlands; this extends to form a low fringing terrace, up to 40m in width, in the embayments of the north and north-west beaches. This terrace is divided into two sections. The upper section slopes downward to terminate at a well-defined margin (seen on five of the seven profiles) at 7.3-8.3m. This forms the top of a small cliff whose base is found at 6.3-7.0m above sea level. Below this cliff, the lower section of the terrace forms a highly dissected and often stepped profile, either composed of a series of joint-controlled blocks or characterised by a number of deep (>1m) clefts in a pitted surface topography, ending in a marginal cliff whose upper surface varies in height between 2.6 and 3.7m above sea level. These heights , however, have no significance but merely indicate the degree of shoreward retreat within a unit which slopes upwards onshore. Fallen blocks in front of the seaward margin of the terrace, and remnants of blocks offshore, show that marine erosion is currently active. On the north-west beach, for example, at high tide waves break not on the reef edge but at the terrace margin.

At the eastern end of the central section of the north beach the low limestone unit is divided by a series of steep (>30^{0}), narrow (~1.5m) gullies which exit on the terrace surface (e.g. profile 5, Figure 6; Plate 13). These features may represent the grooves of a groove-and-spur fore-reef topography. Fossil groove-and-spur features of a similar scale have been described from Last Interglacial reef limestones on Mangaia, Southern Cook Islands (Stoddart et al. 1985). Some of the grooves on Henderson Island are roofed over at their seaward margins in a manner reminiscent of similar fossil grooves on Mauke and Mitiaro, Southern Cook Islands. Although the exits of the grooves and the lower groove walls are characterised by large colonies of *Montastrea* sp. 1, the Henderson grooves (Plate 13), unlike the groove-and-spur features of the Southern Cooks, are not lined with a wide range of well-preserved encrusting corals. The low limestone unit is, in fact, very poor in preserved corals with only the occasional colony of *Montastrea* sp. 1 and, uniquely, a large colony of *Porites* sp. at 1.8m above present sea level near the seaward margin of profile 6 (Figure 7).

At the north-west beach, the low limestone unit terrace is characterised not by narrow grooves but by broader embayments which widen seawards. The embayments are floored by a bevelled bedrock ramp (Figure 13) which slopes upwards from the beach foot within the intertidal zone to a small cliff, 20cm in height and with a base at 2.2m above present sea level, which marks the ramp's erosional contact with the cliffed margin of the low limestone unit. In some places, there is clear evidence for the bevelling of *Montastrea* sp. 1 in growth position within the ramp (Plate 15). On profile 4 (Figure 5) the ramp includes a smooth dome at 1.9m above sea level which resembles the exfoliating coralline algal crusts described from Vahitahi, eastern Tuamotu Archipelago by Pirazzoli et al. (1987b). Locally at its seaward margin the ramp is overlain by beachrock; individual plates may be 0.35m in thickness and extend up the ramp to a height of 0.8m above present sea level (Figure 13). The upper plates of this beachrock are frequently composed of cemented coral sticks. Similar agglomerations of coral rubble, with typical acroporid branch diameters of 0.5-0.8cm, plaster the contemporary notch, related to present sea level, in the cliffed margin to the terrace. In addition, on the north-west beach, coral debris on the bevelled ramp forms cemented blocks or pillars up to 0.8m above mean sea level. It seems likely that these deposits are the product of storm wave attack and subsequent transport from the coral ledges offshore. Accumulation and ensuing cementation has clearly been locally variable, and we ascribe no significance to the height of these deposits.

THE CENTRAL DEPRESSION: TOPOGRAPHY AND PALAEO-ENVIRONMENTS

Although many of the early descriptions of Henderson, made from the sea, stressed the apparent flatness of the top of the island, the 1934 Mangarevan Expedition recorded the presence of a shallow depression in the island's interior (St. John and Philipson 1962, Fosberg et al. 1983). This they interpreted as a former lagoon, thus adding weight to the explanation of the Henderson topography as being that of an elevated former atoll. The 1987 expedition was able to confirm the presence of both an interior depression and lagoonal deposits on Henderson Island.

On the north-west coast inland from the immediate cliff top margin the island limestones reach 31.3m, and generally exceed 29.0m, above sea level (Figure 12). In this area the surface topography is characterised by both joint-bounded limestone blocks 0.2-0.5m in height and pinnacles with an amplitude in excess of 1.0m. At a larger scale the limestones also exhibit straight-sided basins 0.5m deep and 2.0m in diameter and solution holes with vertical walls up to 2.5m high and flat floors 3m in width. The top of this surface is, however, covered by patches of loose, uncemented coral rubble, composed of both small coral sticks (*Acropora* spp., *Pocillopora eydouxi*, *Pavona* sp. 1), as well as small coral colonies (massive *Porites* sp(p)., *Montastrea* sp. 1, branching *Acropora* spp.) and frequent *Turbo argyrostomus* and *Tridacna maxima* shells, even on the cliff margin at 30.7m above sea level. The abundance of *Pocillopora eydouxi* and *Turbo* indicates that this area, as expected from its physiography, was probably part of the outer reef flat of the original atoll (coral collecting station FHEN-4).

Although the surface topography is irregular, there is clearly a regional slope downwards into the island's interior (Figure 12). However, no continuous slope profiling was undertaken by the 1987 expedition across this area and, therefore, the heights which follow with regard to the central depression should be seen as rough first estimates only.

The contact between the island rim limestones and the central depression is marked, first, by an area of pinnacle-pitted limestone ~26m above sea level and 220m from the cliff-top margin (Plate 15). It is not clear from our field surveys and available aerial photography whether this landform forms a band encircling the central depression or is only present in more localised patches. The pinnacle-pitted limestone is a landscape of sharp, recrystallised limestone pinnacles and deep solution pits with a vertical relief of ~2m, and lacks the coral rubble that characterises the plateau surface elsewhere. While fossils of *Montastrea* sp. 1 are commonly visible in cross-section, branching corals that form most of the coral rubble elsewhere were not seen, although this could be due to excessive remineralisation of their finer structure. *Turbo* shells were also noted embedded in this landscape. The pinnacle-pitted limestone is followed by a rugged yet marked slope, of 3m vertical fall over 15-20m horizontal distance, down to the interior depression at an estimated 22m above sea level and 300-350m inland (Figures 12, 15). Over the next 300m (i.e.to the end of our trail) the level floor of this depression is characterised by a largely uniform cover of coral sticks, dominated by branches of *Acropora* spp. but with *Pavona* sp. 1 and less commonly *Porites* cf. *mordax* also ubiquitous and locally dominant. Scattered amongst this rubble are entire colonies of these branching species as well as massive *Montastrea* sp. 1, *Favia rotumana*, *Favia stelligera*, *Montastrea curta*, *Plesiastrea* cf. *versipora*, plates of *Astreopora* cf. moretonensis and small *Fungia* spp. Although these corals lie uncemented to each other, many appear to be in growth position, perfectly preserved, often allowing identification to the species level (Plates 16, 17). However, the branching skeletons fracture easily on contact and *in situ* diagenesis has altered the original aragonitic skeletons to low magnesium calcite. While coral rubble forms most of the substrate, other fossils (molluscs, echinoderms, crustaceans) are rare. An essentially identical community was encountered in the north shore interior (see below); and it is possible that most of the central lagoon has similar cover (coral collecting stations: FHEN-6/9).

The topography of the central depression as reached from the north coast is rather different. (Figure 12). Unlike the narrow transition zone from limestone bedrock to coral-covered depression on the north-west coast interior, and although lagoonal deposits appear to be first encountered 300m inland from the cliff top, pinnacled limestone outcrops are present over 1 km from the island margin (Figures 12, 16). On the north coast the island rim reaches, in a pinnacled zone, a maximum height of 33.6m above sea level 250m from the cliff edge (Figure 12). The wide expanse of makatea seaward of the highest point could represent a former outer reef flat backed by an atoll rim. *Motu* on this rim might have been characterised by emergent limestone (e.g. cf. *feo* limestones, N W Tuamotu archipelago). However, it is likely that the solid limestone that outcrops at, and dominates, the present cliff-top margin both here and on the north-west shore corresponds to the cemented reef flat that surrounded the atoll lagoon.The clear presence of a cliff-top ridge topography from aerial photography further suggests that a similar palaeo reef flat is present above the south-west cliffs (Figure 1). Inland from this makatea zone on the north coast, a series of basins are encountered between well-defined limestone outcrops. The basin floors are 30-31m above sea level and are generally characterised by *Montastrea* sp. 1 and valves of *Tridacna* . There does appear, however, to be a greater diversity of corals near the limestone outcrops as coral rubble is often banked up around the basin margins. We suggest that these basins represent a very shallow lagoon margin. Beyond this zone of alternating basins and limestone outcrops, a much more diverse lagoonal assemblage is encountered. It comprises the following genera and species:-

Very common	*Acropora* group 3
	Pavona sp. 1
	Porites cf. *mordax*
	Favia stelligera
Common	*Montastrea* sp. 1
	Acropora groups 1+ 2
	Montastrea curta
	Astreopora cf. *moretonensis*
Occasional	*Favia rotumana*
	Plesiastrea cf. *versipora*
	Fungia scutaria
	?Fungiid sp(p).
	Pocillopora damicornis
	Pocillopora sp(p).
	Leptoria phrygia
	Scolymia vitiensis
	Psammocora ?obtusangula
	Montipora spp.

The fossil lagoon appears to have had considerable interchange with the surrounding ocean. This is indicated by the following features:
1) Great coral diversity. That faunal diversity of atoll lagoons is directly related to the extent of water exchange with the surrounding ocean is especially well documented for corals (Salvat 1967, Chevalier 1979). Thus in the Tuamotu archipelago, closed Taiaro atoll has only one coral living in the lagoon whereas Takapoto atoll, where two shallow passages break the island rim, has 21 lagoonal species in a total fauna of 63 species (Chevalier 1976, Kuhlmann and Chevalier 1986). At Aitutaki (S.Cook Islands), an almost-atoll where one large and many small passages allow water exchange between ocean and lagoon, 60 of the total count of 68 non-acroporid scleractinians are found within the lagoon

(Paulay 1988). On Henderson 22 of the 26 fossil coral species (15 of 17 genera) encountered were found in lagoonal deposits (Table 1).
2) Prodigious coral growth, such that the whole laggon thus far investigated is filled with coral rubble and
3) the concomitant lack of sediments finer than coral rubble, indicating either rapid coral growth filling the lagoon with coral rubble faster than fine sediments could be produced, or loss of such sediments to the surrounding ocean through vigourous water exchange.We are not aware of any contemporary atolls that exhibit such uniformly coarse bottom sediments.
4) The presence of corals requiring oceanic water conditions, such as *Pocillopora eydouxi* and *Pavona maldivensis*, and the rarity of species that are usually common under more stagnant conditions, such as *Pocillopora damicornis* or massive *Porites* spp. (cf. Paulay, 1988).

There are few differences in species composition between the north and north-west fossil communities, the most notable being *Leptoria phrygia*, a species occasionally encountered both on the north coast fossil fore-reef and lagoon but not on the north-west coast. Interestingly, *Leptoria* is currently only known from southern, subtropical localities within French Polynesia: the Austral, Rapa and Gambier Islands (Chevalier 1974, 1980, Faure 1985). It has not been recorded living in the Tuamotu Archipelago or Society Islands (Chevalier 1979, 1981) or the Pitcairn group (Paulay, this volume). *Leptoria* has been recovered, however, from cores into Pleistocene limestones on Fangataufa atoll, southern Tuamotus (Chevalier and Repellin 1978) which together with the present find suggests considerable range constriction of this species since the Pleistocene. Further into the northern areas of the lagoonal depression, local topographic highs, with a distinctive non-forest vegetation cover (see Paulay and Spencer, this volume) consist of large accumulations of *Acropora* sticks (A. group 3; Plate 18) with only a few other corals present. These include *Montastrea* sp. 1 (Plate 17), *Favia stelligera*, *Porites* cf. *mordax*, *Acropora* group 2, *Pocillopora* sp(p). and *Pavona* sp. 1. We interpret these areas as large lagoonal patch reefs. Additional distinct reef complexes up to 15m across are found both in the north and north-west interior, composed of associations dominated by massively branching (5cm + branch diameter) *Acropora* (A. group 2; Plate 16) and large tabloid *Acropora* (A. group 1).

INTERPRETATION

Reconstructions of the plate-tectonic history of the south-east Pacific (see Spencer, this volume) suggest that initial island-building at Henderson took place at ~13 m.y. BP; thereafter, with the cessation of volcanism, island subsidence and the development of a carbonate cap followed. Fosberg et al. (1983) have suggested that Henderson Island stands comparison with the makatea islands of the central and southern Pacific and, therefore, that the limestones which comprise the core of the island are of mid-Tertiary age. By extension, the central depression has been interpreted by these authors as a karst erosion feature and, as such, characterised by residual pinnacles and columns of limestone rather than a depositional topography of lagoonal patch reefs. Such a history requires a period of emergence; presumably this would have taken place in the late Tertiary (Miocene-Pliocene) and would have been accompanied by the severe meteoric alteration of emergent carbonates and the commencement of dolomitization (e.g. Schlanger 1981). The degree of emergence of Henderson is in the range of Tertiary makatea islands: intermediate between Makatea Island (113m, N.W.Tuamotu Archipelago), Rurutu(100m, Austral Islands) and Mangaia (73m, S. Cook Islands) on the one hand, and Atiu (22m), Mauke (15m) and Mitiaro (11m; all S. Cook Islands) on the other (Montaggioni et al. 1985a, Stoddart et al. 1985, Stoddart and Spencer 1987, Spencer et al. 1987, 1989). The physiography and sediments of the central depression on Henderson, however, suggest a young age. Although field observations clearly show that on the north coast near the depression margin lagoonal deposits drape an older, erosional topography, the rest of the plateau surface is covered by very well preserved, unconsolidated coral skeletons. Moreover, putative depositional patch reefs are encountered further inland and it seems probable that more original depositional structures might be encountered as the centre of the island is approached. Indeed, no unambiguous erosional features were seen within the central lagoonal deposits. In addition, the cliff-top of the island on both the north and north-west coasts shows the presence of well-preserved, framework-building corals in original depositional features. None of the uplifted islands in French Polynesia or the S. Cook Islands have such clearly depositional, lagoonal features, or as well preserved coral fossils that lack advanced diagenesis on their core reefs. Henderson also lacks an accumulation of phosphorites (Fosberg et al., pers. obs.), unless they have been buried beneath the lagoonal deposits. Their absence could otherwise be explained by 1) a lack of upwelling areas and large sea bird rookeries (at least at the present time) and 2) a lack of time for accumulation of such deposits. Thus although it seems possible that Pleistocene deposits fringe an older (?Tertiary-?early Pleistocene) core on Henderson, it is likely that the entire surface structure of the island is of Pleistocene age. It is to be hoped that petrological studies of limestone samples collected on the shore to central depression transect on the north-west coast will test between these two competing hypotheses. A Pleistocene age would lend support to the hypothesis that uplift at Henderson has been the product of lithospheric flexure consequent upon the formation of Pitcairn Island within the last million years (see below, and Spencer, this volume).

A Pleistocene age for the island is further supported by palaeontological estimates. Since the proportion of extant species in a fossil assemblage decreases with increasing age, one may use the percent extant species (Lyellian percentage) in a fossil deposit as a crude indicator of its time of formation. Stanley et al. (1980) and Stanley and Campbell (1981) present Lyellian curves for bivalve and gastropod faunas from Japan, California and the Western Atlantic where early Pleistocene mollusc assemblages have Lyellian percentages of 70-90%. Similarly, Wells (1954) provides estimates of Lyellian proportions for Oligocene to Recent corals from Indonesia with the separation of Pliocene to Pleistocene occuring at ~70% living species. Preliminary identification of fossil corals from Henderson (Table 1) indicates that 95% of the 21 corals identified to species level are still extant. Similarly, all fossil molluscs identified to date are known to be living (Paulay, in prep.).

If, as suggested by the lithospheric flexure model of McNutt and Menard (1978), uplift at Henderson has been the product of crustal loading by the volcano of Pitcairn Island 200 km to the west-southwest, then this emergence probably dates from the mid-Pleistocene. Potassium-argon (K-Ar) dating of exposed volcanics on Pitcairn has identified two phases of volcanism, at 0.46-0.63 and 0.76-0.93 m.y. BP. Petrological studies and palaeo-magnetic chronologies suggest that the older of these two phases represents the main island-building stage and that island construction could have been rapidly achieved between 0.85-0.93 m.y. BP (Duncan et al. 1974). Rapid shield-building has been characteristic of many mid-plate Pacific volcanoes (Jarrard and Clague 1977). Assuming an average age of 0.90 m.y. for Pitcairn Island then the average rate of tectonically-induced uplift at Henderson since this time has been ~1m 25kyr^{-1} (4cm kyr^{-1}). This is comparable to the rate of island uplift calculated for Mangaia, Southern Cook Islands under crustal loading from the Pleistocene volcano of Rarotonga (Stoddart et al. 1985). The sea level features within the coral buttresses at 24-25m and 21-22m above present sea level may represent stillstands during island emergence. Once sea level fell below these levels the lagoon became a subaerial feature and subject to terrestrial weathering processes, including the commencement of diagenesis within the stranded and emergent coral communities. Subsequent sea level fluctuations were not of a sufficient magnitude to re-flood the lagoon. The two main reef units preserved below the reef buttresses represent the interaction between tectonic uplift and glacio-eustatic sea level fluctuations. We suggest that the fossiliferous reef unit which reaches 16.9m (profile 1; Figure 2) represents coral growth associated with the high sea level stand of the Penultimate Interglacial (>200-400 kyr BP) and that the low limestone unit and terrace, averaging 10.0m above present sea level at its contact with the fossiliferous unit, dates from the Last Interglacial (100-140 kyr BP) sea level high stand. Fossil corals from known altitudes have been collected from both units and it is hoped that uranium-series and electron-spin resonance (ESR) dating of these samples will establish a firm chronology for reef growth and sea level change during the late Pleistocene at Henderson.

The Henderson reef limestones can be compared to other coralline islands in Polynesia which are widely believed to have been affected by lithospheric flexure. At Makatea Island the Penultimate Interglacial and Last Interglacial deposits form cliff-veneering apron reefs reaching altitudes of 20-25m and 5-8m respectively (Veeh 1966, Montaggioni 1985). On Mangaia, Southern Cook Islands, Last Interglacial reef limestones (uranium-series dates: 101-135 kyr BP, Spencer et al. 1989) contact Tertiary makatea, and perhaps older Pleistocene limestones, at 14.5m above sea level. Both these islands, like Henderson, are regarded as falling on the crest of the arch in the moat-and-arch response to lithosphere loading and thus should show the greatest degree of tectonic uplift. These predictions appear to be validated by the degree of uplift on islands beyond the radius of the crest of the arch: thus in the atolls of the N.W. Tuamotus Pleistocene *feo* limestones are found at 2-10m above sea level (Delesalle 1985, Pirazzoli 1985, Harmelin-Vivien 1985) and in the Southern Cook Islands deposits as yet undated but provisionally identified as of Late Pleistocene age reach elevations of 12.2m on Atiu, 10.0m on Mauke and 9.8m on Mitiaro (Spencer et al. 1987, 1989). These heights compare with the height of presumed Last Interglacial reefs on Rarotonga, Southern Cook Islands, assumed to be unaffected by tectonic uplift, which reach a maximum altitude of 3.5m above present sea level (Stoddart et al. 1985). Assuming the Last Interglacial limestones on Henderson Island were formed under a sea level at ~13.0m above present sea level at ~120 kyr BP yields an average uplift rate since that time of 9-4 cm kyr^{-1}.

Surprisingly, there is little evidence on Henderson Island for the higher-than-present Holocene sea level of ca. +1.0m between 6,000 and 2,000 yr BP which is so prevalent throughout Polynesia (see Spencer, this volume). The reasons for this may relate to the lack of full reef development around Henderson for there is no sheltered lagoon or intertidal reef flats within which micro-atolls might have developed at, and subsequently reflected, a raised Holocene sea level. In addition, the lack of a modern algal ridge around the island makes the preservation of a fossil algal ridge, as on Suwarrow, Northern Cook Islands (Scoffin et al. 1985), Mangaia, Southern Cook Islands (Yonekura et al. 1986), Reao, eastern Tuamotu Archipelago (Pirazzoli et al. 1987a) and Makatea Island (Montaggioni et al. 1985b), unlikely. Finally, unlike many Polynesian barrier reefs and atolls, there are no obvious sites for the accumulation of conglomerate deposits which may record high sea level stands (Montaggioni and Pirazzoli 1984). It is perhaps to be expected, therefore, that the possible evidence that is present on Henderson for a Holocene high sea level is erosional in nature, in the form of the bevelled ramps which terminate at 2.2-2.4m above present sea level.

CONCLUDING REMARKS

Henderson Island, like many raised reef islands, clearly preserves an important record of climatic, oceanographic and biogeographic change in the south Pacific. What is also clear is that the 1987 expedition was only able to perform a spatially-limited reconnaissance of the structure and topography of the island. It can only be hoped that the geology and geomorphology described here provides a context and a basis for more detailed studies which should be undertaken on Henderson in the coming years.

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Table 1. Fossil corals of Henderson Island

Species	Lo	Fo	Bu	Or	La	Loc
Pocillopora eydouxi		X	X	X	X	H
Pocillopora damicornis					X	P
Pocillopora sp. 1		X				H
Pocillopora sp(p).	X	X	X	X	X	?
Acropora group 1 =						
Acropora hyacinthus					X	T
+*Acropora cytherea*					X	P
+*A.* sp(p).					X	?
Acropora group 2		?		X	X	?
(= *A.robusta* spp. group)						
Acropora group 3				X	X	?
(= *A.valida* and/or *A. nasuta*, *A.* spp.)						
Montipora spp.			?	?	X	?
Astreopora cf. *moretonensis*		X		X	X	H
Porites cf. *mordax*		X		X	X	T
Porites massive	X	X	X	X	X	?
Psammocora ?obtusangula		X			X	H?
Coscinarea columna		X		X		G
Pavona sp. 1		X		X	X	H
Pavona maldivensis		X			X	H
Fungia scutaria		X	X		X?	P
Fungiid sp(p). other					X	?
Scolymia vitiensis					X	H
Acanthastrea ?echinata				?	X	G
Lobophyllia corymbosa				X		G
Favia stelligera				X	X	P
Favia rotumana			X	X	X	H
Leptoria phrygia			X		X	G
Montastrea curta				X	X	H
Montastrea sp. 1	X	X		X	X	E
Plesiastrea cf. *versipora*		X		X	X	H?
TOTAL: 26	3	14	7	17	23	

Lo: low limestone unit; Fo: fossiliferous reef unit; Bu: core reef buttresses; Or: outer island slope fossils not *in situ*, thus not definitely located stratigraphically; La: central lagoon; Loc: The closest locality from where this species is known today: H: Henderson Island; P: other islands in the Pitcairn Group; T: Tuamotu Archipelago; G: Gambier Islands; E: species presumed globally extinct.

Taxonomic notes:
Pocillopora sp. 1 (= *P.* cf. *verrucosa* of Paulay and Spencer 1989): see Paulay (this volume) for a discussion of this species. *Pocillopora* sp(p). : other *Pocillopora* spp. than listed above, likely includes *P.meandrina*. *Acropora* group 1: large tabloid *A.* species, many not identified to species, includes *A. hyacinthus* and *A. cytherea* listed above, as well as at least 1 additional species. *Acropora* group 2: species with very massive branches, often 5cm+ diameter, most or all in *A. robusta* group. *Acropora* group 3: other *Acropora* species, mostly of corymbose growth form, many not identified to species, includes *A. nasuta* and/or *A.*. *valida* listed above as well

as other species. *Montipora* spp. : unidentifiable due to poor preservation. *Astreopora* cf. *moretonensis* (= *A.* sp. 1 of Paulay and Spencer 1989): a plate forming *Astreopora*, kindly identified by J E N Veron as *A.* cf. *moretonensis*. *Psammocora ?obtusangula* (= *P.* sp. 1 of Paulay and Spencer 1989): a subarborescent *Psammocora* that appears to be conspecific with *P. obtusangula* collected alive on Henderson; however,it is not sufficiently well preserved to allow for a definite identification. *Pavona* sp. 1 (= *P.* cf. *clavus* of Paulay and Spencer 1989): see Paulay (this volume) for a discussion of this apparently undescribed species. ?Fungiid sp(p): poorly preserved, small specimens of *Fungia* and/or *Cycloseris*. *Montastrea* sp. 1: an apparently extinct species, with second order septo-costae greatly reduced or aborted. *Plesiastrea* cf. *versipora*: fossils have consistently 12 septo-costae while recent specimens are more variable.

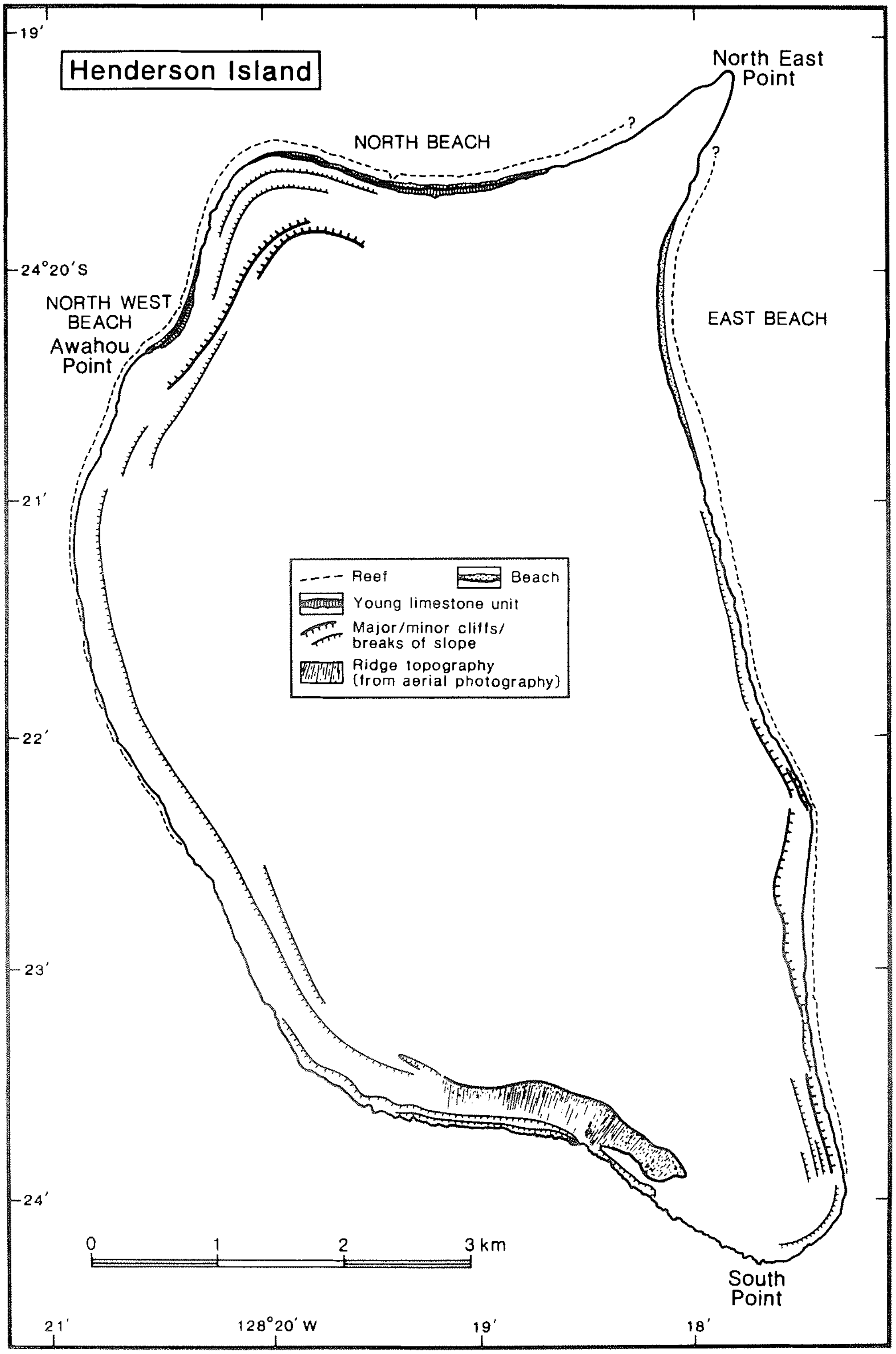

Figure 1. Henderson Island (from aerial photography sortie 035/85 and Admiralty Chart 987 (1953)).

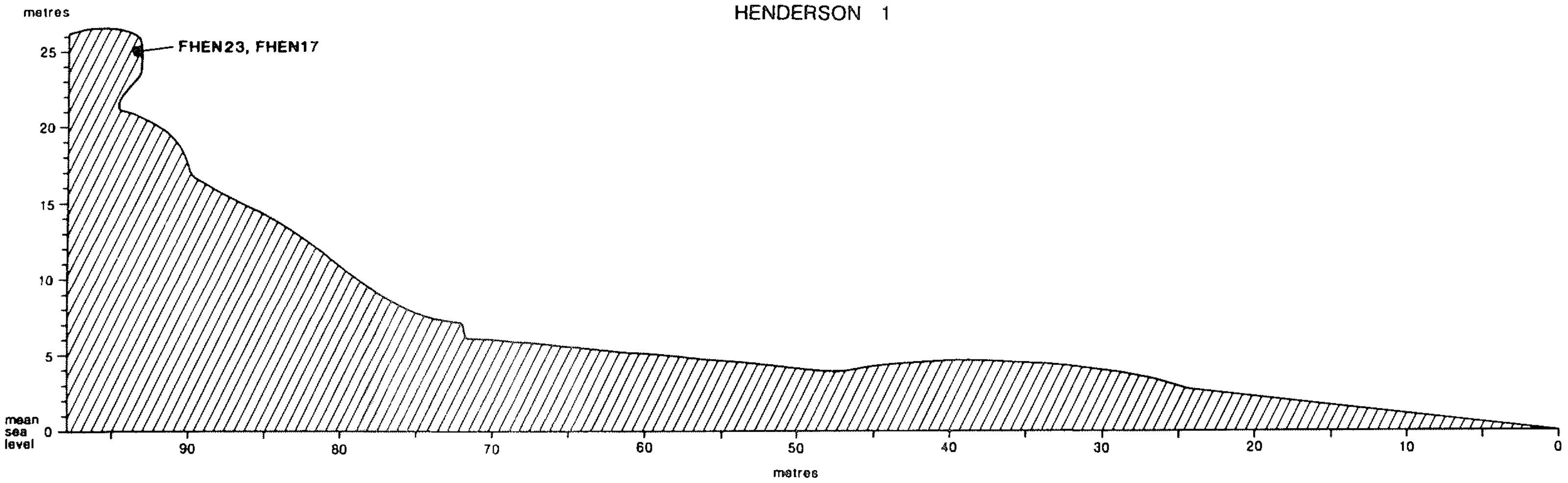

Figure 2. Profile 1, North Beach, Henderson Island (location: see Figure 10).

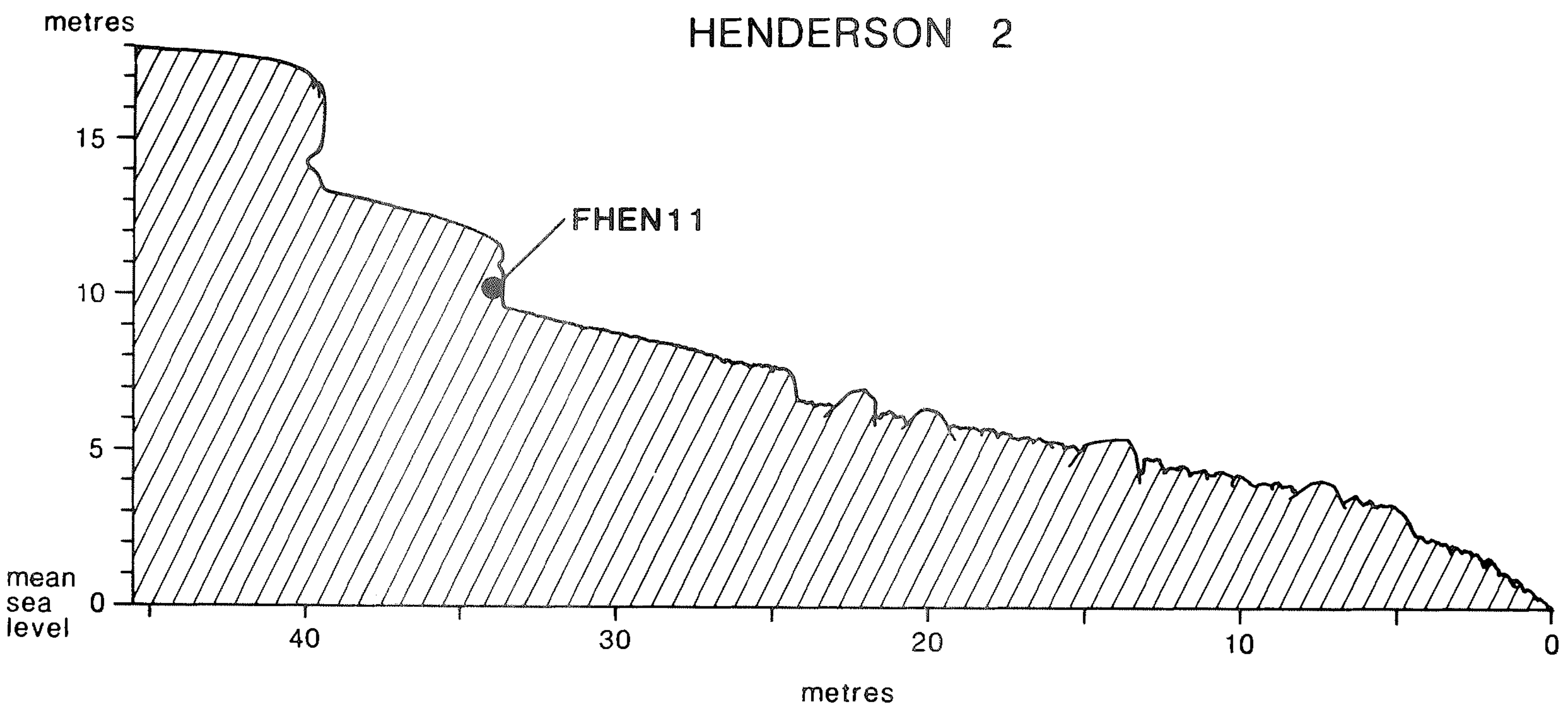

Figure 3. Profile 2, North-west Beach, Henderson Island (location: see Figure 9)

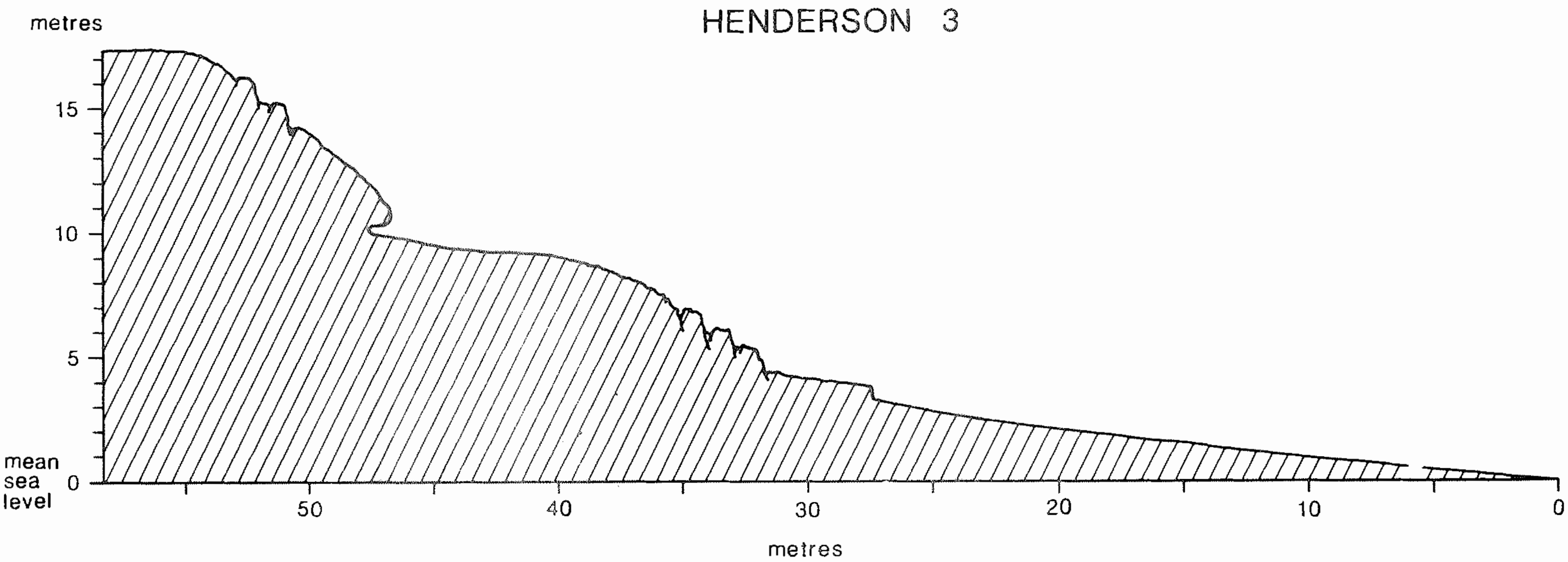

Figure 4. Profile 3, North Beach, Henderson Island (location: see Figure 10).

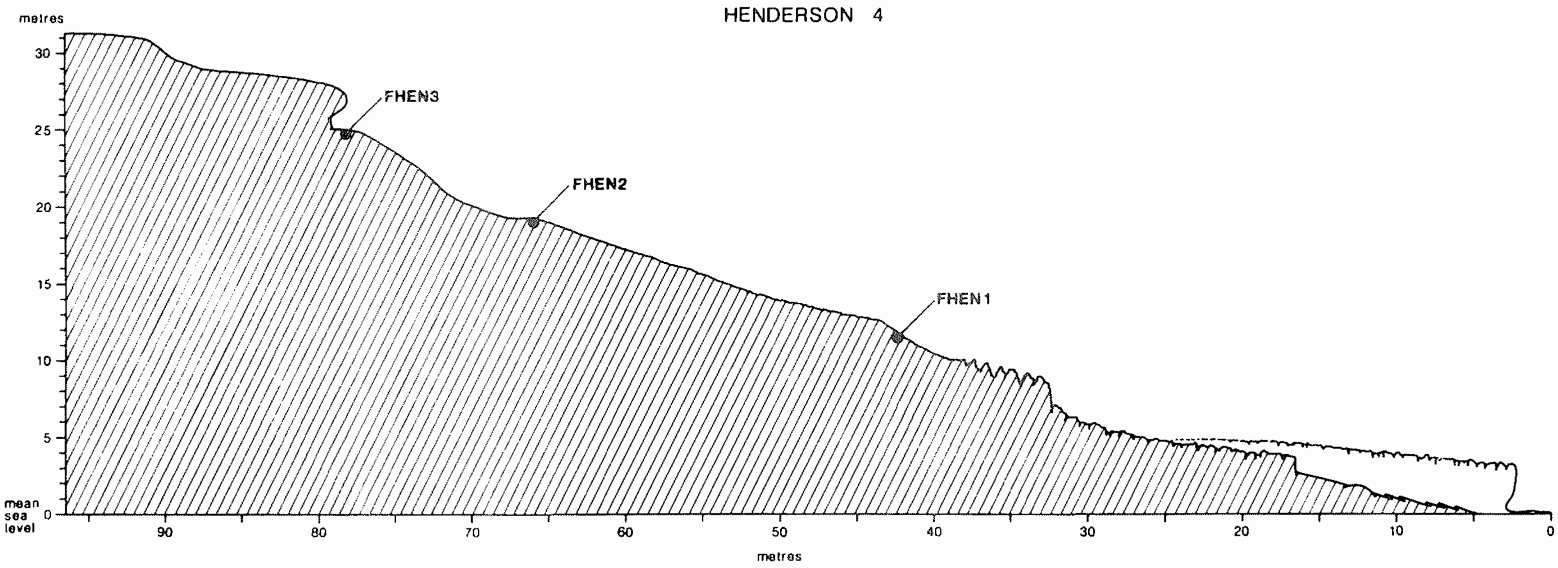

Figure 5. Profile 4, North-west Beach, Henderson Island (location: see Figure 9).

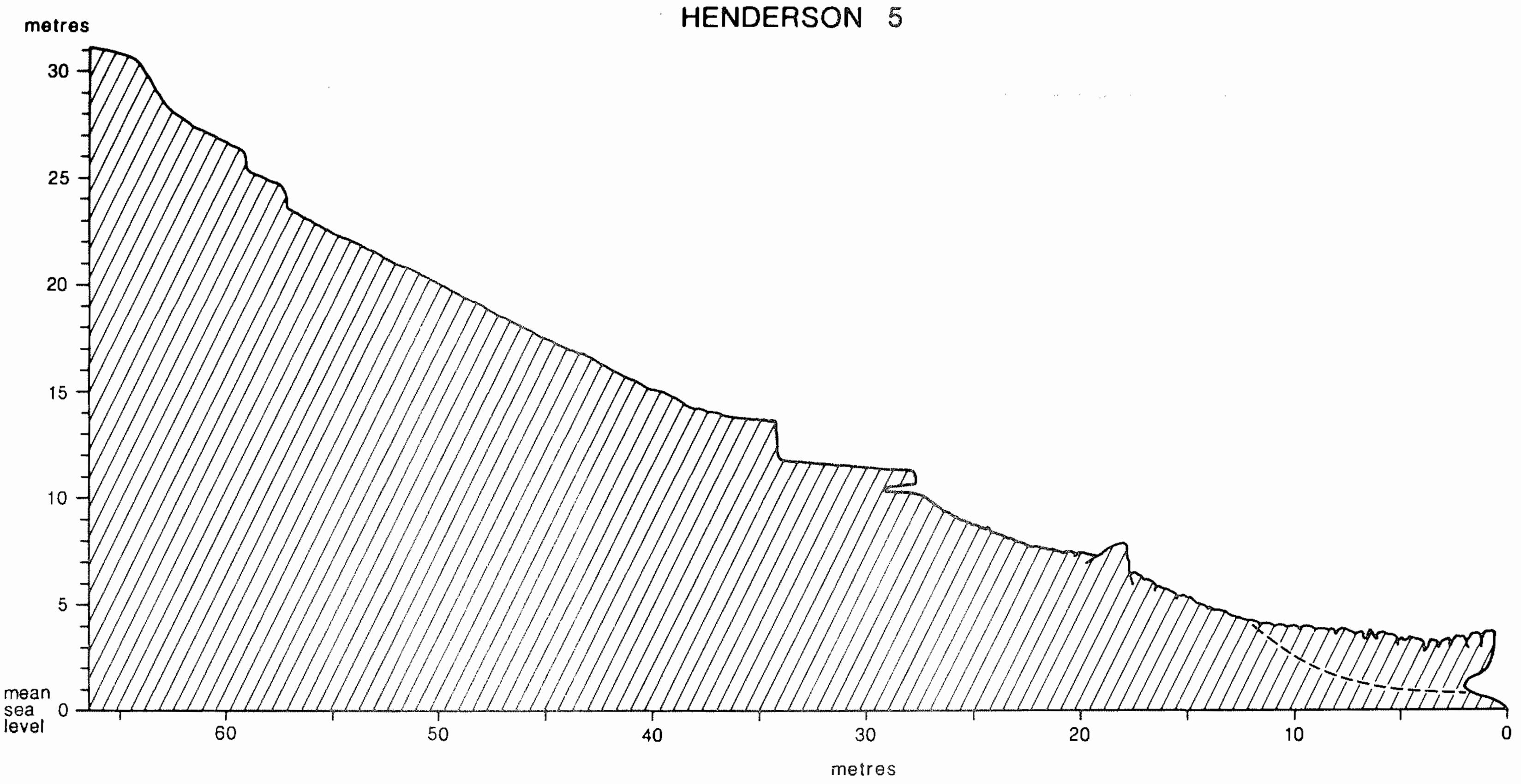

Figure 6. Profile 5, North Beach, Henderson Island (location: see Figure 10).

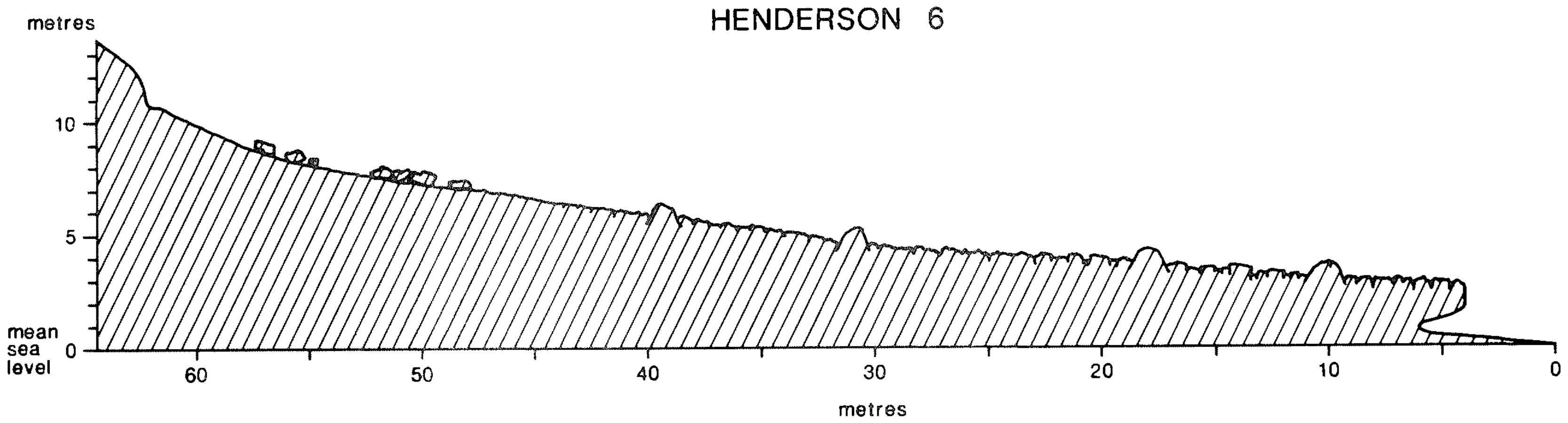

Figure 7. Profile 6, North-west Beach, Henderson Island (location: see Figure 9).

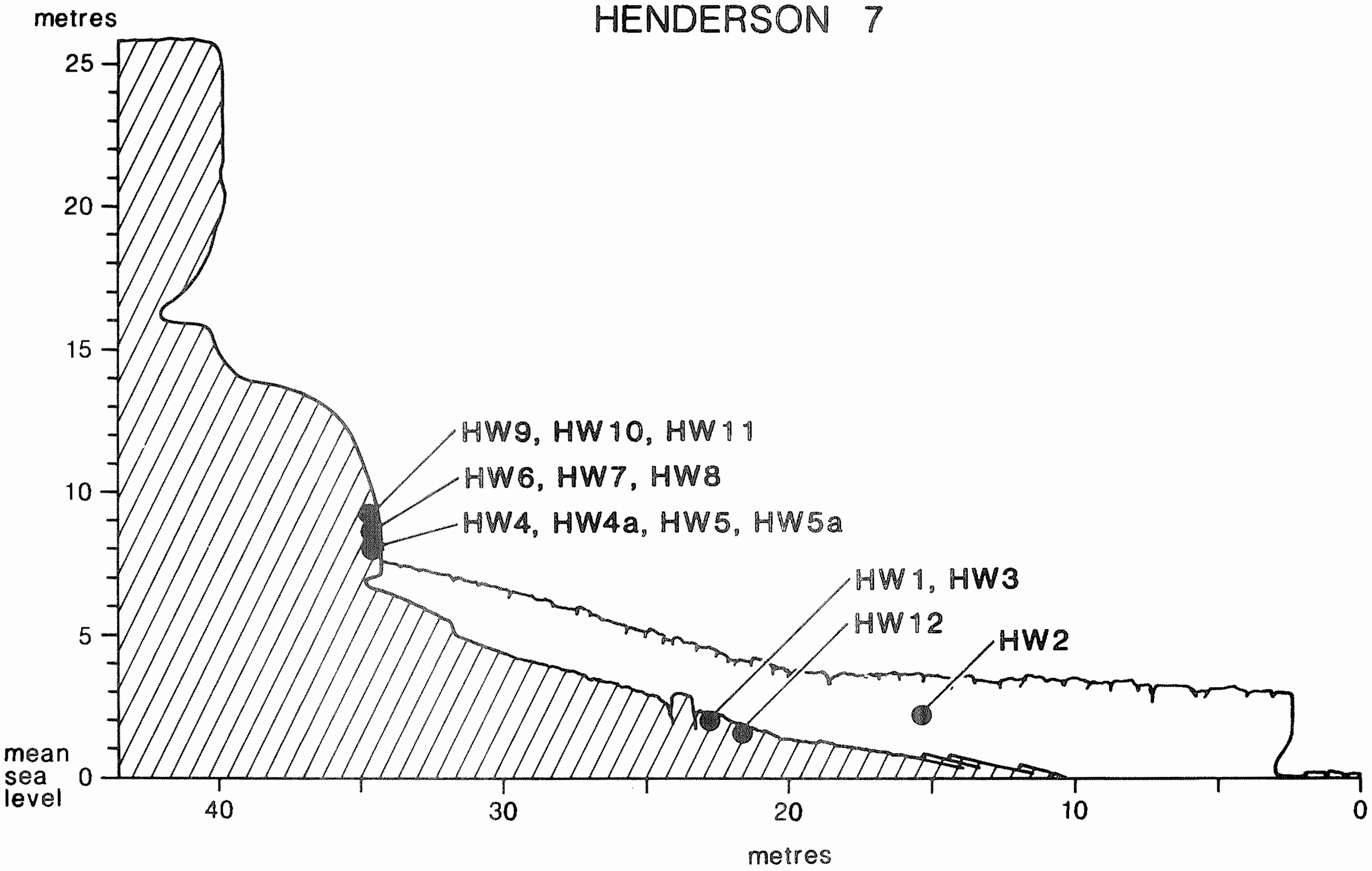

Figure 8. Profile 7, North-west Beach, Henderson Island (location: see Figure 9).

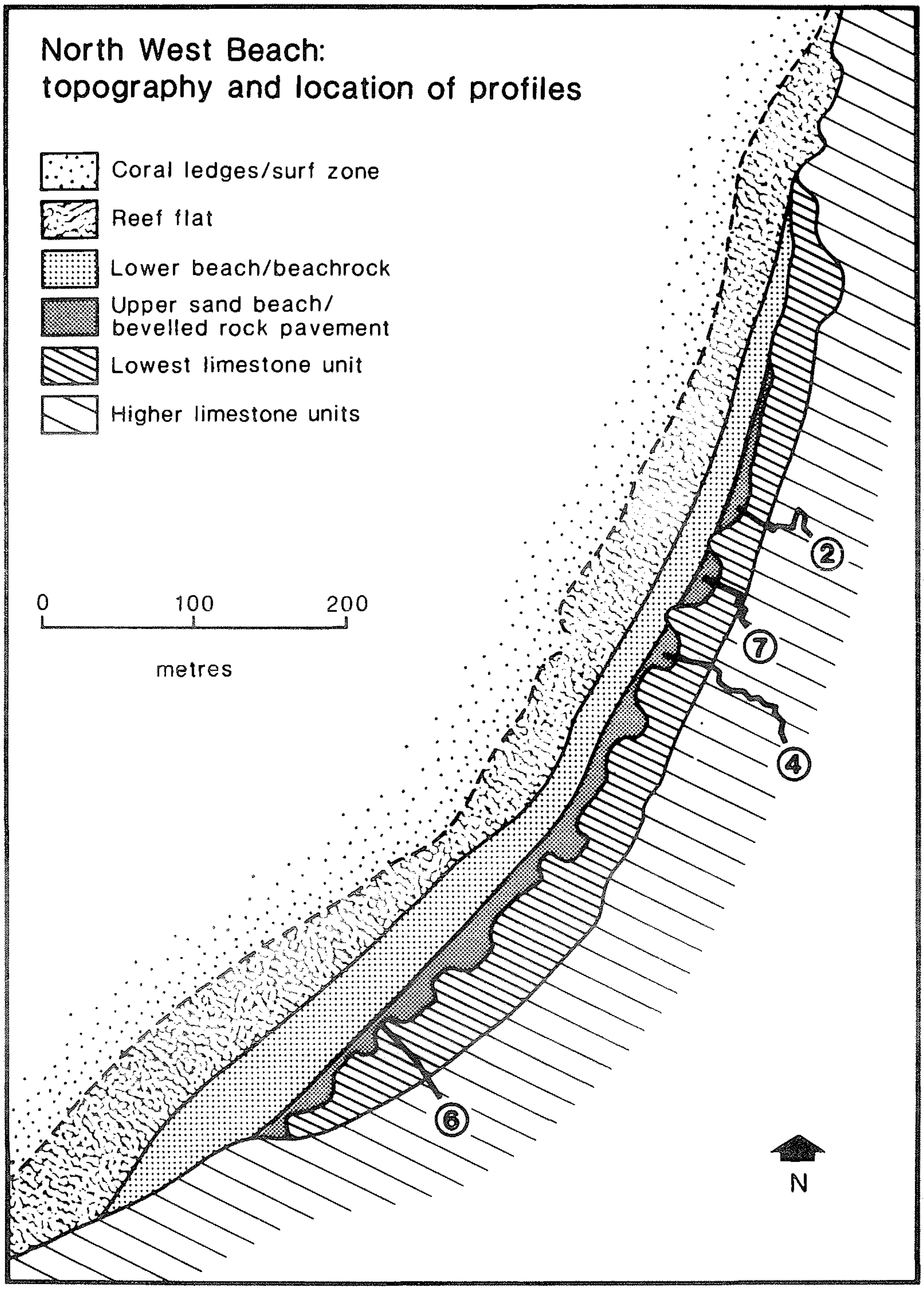

Figure 9. North-west beach: topography and location of profiles.

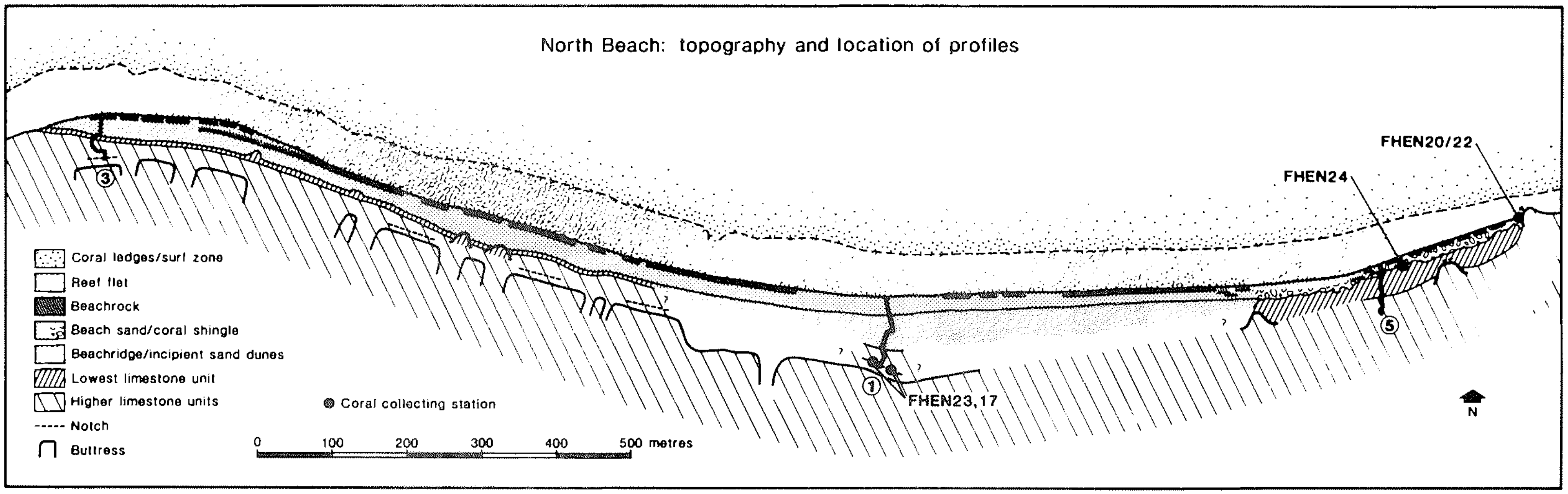

Figure 10. North beach: topography and location of profiles.

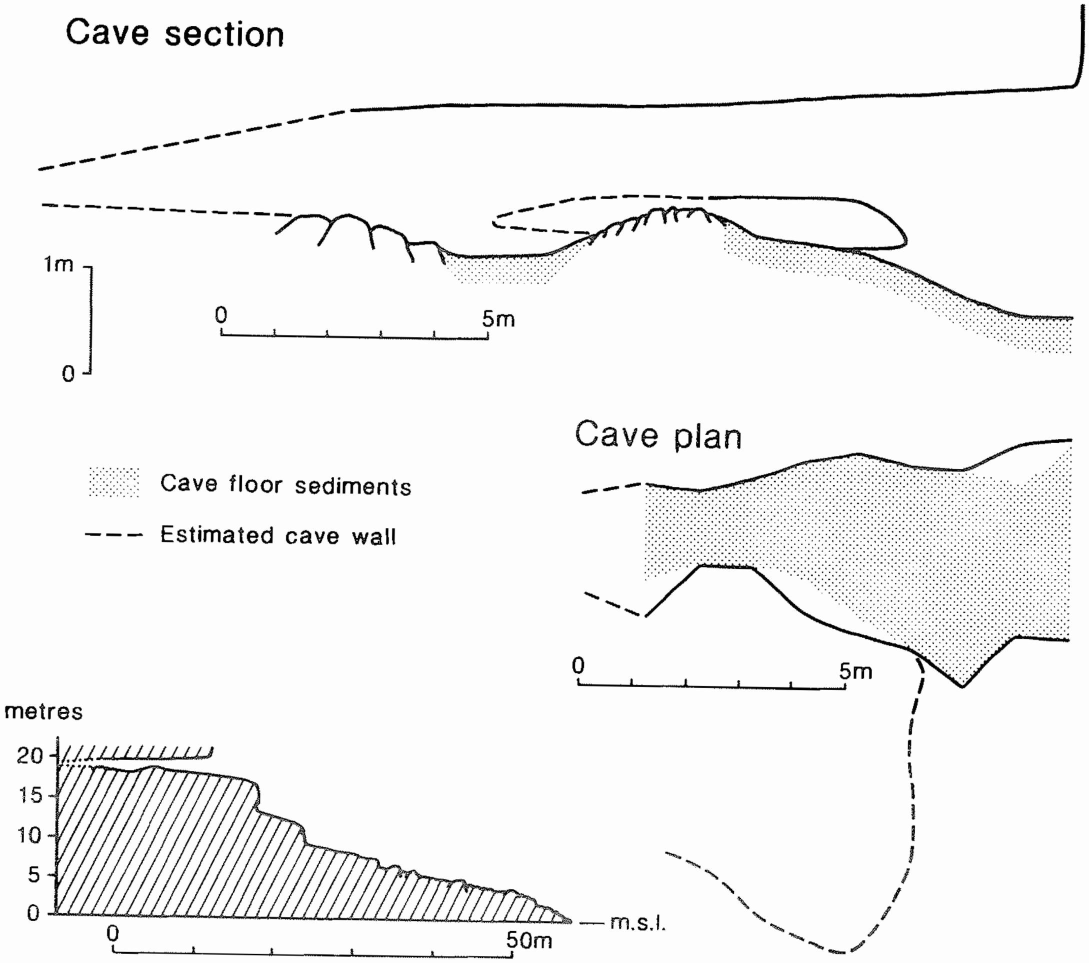

Figure 11. Cave morphometry, profile 2, North-west beach.

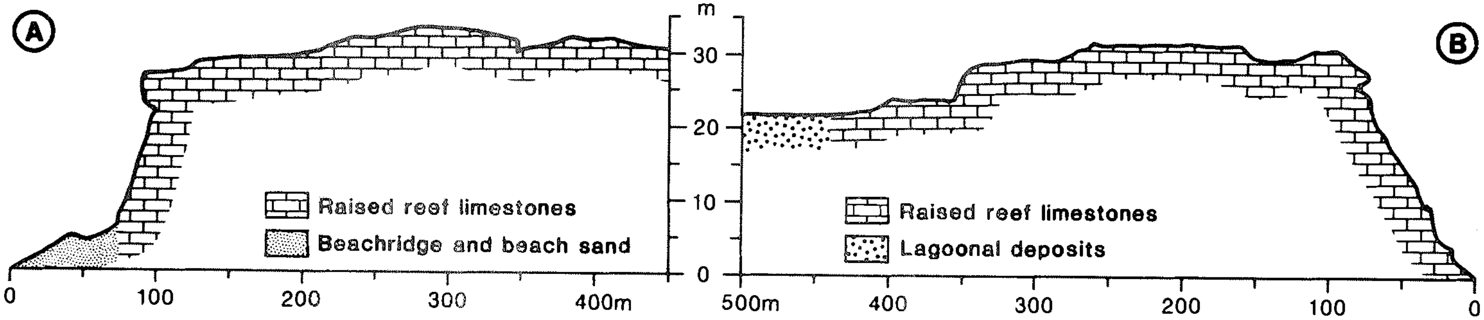

Figure 12. Topographic profiles from island cliff margin to island interior, North (A) and North-west (B) transects.

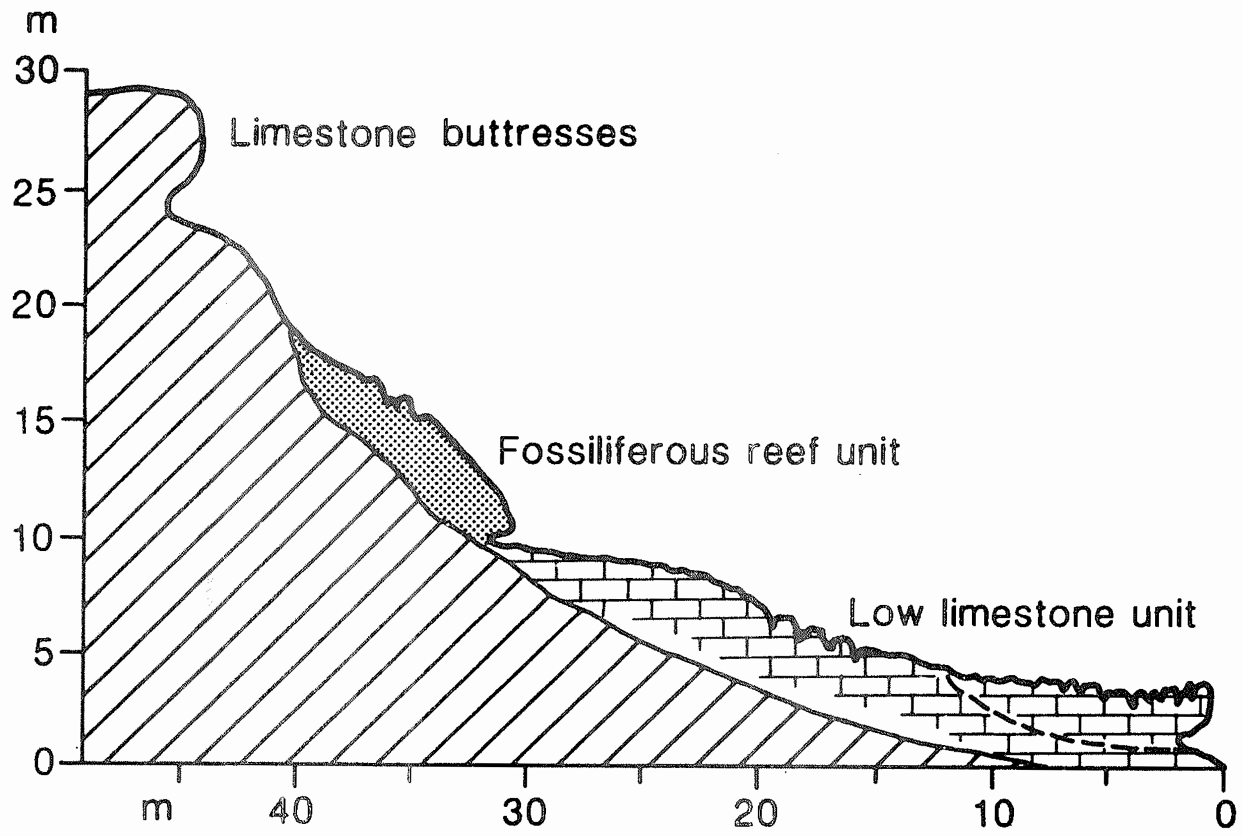

Figure 13. Summary diagram of stratigraphic units and sealevel features in north embayment, Henderson Island.

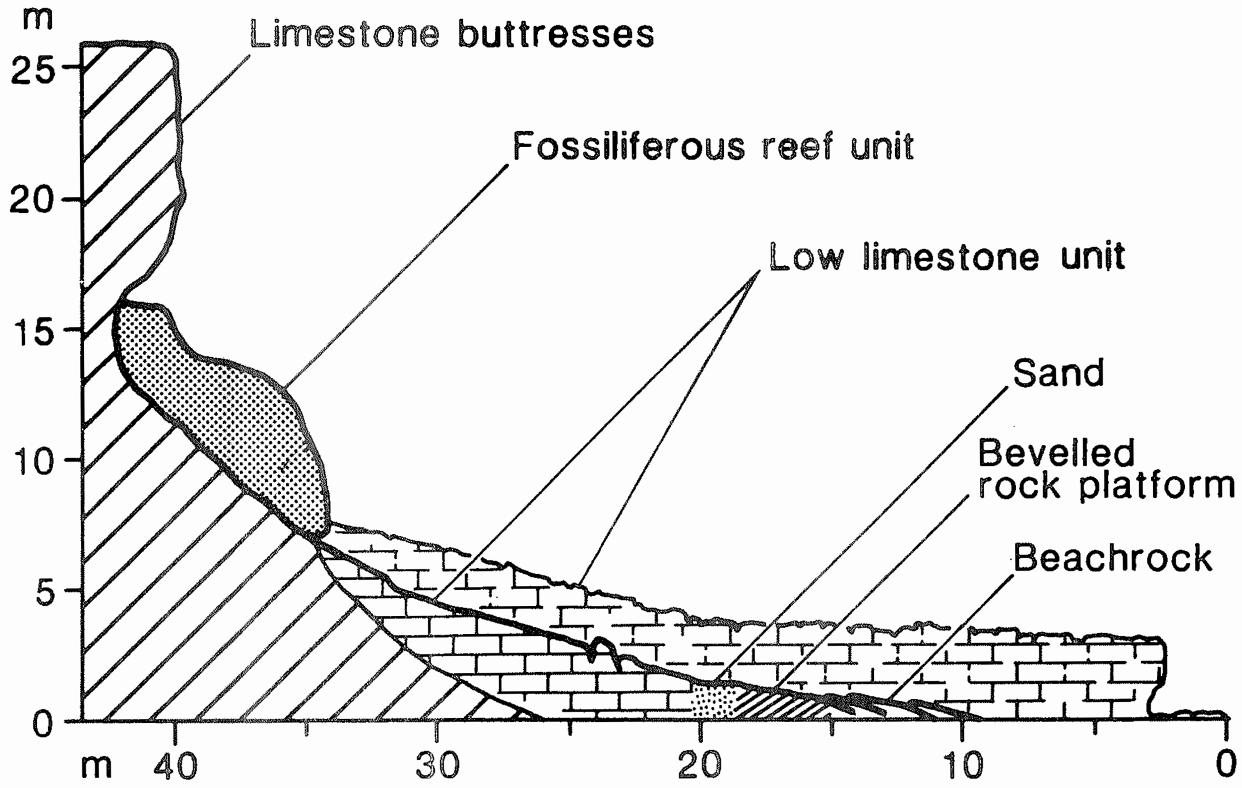

Figure 14. Summary diagram of stratigraphic units and sealevel features in north-west embayment, Henderson Island.

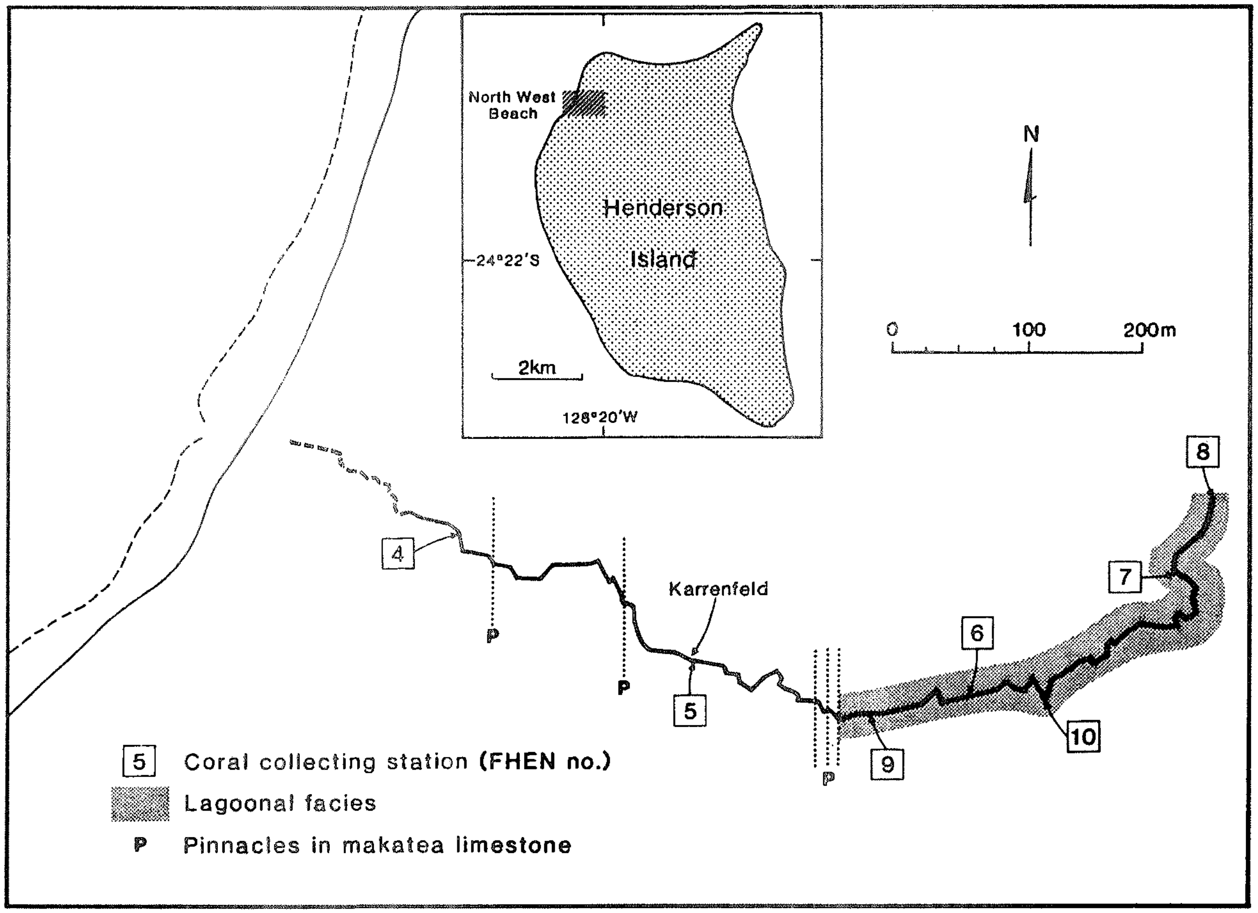

Figure 15. Plan of island cliff margin to island interior transect, North-west beach.

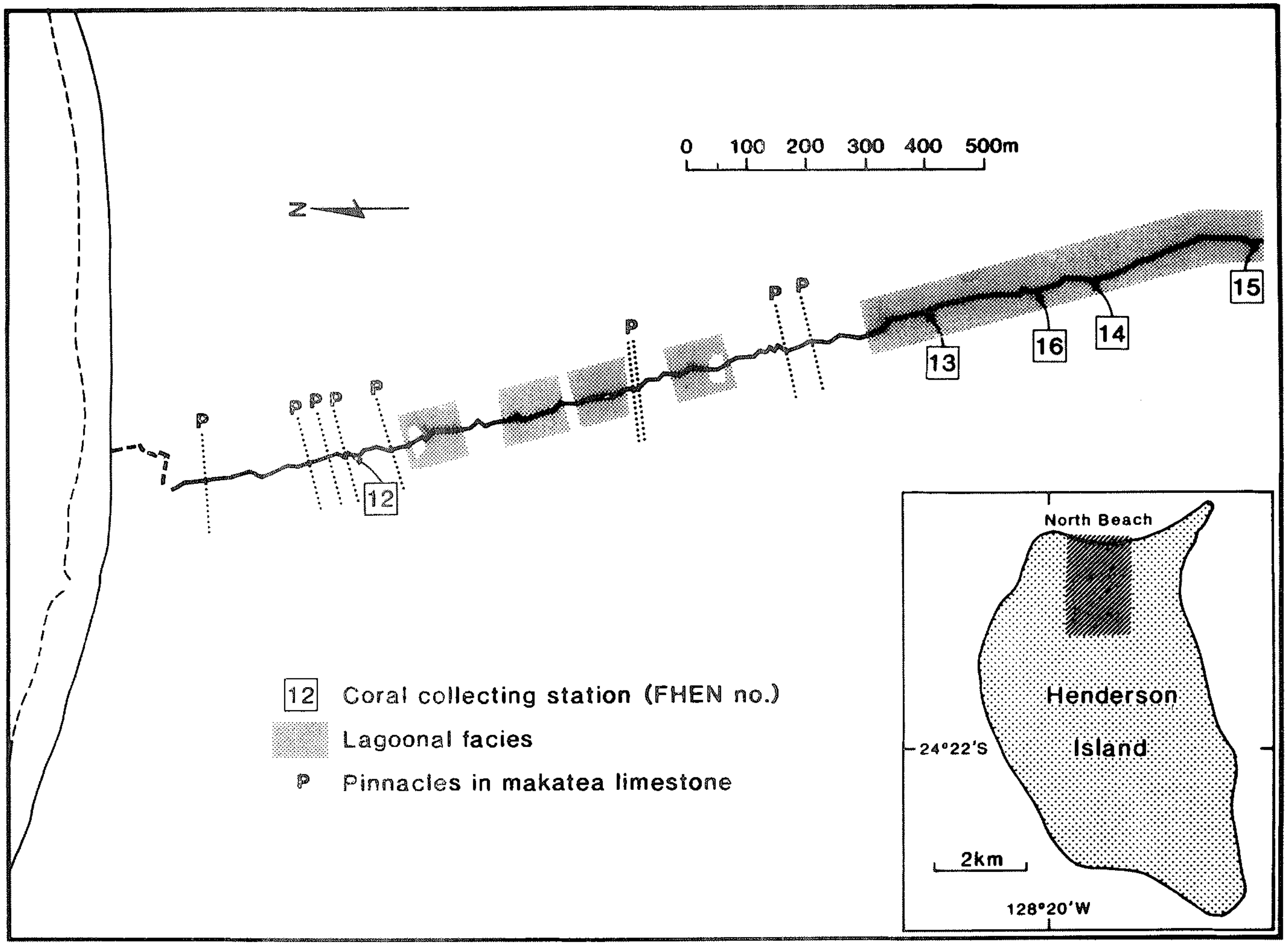

Figure 16. Plan of island cliff margin to island interior transect, North beach.

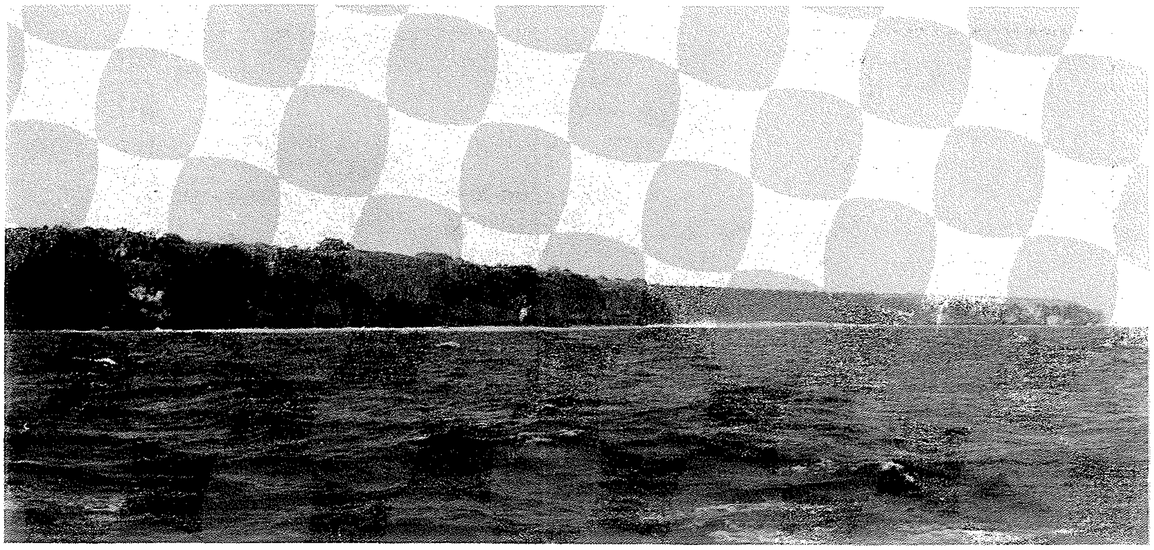

Plate 1. Western cliffs, looking south-southwest towards the south point.

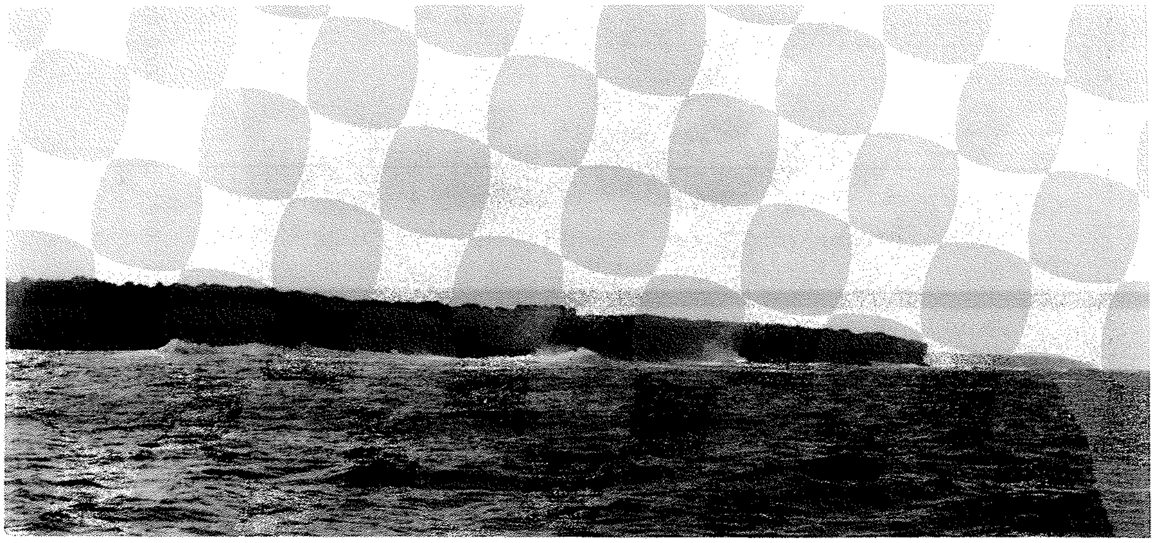

Plate 2. North-west embayment and beach. Awahou Point at far right.

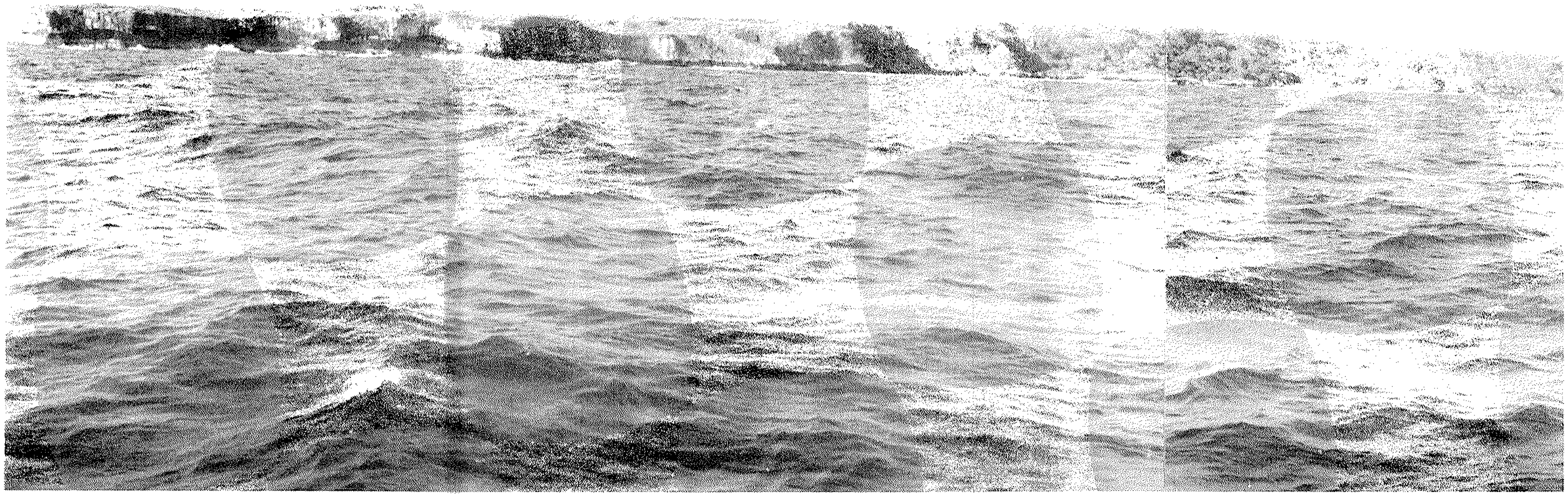

Plate 3. North-east Point and eastern end of North Beach, approaching Henderson from the north.

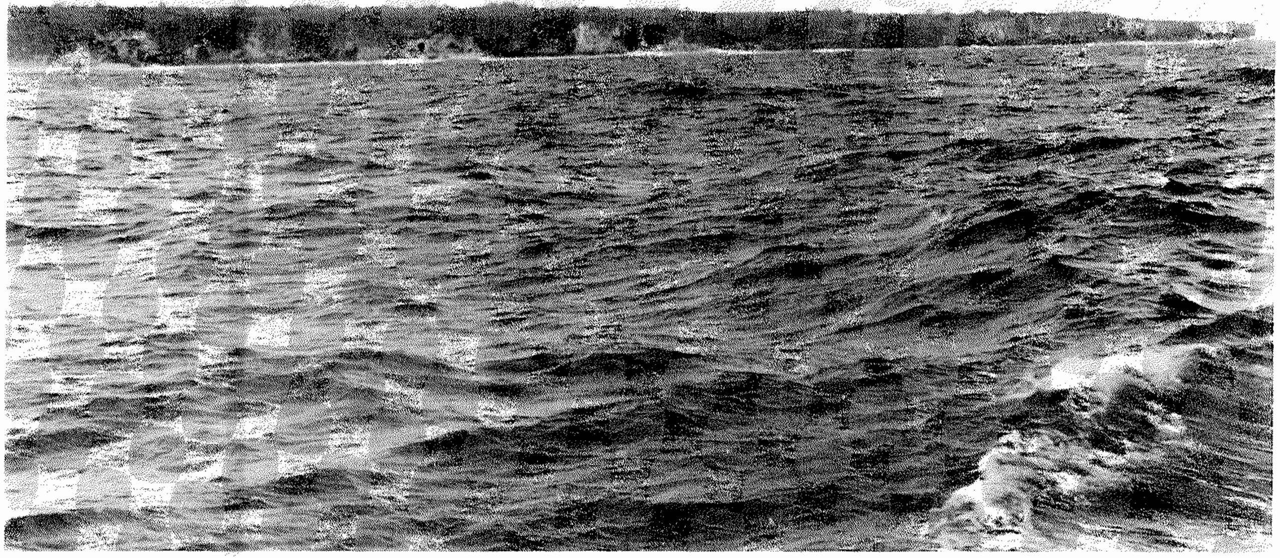

Plate 4. Northern end of East Beach and North-east Point, approaching Henderson from the east.

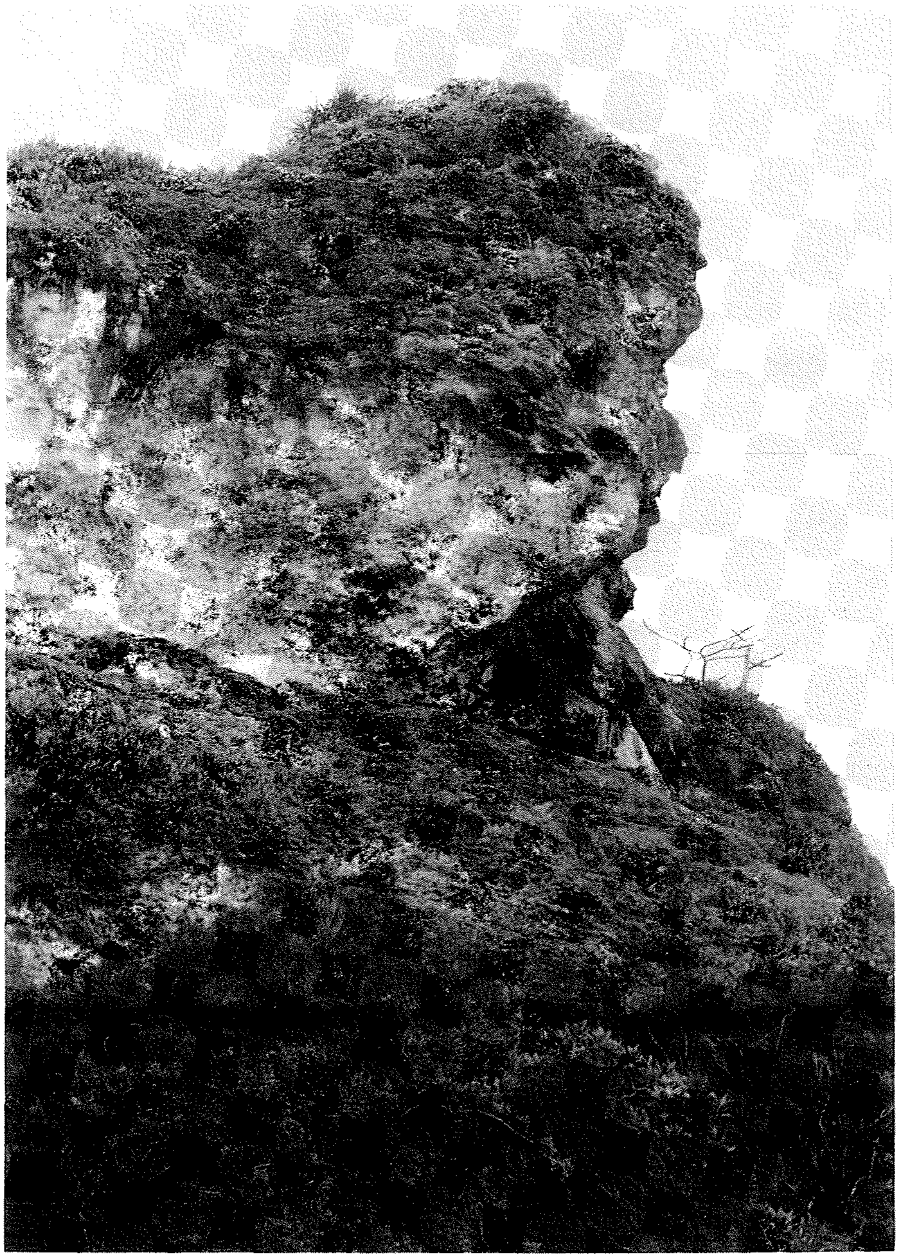

Plate 5. Fore-reef buttress, profile 7, North-west Beach. Notch at 16.2m above mean sea level with fossiliferous reef unit below (in foreground).

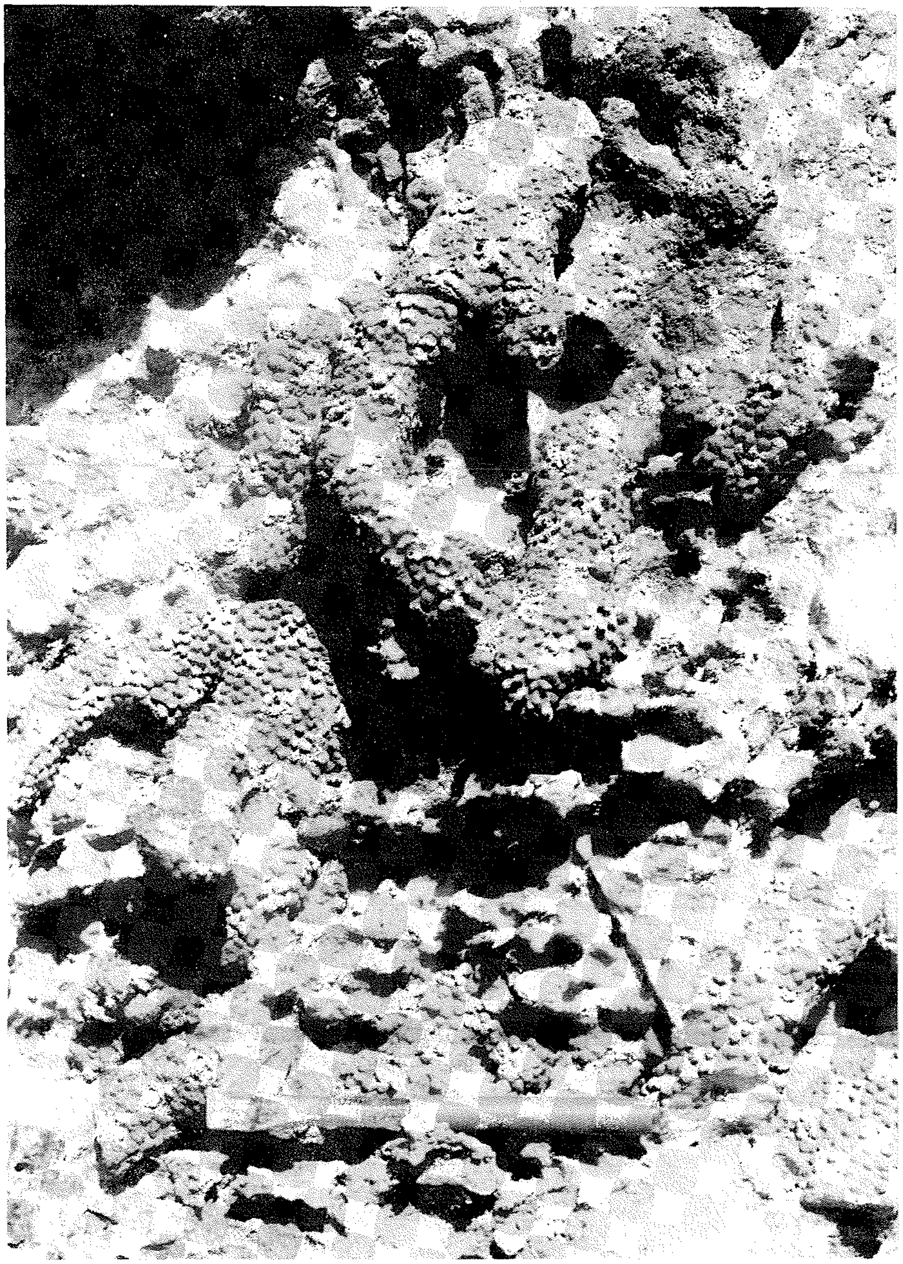

Plate 6. *Pocillopora eydouxi* in cliff face, ~ 24m above sea level, central North Beach.

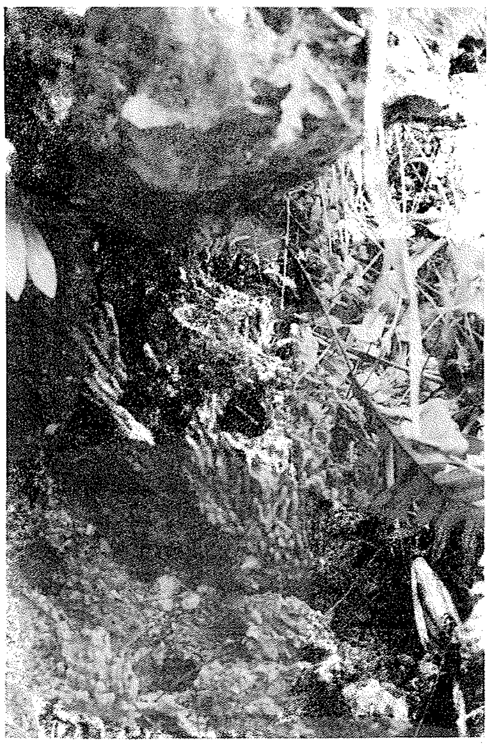

Plate 7. 25m notch, profile 4, North-west Beach. Well-preserved *Acropora* sp. and sand fill in notch.

Plate 8. Coral buttress with notch level at 17-18m above sea level, eastern section, North Beach. Note post-erosional flowstone pillars within notch.

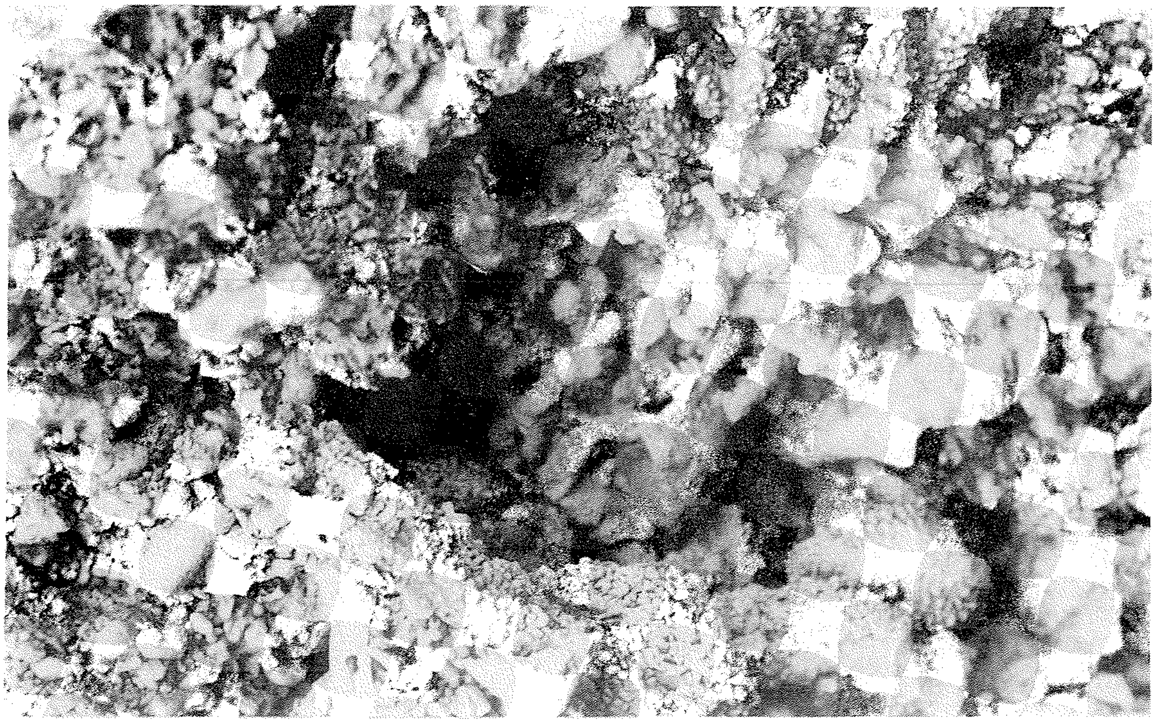

Plate 9. Upper facies, fossiliferous reef unit, eastern end of central section, North Beach.

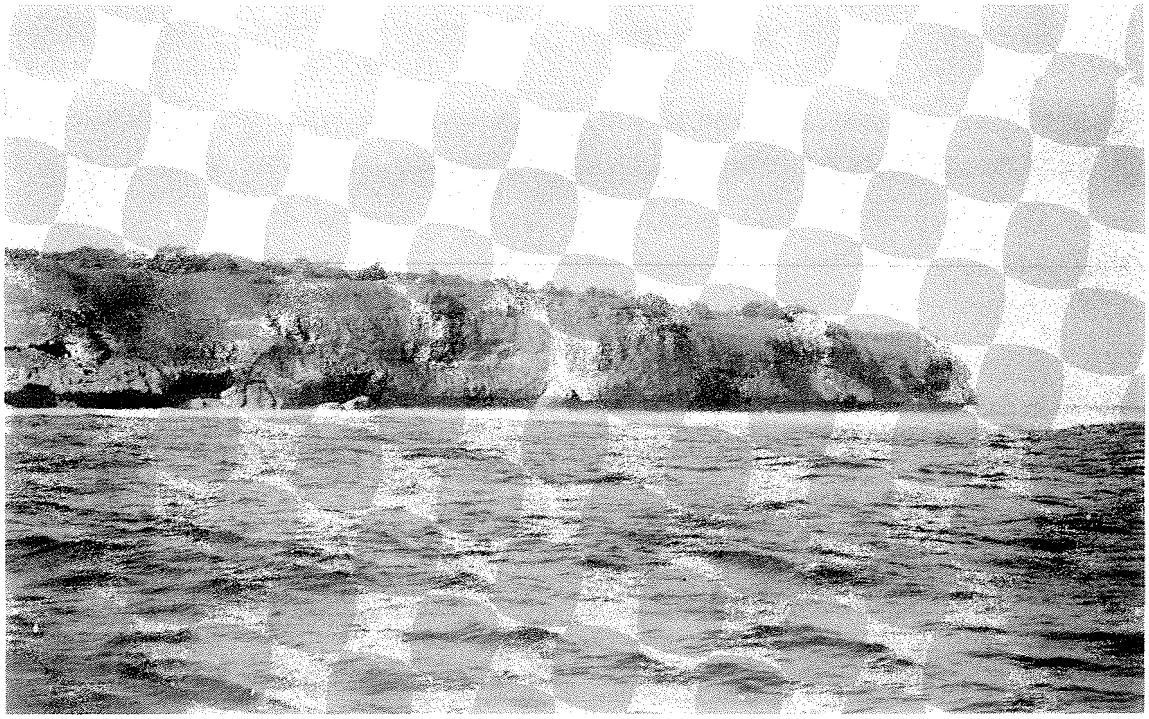

Plate 10. Headland at western end of North Beach. Note contemporary notch and (at centre) upper boundary of low limestone unit at ~ 10m above sea level. Upper, fossiliferous reef unit and low limestone unit well distinguished in headland profile.

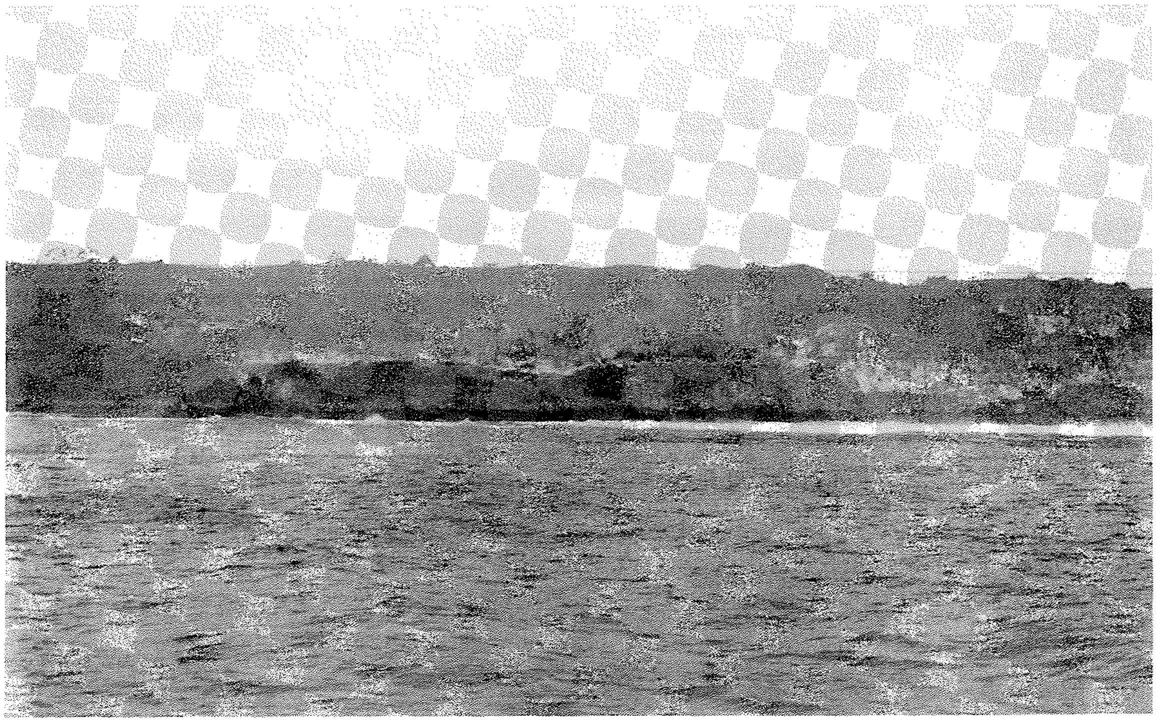

Plate 11. Cliffs to north of North-west Beach. Low limestone unit upper boundary marked by pale contact and large caves/overhangs.

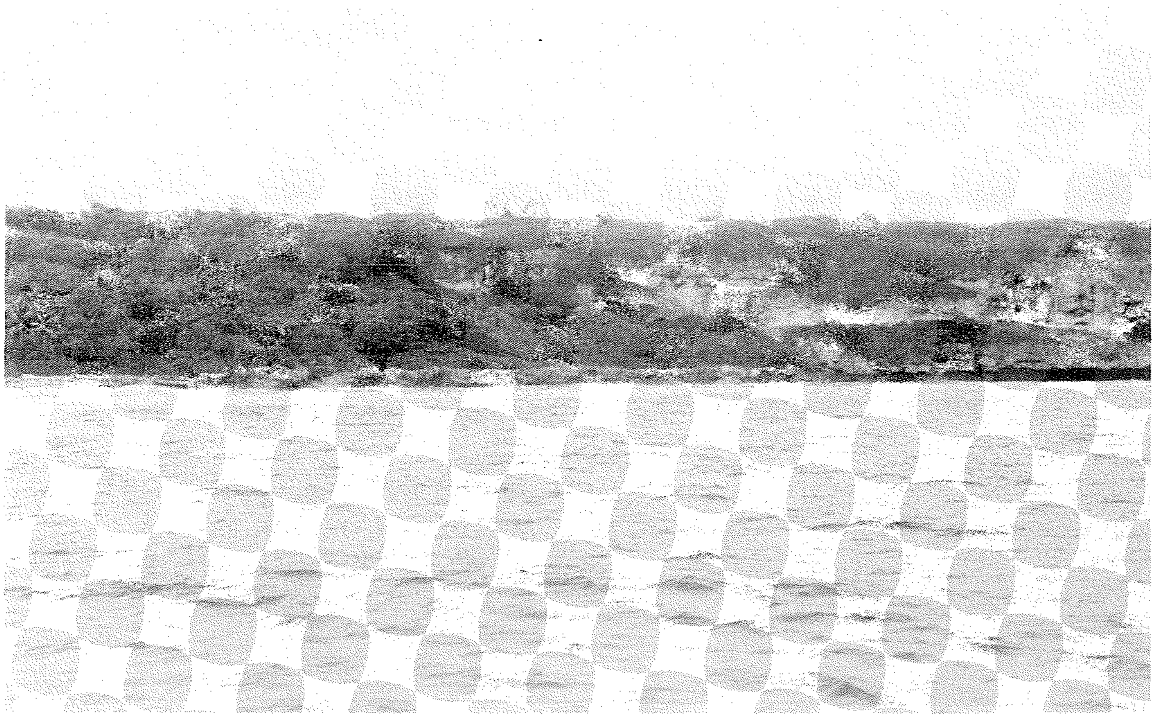

Plate 12. Southern end of North-west Beach. Note low limestone unit as terrace, with spur-and-groove margin, in bay (to left) and as cliff front veneer at bay southern margin (to right). Fossiliferous unit and notch/cave level above with high notch level (see Plate 7) near cliff top.

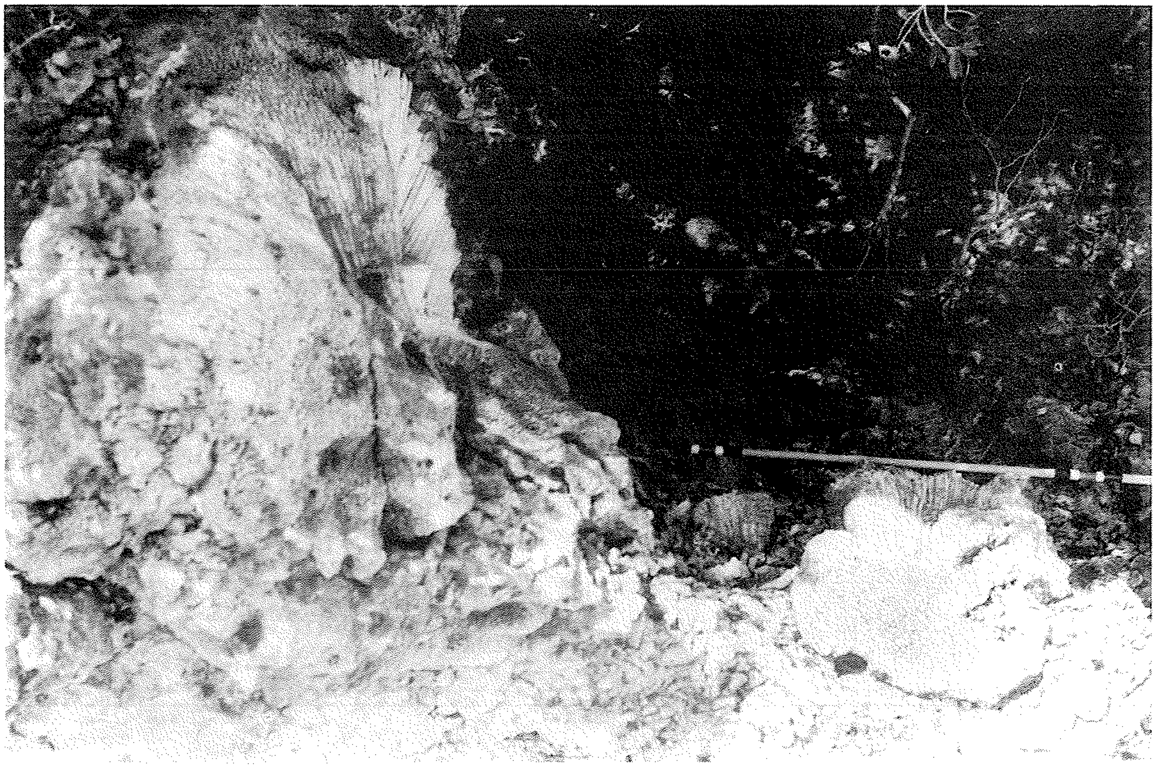

Plate 13. Groove exit in low limestone unit, eastern end of central section, North Beach. Note massive *Montastrea* sp.1 colony to left and similar colonies on groove floor.

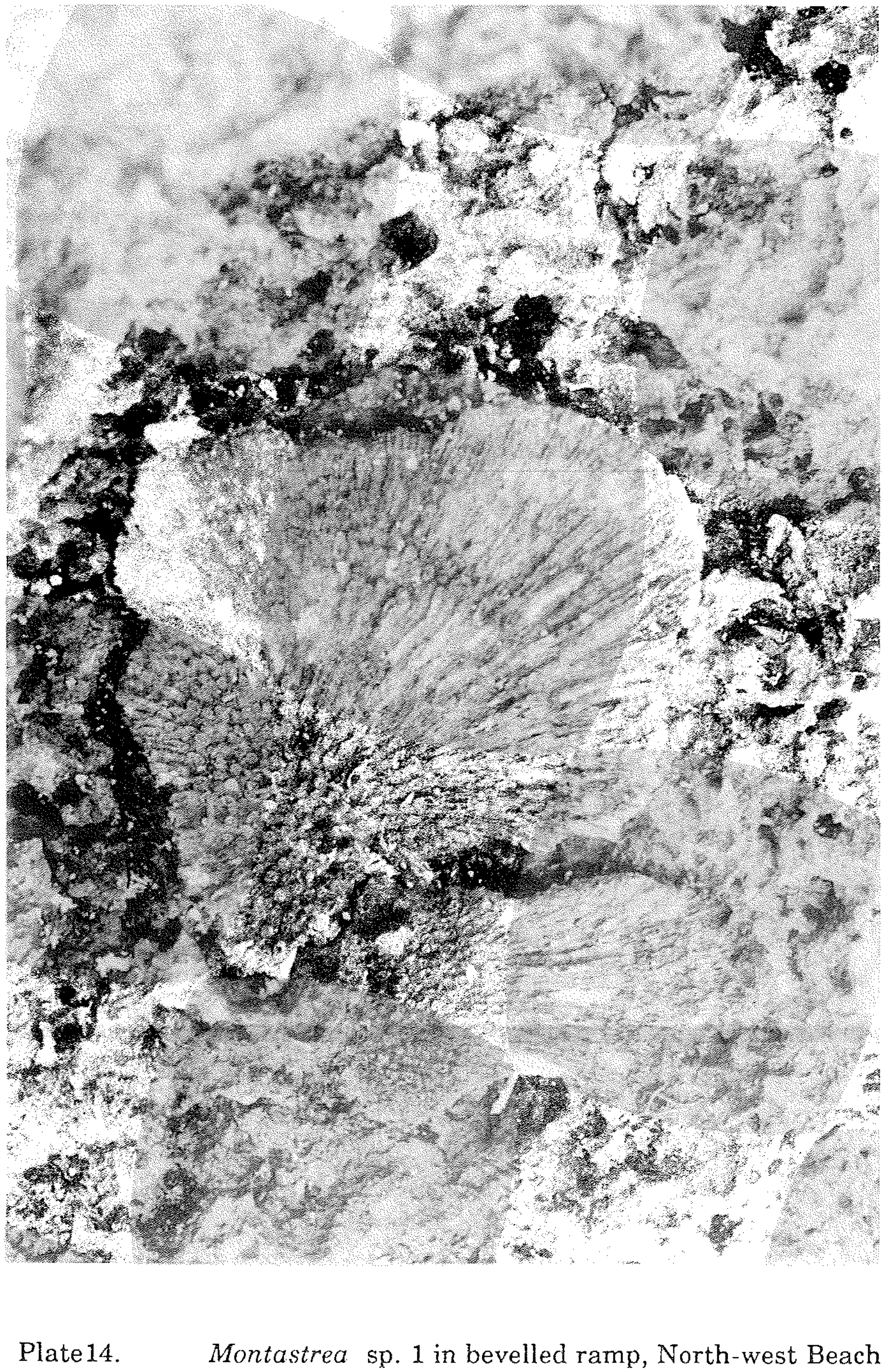

Plate 14. *Montastrea* sp. 1 in bevelled ramp, North-west Beach.

Plate15. Pinnacle-pitted limestone on transect to island interior from the North-west Beach.

Plate 16. Massively branching *Acropora* (group 2) colony, near interior lagoon margin, North-west Beach. (Scale bar: 50 cm.)

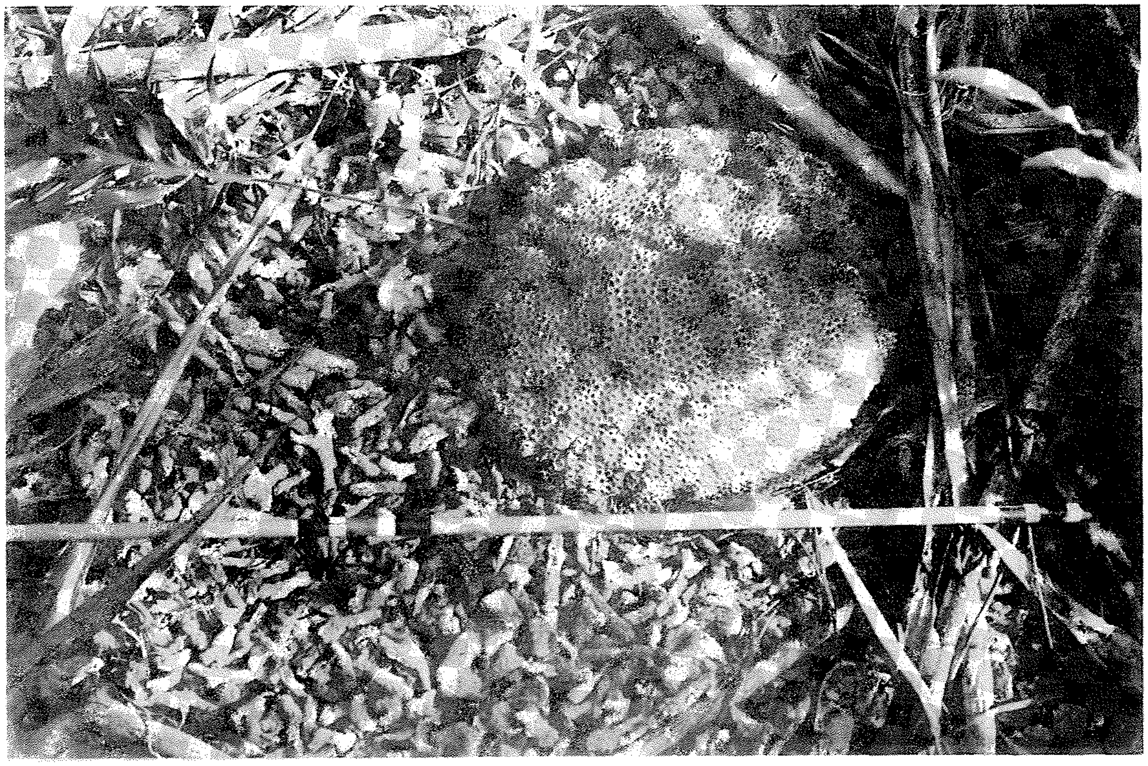

Plate 17. *Montastrea* sp.1 with *Acropora* sticks, interior lagoon deposits, North-west Beach. (Scale bar: 50 cm).

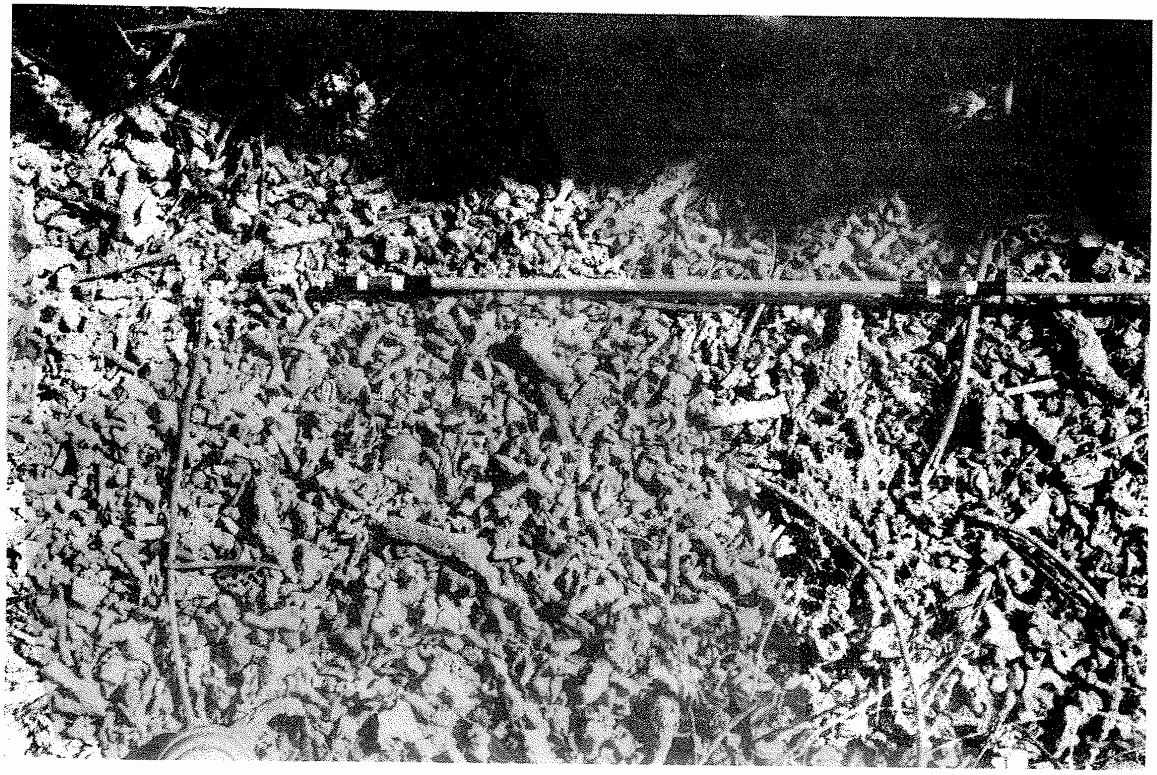

Plate 18. *Acropora* rubble of lagoonal patch reef, North Beach. (Scale bar: 50cm).

ATOLL RESEARCH BULLETIN

NO. 324

SEDIMENTS AND SEDIMENTARY ENVIRONMENTS OF HENDERSON ISLAND

BY

T. SPENCER

APPENDIX: FORAMINIFERAL COMPOSITION OF HENDERSON ISLAND BEACH SAND

BY OWEN GREEN

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
OCTOBER 1989

SEDIMENTS AND SEDIMENTARY ENVIRONMENTS OF HENDERSON ISLAND

BY

T. SPENCER [1]

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° 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 >0ϕ 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 +0.5ϕ - +1.0ϕ 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 +1.5ϕ - +2.0ϕ 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.

ACKNOWLEDGEMENTS

I am grateful to Gustav Paulay for the collection of sediments samples H10 and H11 and to Susan Schubel for sample H9. Gustav Paulay also kindly supplied information of fore-reef morphology and provided insights into the biogeography and ecology of *Halimeda*. I am indebted to Paul Wilson for the laboratory analyses for grain-size distributions. Compositional information on the samples would not have been possible without the help and advice of Sandy Tudhope, Tony Greer and, in particular, Owen Green.

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APPENDIX : FORAMINIFERAL COMPOSITION OF HENDERSON ISLAND BEACH SAND

Owen Green[1]

Site location: Beach location 1 (see Figure 1)

Foraminiferal component by weight : 2.73 per cent (from 4.43 g sample).

SUPERFAMILY	FAMILY	No. of frags	%	F%	SF%
Textulariacea	Textulariidae				
	Textularia ?mayori	2	0.19		
				0.19	0.19
Tawitawiacea	Tawitawiidae				
	Tawitawia sp.	1	0.09		
				0.09	0.09
Lituolacea	Lituolidae				
	Triplasia sp.	4	0.38		
				0.38	0.38
Miliolacea	Miliolidae				
	Spiroloculina antillarum	1	0.09		
	Spiroloculina sp.	2	0.19		
	Quinqueloculina bidanta	2	0.19		
	Quinqueloculina polygona	7	0.67		
	Cruciloculina triangularis	7	0.67		
	Triloculina sidebottomi	23	2.19		
	Triloculina sp.	24	2.29		
				6.29	6.29
Soritacea	Peneroplidae				
	Peneroplis pertusus	1	0.09		
				0.09	
	Soritidae				
	Amphisorus sp.	13	1.24		
	Marginopora vertebralis	153	14.60		
				15.84	
	Alveolinidae				
	Borelis pulchra	1	0.09		
				0.09	0.09

SUPERFAMILY	FAMILY	No. of frags	%	F%	SF%
Discorbacea	Discorbidae				
	Discorbis ?mira	2	0.19		
	Tretomphalus atlanticus	5	0.48		
				0.67	0.67
Planorbulinacea	Cibicididae				
	Cibicides ?lobatulus	5	0.48		
				0.48	0.48
Asterigerinacea	Asterigerinidae				
	Asterigerina carinata	196	18.70		
				18.70	
	Amphisteginidae				
	Amphistegina lessonii	269	25.67		
				25.67	44.37
Cassidulinacea	Anomlinidae				
	Anomlinella rostrata	5	0.48		
				0.48	0.48
Acervulinacea	Homotrematidae				
	Homotrema rubrum	320	30.53		
				30.53	30.53
Rotaliacea	Rotaliidae				
	Ammonia becarri	1	0.09		
				0.09	
	Elphidiidae				
	Elphidiella sp.	1	0.09		
				0.09	0.09
Nummulitacea	Nummulitidae				
	Heterostegina depressa	2	0.19		
	Eponides repandus	1	0.09		
				0.28	0.28
	TOTALS	1048	99.96		

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Location	Environment	Sample	D_{50}	M_Z	σ_I	Sk_I	K_G
North Beach	Beach face	H1	-0.39	-0.26	1.01	+0.21	0.88
	Beach face	H2	-1.70	-1.71	0.71	+0.10	1.30
	Beach face	H3	+1.18	+0.91	1.44	-0.52	1.81
	Incipient dune	H4	+1.77	+1.71	0.42	0.16	1.01
	Beach face	H5	+0.36	-0.51	2.14	-0.45	1.25
	Beach face	H6	+0.36	-0.83	2.51	-0.54	1.37
	Beach face	H7	-3.67	-3.82	0.67	-0.29	0.65
	Beach face	H8	-2.25	-1.60	1.95	+0.43	0.57
North-west Beach	Beach face	H9	+0.57	+0.54	0.59	-0.16	1.26
North Beach	Reef-front terrace, -12m	H10	-0.52	-0.57	1.08	-0.12	1.17
	Reef-front terrace, -30m	H11	-1.75	-1.11	2.33	+0.33	0.56

Table 1. Characteristics of beach, incipient sand dune and fore-reef sediments at Henderson Island (ϕ units).

	Coral	Coralline algae	Halimeda	Foraminifera	Molluscs	(Echinoids, Bryozoans, Crustaceans)
Henderson Island	42	2	6+	18	17	1
Indo-Pacific Atolls [a]						
Bikini lagoon	1	–	43	8	8	35
Eniwetok lagoon	12	–	28	30	3	26
Cocos lagoon, Guam	45	18	11	3	15	–
Midway	25	35	6	14	12	8
Suwarrow, N. Cooks: [b]						
deep lagoon	3	–	62	27	6	1
shallow lagoon	8	5	4	64	12	1
patch reef	12	7	9	30	29	4
Great Barrier Reef: [a, c]						
Reef flat	15-28	4-8	11-34	14-54	6-11	9-13
Reef	20-40	17-40	10-30	8-20	4-15	<5
Inter-reef	5-10	0-15	5-65	15-40	20-35	5-30

+ includes other algal constituents

Sources : a = Orme (1977); b = Tudhope et al. (1985); c = Flood and Scoffin (1978)

Table 2. General composition of reef sediments, Henderson Island and other localities, Indo-Pacific reef province.

Constituent	Environment		
	Fore-reef (%)	Beach (%)	Dune (%)
Coral	37.7	43.9	37.8
	(18.8)	(24.1)	(8.5)
Mollusc	17.5	17.2	15.1
	(5.6)	(1.1)	(2.1)
Coralline red algae	2.0	1.7	2.6
	(1.0	(0.8)	(1.7)
Homotrema rubrum	0.3	0.5	0.1
	(0.3)	(0.4)	(0.2)
Amphistegina lessonii	8.5	9.5	8.5
	(10.6	(1.8)	(9.1)
Asterigerina carinata	0.7	1.5	0.4
	(1.0)	(1.9)	(0.6)
Marginopora vertebralis	4.4	3.9	9.4
	(3.9)	(1.7)	(11.9)
Heterostegina depressa	0.1	0.1	0.1
	(0.2)	(0.2)	(0.2)
Other benthic foraminiferans	4.3	4.3	1.8
	(2.5)	(0.3)	(3.1)
Other algae (+ *Halimeda*)	8.9	4.4	9.2
	(10.2)	(2.7)	(0.0)
Echinoid	0.6	0.7	0.2
	(0.4)	(0.5)	(0.3)
Lithoclasts	1.1	0.9	0.4
	(1.7)	0.8)	0.6)
Others and unknowns	7.9	7.1	4.4
	(3.30	(2.3)	(6.2)

Table 3. Component composition of Henderson Island sediments by environment. (Mean percentage composition, with standard deviation in parentheses).

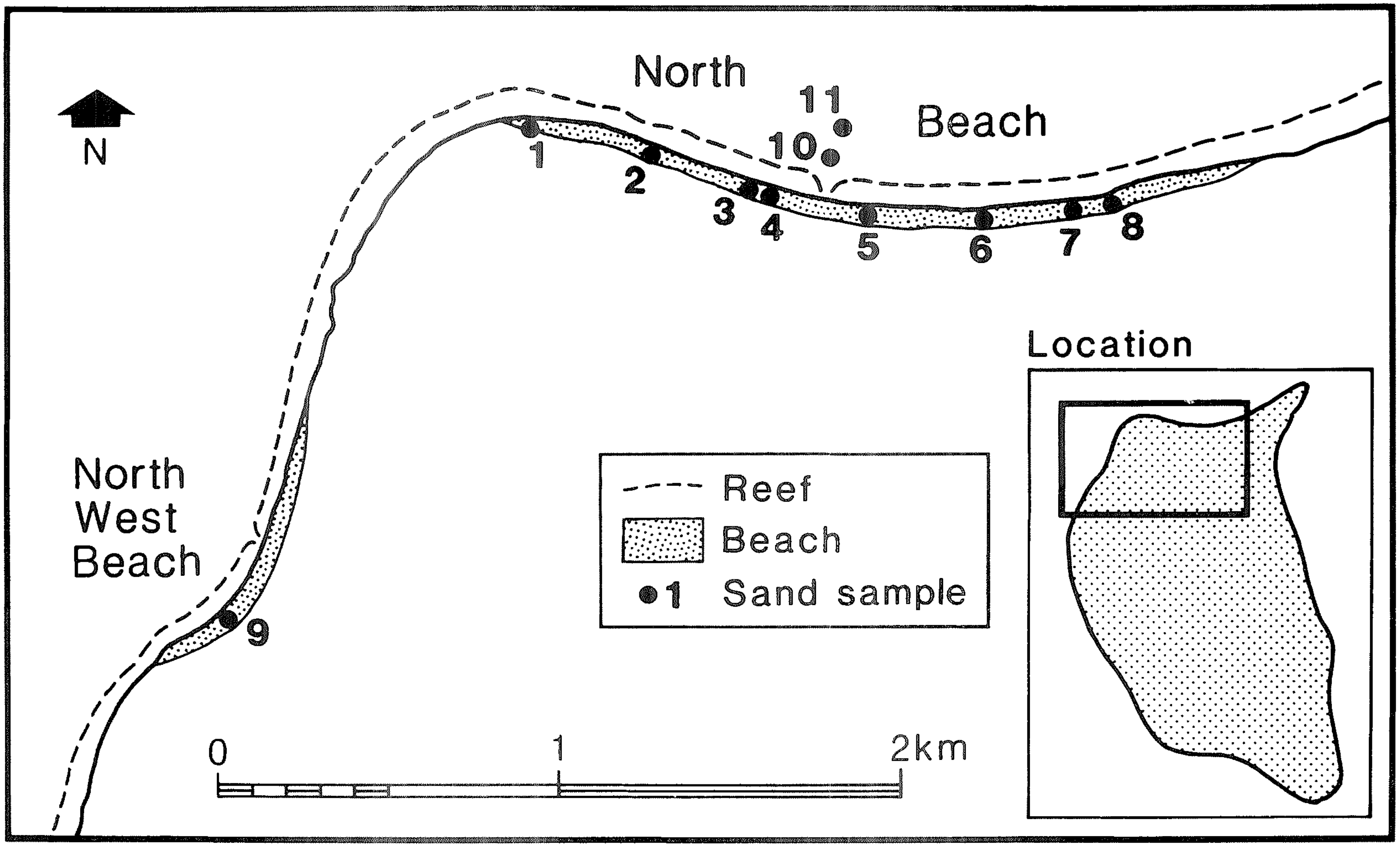

Figure 1. Location of sediment samples, Henderson Island

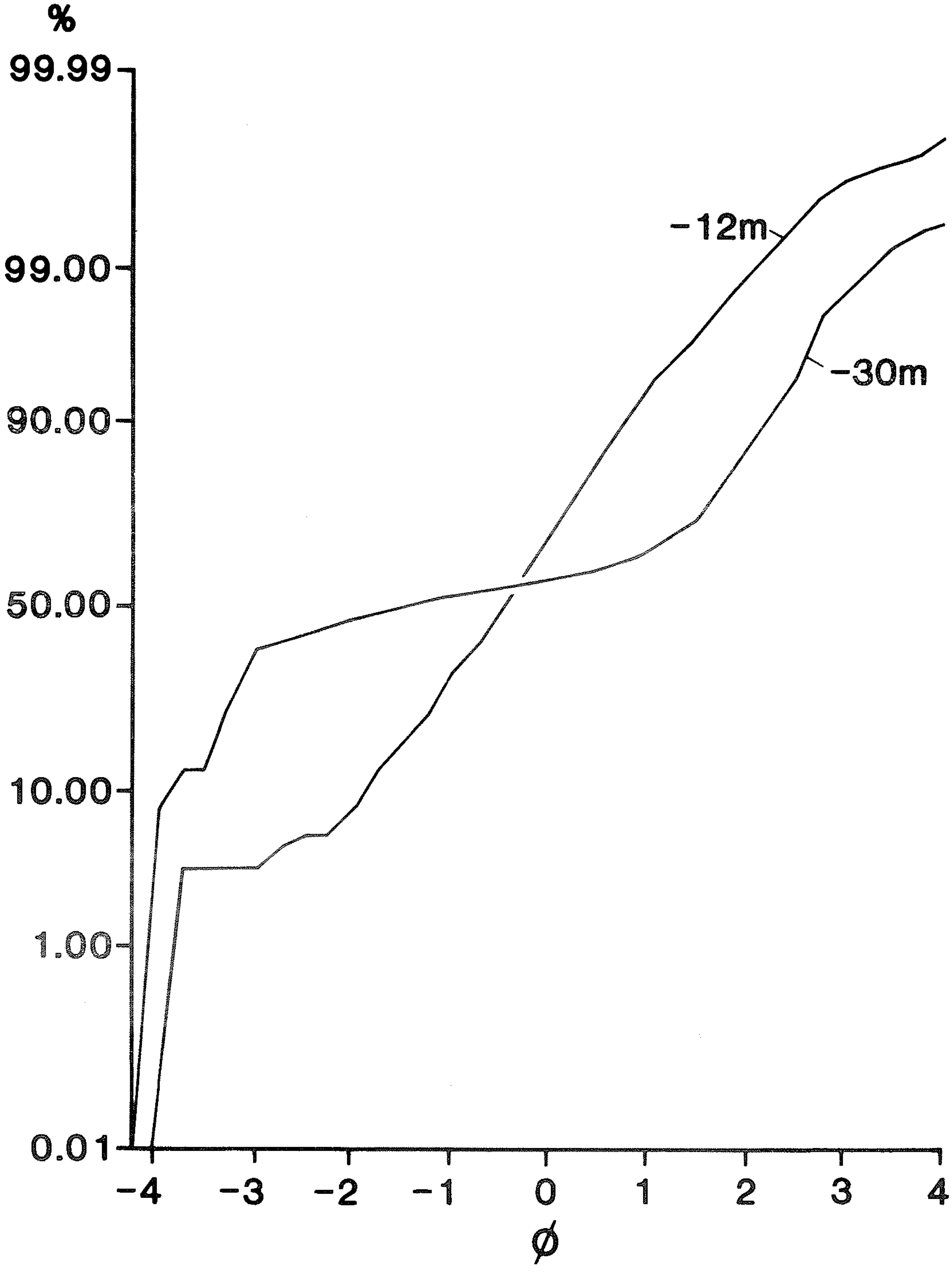

Figure 2. Cumulative frequency curves for fore-reef sediments, Henderson Island

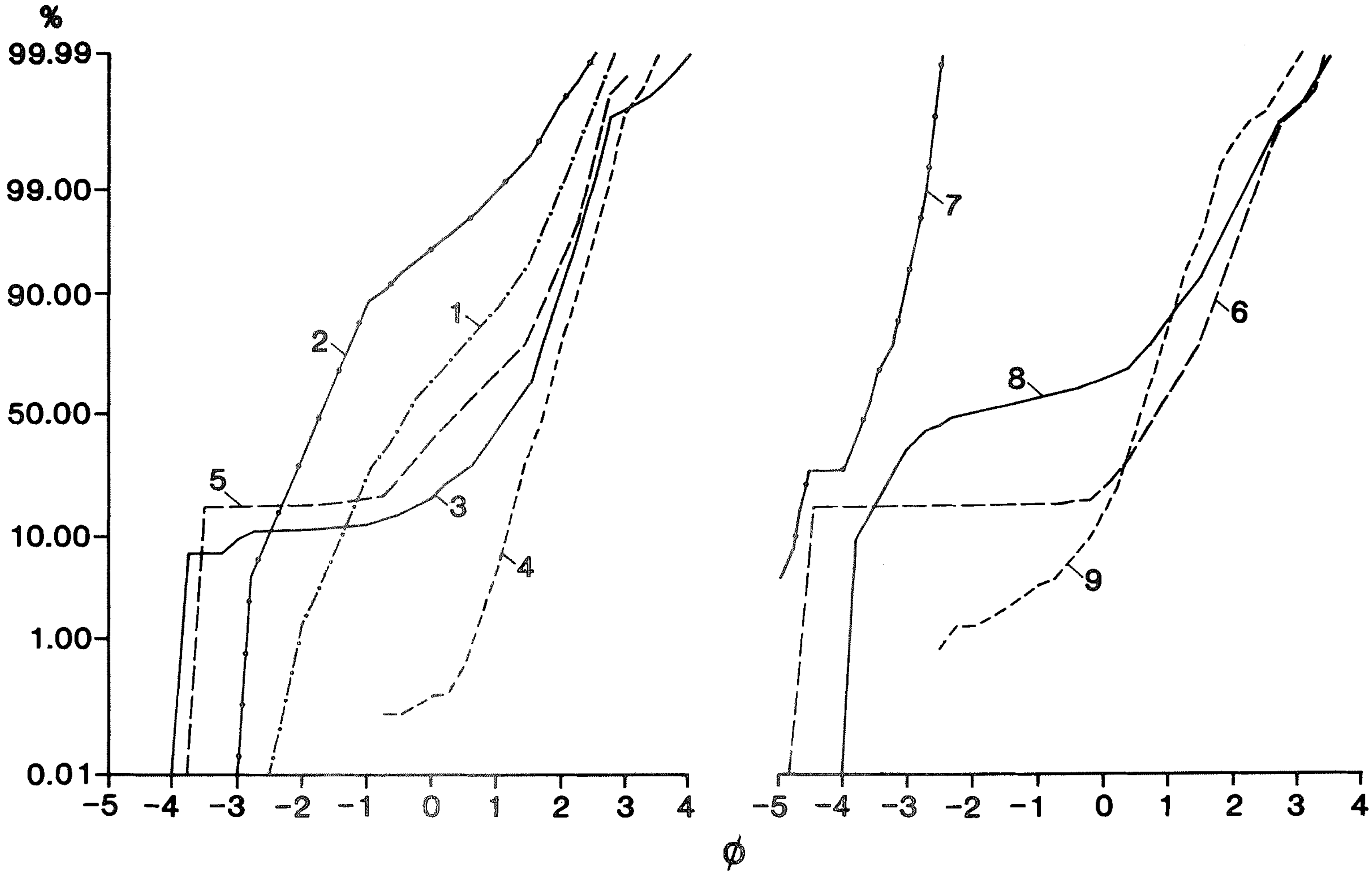

Figure 3. Cumulative size frequency curves for beach (1-3, 5-9) and incipient sand dune (4) sediments, Henderson Island

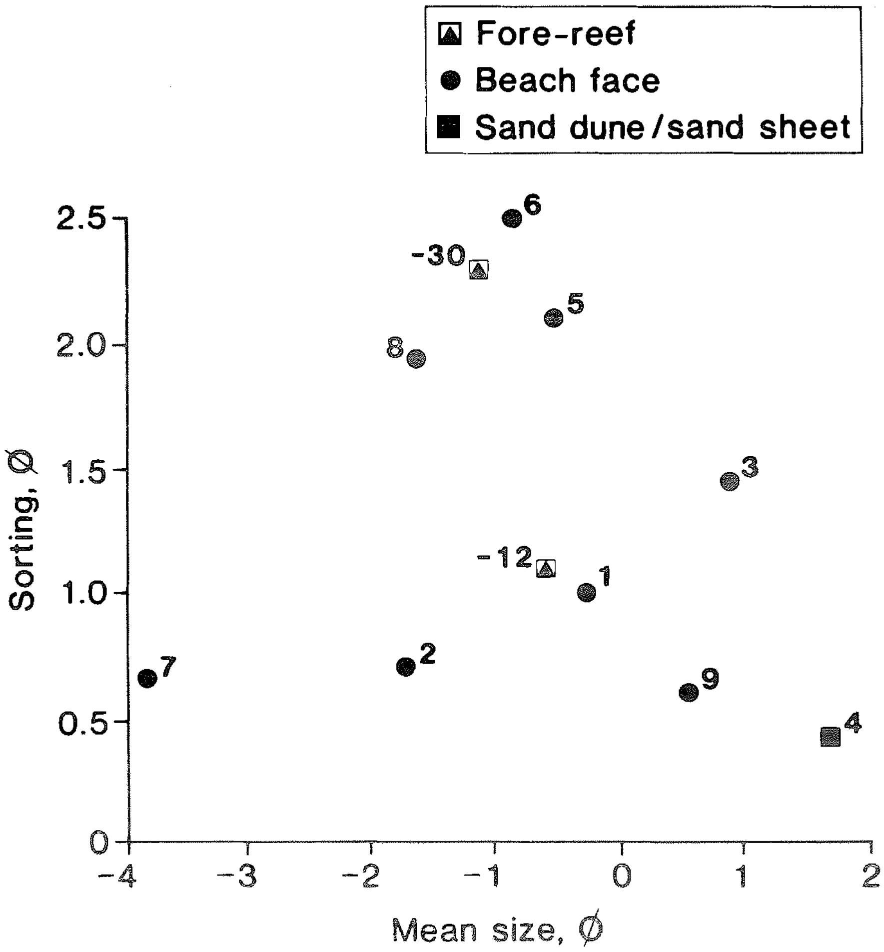

Figure 4. Mean size - sorting relationships, Henderson Island sediments.

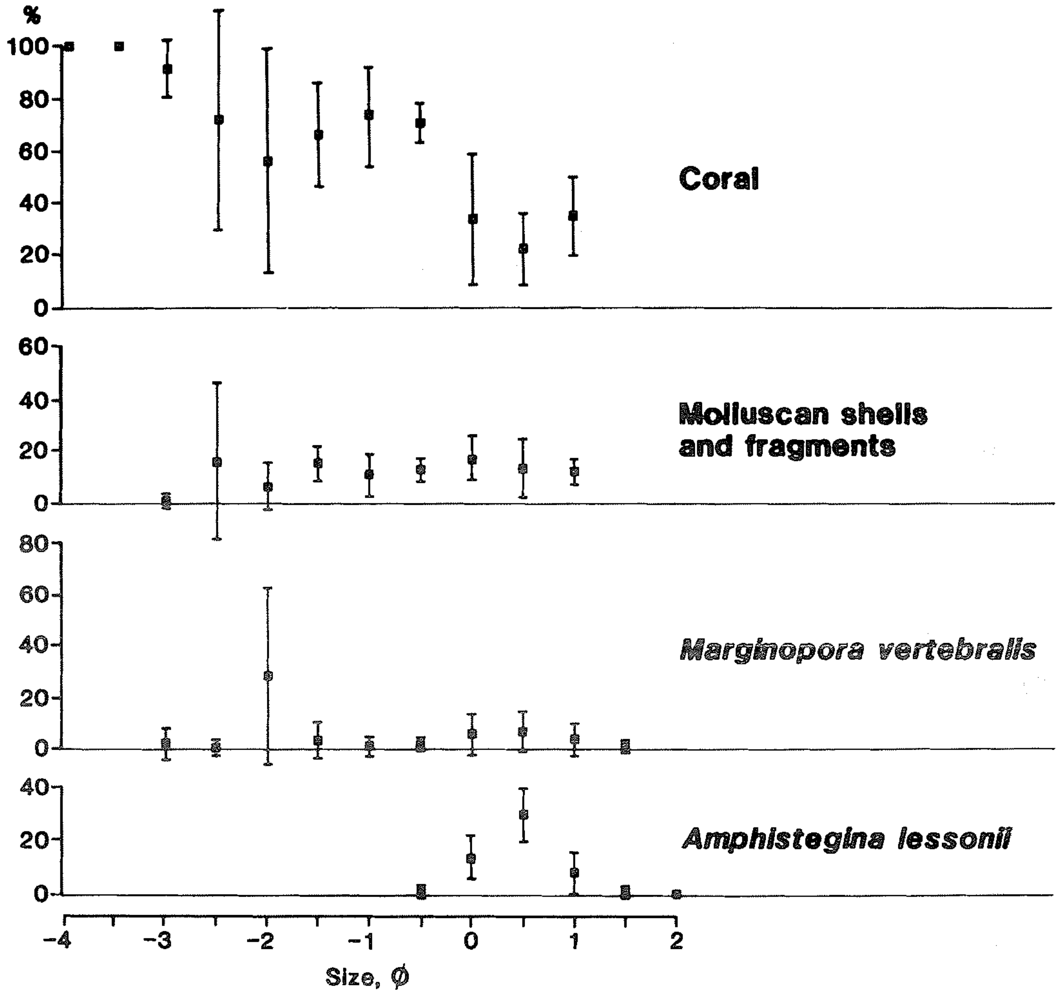

Figure 5. Percentage of selected sediment components by sediment size clases, Henderson Island sediments.

Plate 1. Fractured beach rock and coarse coral rubble beach, eastern end of central north beach, Henderson Island.

Plate 2. North beach and lagoon, looking east. Small reef passage at centre, North-east Point in distance, far left. Note extensive beachrock.

ATOLL RESEARCH BULLETIN

NO. 325

MORE BIRD BONES FROM POLYNESIAN ARCHEOLOGICAL SITES ON HENDERSON ISLAND, PITCAIRN GROUP, SOUTH PACIFIC

BY

SUSAN E. SCHUBEL AND DAVID W. STEADMAN

APPENDIX: ARTIFACTS FROM 1987 EXCAVATIONS ON HENDERSON ISLAND

BY

MELINDA S. ALLEN

ISSUED BY
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ABSTRACT

This study is based upon 2795 bird bones collected in 1987 from Polynesian archeological sites in limestone caves on Henderson Island. Two radiocarbon dates on charcoal from these sites are 400 ± 60 and 870 ± 70 yr B.P. 70% of the bird bones are of *Pterodroma alba* (Phoenix Petrel), which still nests on Henderson. A single bone of *Gallicolumba* sp. represents a new species for Henderson and the easternmost record for the genus. Other extirpated species of birds represented in the sites are *Pterodroma externa* (Juan Fernandez Petrel), a smaller unknown species of *Pterodroma*, and *Nesofregetta fuliginosa* (White-throated Storm-Petrel). These findings, combined with other extirpated species recorded in earlier archeological excavations, show that the resident avifauna of Henderson Island has lost two to five species of seabirds and three species of landbirds since the arrival of humans more than 800 years ago. We presume that hunting and habitat disturbance were primarily responsible for the loss of species on Henderson.

INTRODUCTION

In 1971, Y.H. Sinoto and A. Sinoto excavated several archeological sites on the north coast of Henderson Island, an island that had been regarded as uninhabited before the European exploration of the Pacific (Sinoto 1983). The bird bones from Sinoto's only stratified site, named HEN-1 (Figure 1), included the remains of three species that no longer occur on Henderson (the storm-petrel *Nesofregetta fuliginosa* and the pigeons *Ducula galeata* and *Ducula* cf. *aurorae*) and of two other species (the shearwater *Puffinus nativitatis* and the booby *Sula sula*) that visit Henderson but are not known to nest there (Steadman and Olson 1985). The sample of bird bones reported by Steadman and Olson was rather small (303 identifiable specimens). To increase the data base for the prehistoric avifauna of Henderson, as well as to learn more about the natural distribution of birds in Eastern Polynesia, SES excavated several bone-bearing deposits in limestone caves (different from HEN-1) on Henderson Island from 12 to 21 May 1987.

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MATERIAL AND METHODS

Our identifications are based upon comparisons of the fossils with modern skeletons from the National Museum of Natural History, Smithsonian Institution (USNM), the New York State Museum (NYSM), and the University of Washington Burke Museum (UWBM). The fossils from the 1987 Henderson excavations, summarized in Table 1, are catalogued in the Vertebrate Paleontology collections of USNM. Osteological nomenclature follows Baumel et al. (1979). Measurements were taken with digital calipers with 0.01 mm increments, rounded to the nearest 0.1 mm. yr B.P. = radiocarbon years before present. Unless stated otherwise, modern distributions of birds are based upon Pratt et al. (1987) for Polynesia, and Williams (1960), Bourne and David (1983), and Fosberg et al. (1983) for Henderson. Prehistoric distributions are based upon Steadman (1989).

SITE DESCRIPTIONS

Site 1, known as Lone Frigate Cave, is approximately 18 m above sea level and 350 m south of the northern edge of Henderson's Northwest Beach (Figures 1 and 2 herein; also see Figures 3 and 9 of Spencer and Paulay 1989). The entrance is 2.13 m high and the greatest interior height is approximately 3.5 m. The cave's passage extends inland for 17 m (Figure 2). The rocky terrain in front of the cave was covered with a thick growth of Pandanus, various shrubs, and tall ferns. Of the 2,795 avian fossils collected by SES on Henderson Island, 2,584 were from Lone Frigate Cave.

The floor of the main passage of Lone Frigate Cave was covered with powdery, gray calcareous sediment, with angular cobbles up to 10 cm in diameter. A layer of green mold covered most of the rocks and wall surfaces. The elevated floor in the North Chamber consisted mostly of solid limestone, with some loose calcareous sediment.

Fresh water dripped from the top of the entrance of Lone Frigate Cave for a number of days after a rain. This is one of the few sources of fresh water on Henderson, and may have been a factor in the habitation of the cave.

A 0.5 m by 0.5 m test pit just inside the entrance revealed the following stratigraphy.

Layer I (0-6 cm) is a fairly loose calcareous sediment made up of coarse sand with some brown soil, many angular to subangular pebbles and boulders, and a large number of bones. The surface, which is uneven and disturbed, appears to be a frequently and perhaps recently used site for cooking and eating.

Layer II (6-17 cm) is composed mainly of dark, moist soil mixed with medium sand and occasional angular fragments of white, chalky carbonates. This layer also has a large number of bones.

Layer III (17-30+ cm) is a gray sandy mix that yielded very few bones. In Pit 1, this layer is replaced by an indurated layer of white carbonates.

A 1 m by 1 m pit (Pit 1) was expanded from the test pit, following the stratigraphy described above. Bird bones were abundant in Layers I and II. Throughout the cave, additional collections of bones were made from the surface and by sorting carefully through piles of rubble. The rubble might have been derived from clearing the front living quarters of the cave.

The floor of the North Chamber of Lone Frigate Cave was littered with many small piles containing bones, bits of charcoal and crab claws. The bones and claws in these features were well preserved within a thin layer of calcium carbonate. Charcoal from three of these small surface piles was combined for a radiocarbon date of 870 ± 70 yr B.P., the oldest date yet determined for cultural remains on Henderson Island (see CHRONOLOGY). The piles may have resulted from the actions of crabs that scavenged food (especially cooked birds) from the fires at the cave entrance. A land crab was observed dragging the body of a hermit crab (Coenobita sp.) back into the depths of the cave as we worked there.

A second site (West End Cave) was worked at the far west end of the north beach (Figure 1). This cave is 17.3 m above sea level (Spencer and Paulay 1989, Figures 4 and 10) and has a large entrance approximately 2.7 m by 2.7 m. The main body of the cave is small (5 m by 3 m) with a maximum height of approximately 3.5 m. Three small chambers (2 m deep, 0.75 m wide) extend from the rear of the cave. 179 bird bones were collected from surface piles in Chambers 1-3 and from 0-10 cm deep in the main room. The floor of the main room is of brown soil with a disturbed surface.

A limited number of bird bones were collected from small caves and shelters behind the central coconut grove on the north beach (Figure 1). This area is heavily used by Pitcairners and other visitors, with campsites and woodpiles throughout the grove.

The few artifacts recovered during the 1987 excavations are described by M.S. Allen in Appendix 1.

CHRONOLOGY OF THE 1987 EXCAVATIONS

We obtained two radiocarbon dates on materials excavated in 1987. The dated charcoal samples were collected and stored in aluminum foil and were associated with numerous bird bones. The charcoal was pretreated by examination for rootlets, followed by acid, alkali, acid series of soakings to remove carbonates and humic acids. Benzene synthesis and counting proceeded normally. As reported, both dates are adjusted for C13/C12. The first date is 870 ± 70 yr B.P. (Beta-25244), based upon approximately 6 gm of wood charcoal from the floor surface of the North Chamber, Lone Frigate Cave. This charcoal was collected from three small accumulations of bones and crab claws (see SITE DESCRIPTIONS). The second date is 400 ± 60 yr B.P. (Beta-25245), based upon approximately 7 gm of wood charcoal from Test Pit 1, Lone Frigate Cave. This sample originally comprised 3 gm of charcoal from the 20-30 cm level, but was supplemented by 4 gm of charcoal from the 10-20 cm level when the original sample was determined to be too small.

Our dates of 870 ± 70 and 400 ± 60 yr B.P. correspond remarkably well with those obtained by Sinoto (1983, and in Fosberg et al. 1983) from the cave he excavated in 1971 on the north shore of Henderson. Sinoto's dates were 790 ± 110 yr B.P. (Isotopes-6344) from the base of cultural layer III, and 495 ± 105 yr B.P. (Isotopes-6343) from the upper part of cultural layer II. Considered together, the four radiocarbon dates suggest that Polynesians first arrived on Henderson between 900 and 800 yr B.P. After about 500 years of probably increasingly stressful occupation, Henderson was abandoned (or the people died out) between 400 and 350 yr B.P. No European accounts of Henderson, which begin with the landing of Quiros in 1606 A.D., mention the existence or any evidence of people living there. Quiros, in fact, stated specifically that Henderson was uninhabited (Fosberg et al. 1983:5). Had Polynesians been living on Henderson in 1606, they almost certainly would have made themselves known to Quiros.

SPECIES ACCOUNTS

Order PROCELLARIIFORMES

Family PROCELLARIIDAE

Pterodroma alba

Phoenix Petrel

MATERIAL: NISP = 1,961, MNI = 93; 41 crania, 43 rostra, 13 pterygoids, 1 jugal, 32 quadrates, 125 mandibles, 6 vertebrae, 38 synsacra, 71 sterna, 130 furculae, 206 coracoids, 143 scapulae, 199 humeri, 221 ulnae, 185 radii, 2 ulnare, 71 carpometacarpi, 34 manus digit II, phalanx 1, 60 pelves, 24 femora, 196 tibiotarsi, 120 tarsometatarsi. Among these bones are 820 (various elements) identified as Pterodroma cf. alba, and 46 others too fragmentary for precise identification, but clearly representing Pterodroma rather than Puffinus and indistinguishable from modern specimens of Pterodroma alba. Comparisons were made with the following specimens from the USNM: Pterodroma hasitata (598524), P. rostrata (576827), P. alba (498007, 498009, 498010), P. inexpectata (556261), P. solandri (500641), P. brevirostris (561316), P. ultima (497224), P. neglecta (497176), P. arminjoniana (500318, 500324, 500316), P. phaeopygia (556262), P. externa (498357, 498358), P. cookii (497150), P. hypoleuca (497943), P. nigripennis (495648), Bulweria bulwerii (498246), B. fallax (498366).

REMARKS: Pterodroma alba breeds in the Pitcairn Group (Ducie, Oeno, Henderson), Tuamotus, Marquesas, Kiribati, Tonga, and perhaps Kermadec Islands. It has been recorded at sea near Hawaii, the Society Islands, Samoa, and perhaps the Cook Islands. The bones of P. alba make up 70% of the total bird bones collected in 1987, and 54% of the total bird bones collected in 1971 (Table 2), indicating that these petrels were a major source of food for the prehistoric people of Henderson Island.

Pterodroma externa
Juan Fernandez Petrel

MATERIAL: NISP = 2, MNI = 1; 2 tibiotarsi (388630, 426539).

REMARKS: These two adult specimens are a right and left that may represent the same individual. We refer them to P. externa because of similarity in length (Table 3), stoutness of shaft, concavity of the proximal portion of shaft and depth of sulcus extensorius. The tibiotarsus of P. externa is larger than that in any of the species of Pterodroma known to occur on Henderson (Table 2).

This is the first record of P. externa from Henderson or anywhere in the Pitcairn Group. Pterodroma externa is known to breed only on Juan Fernandez Is., ca. 4600 km east of Henderson. It has been recorded at sea from the Hawaiian, Marshall, Gilbert, Phoenix, and Line Islands. Both specimens are from Lone Frigate Cave (USNM 388630, 8-10 m from entrance, depth 0-10 cm; USNM 426539, Pit 1, depth 0-6 cm). Because petrels do not come ashore except on breeding islands, we conclude that P. externa once nested on Henderson Island. Bones of this species should be sought elsewhere in the Pitcairn Group, on Easter Island, and perhaps in the Gambier or Austral Islands as well.

Pterodroma sp.
Undetermined petrel

MATERIAL: NISP = 4, MNI = 3; 3 carpometacarpi (388627, 426377, 426378), 1 ulna (428361).

REMARKS: These bones, all from Lone Frigate Cave, represent an unknown species of Pterodroma larger than P. nigripennis, P. hypoleuca, or P. cooki, but smaller than any other living species, including all those recorded on Henderson (P. ultima, P. neglecta, P. alba, P. arminjoniana, P. externa). Although these four fossils seem to represent a uniquely sized species of Pterodroma, we hesitate to use them as a basis for documenting an extirpated or extinct species for Henderson, given the uncertainties in species-level systematics and osteology of Pterodroma.

Puffinus nativitatis
Christmas Shearwater

MATERIAL: NISP = 1; 1 tibiotarsus (427192)

REMARKS: The breeding status of Puffinus nativitatus on Henderson is uncertain, although nesting is likely. This shearwater breeds through much of Polynesia (Hawaii, Kiribati, Marquesas, Tuamotus, Australs, and Pitcairn Group), including Pitcairn, Ducie, and perhaps Henderson.

Procellariidae sp.
Undetermined petrels/shearwaters

MATERIAL: NISP = 457; 11 skulls, 1 sclerotic ring, 2 mandibles, 3 atlases, 77 vertebrae, 2 synsacra, 3 sterna, 6 furculae, 2 coracoids, 18 scapulae, 3 humeri, 19 ulnae, 7 radii, 7 ulnare, 4 carpometacarpi, 3 manus digit II, phalanx 1, 65 other manus phalanges, 2 femora, 4 tibiotarsi, 3 tarsometatarsi, 215 pedal phalanges.

REMARKS: Although most of these fragmentary procellariid bones are undoubtedly of Pterodroma alba, they are too incomplete to identify beyond the family level.

Family HYDROBATIDAE

Nesofregetta fuliginosa
White-throated Storm-petrel

MATERIAL: NISP = 1, MNI = 1; 1 tarsometatarsus (426290).

REMARKS: This specimen is slightly longer than comparative specimens at USNM, but is indistinguishable qualitatively. Nesofregetta fuliginosa is the only storm-petrel that breeds widely in Oceania, with breeding records from Vanuatu, Fiji, Kiribati, Tubuai, Marquesas, Gambiers, and Samoa. It visits the Society, Tuamotu, and Marshall islands. Previous archeological records are from Mangaia, Cook Islands (Steadman 1985) and Henderson (Steadman and Olson 1985).

Order PELECANIFORMES

Family PHAETHONTIDAE

Phaethon rubricauda

Red-tailed Tropicbird

MATERIAL: NISP = 104, MNI = 6; 1 skull (427002), 1 rostrum (338560), 2 jugals (388589, 426714), 8 pterygoids (388800, 426282, 426528, 426529, 427035, 427047, 428168, 436260), 9 quadrates (388590, 388752, 388867, 426517, 426748, 426749, 426968, 428942, 428943), 12 mandibles (388839, 417154, 426337, 426538, 426712, 426713, 428169, 428874, 428985, 428989, 428990, 429006), 2 atlases (428145, 428987), 20 vertebrae (388782, 388783, 388798, 388840, 417107, 417115, 417156, 417157, 426523, 426524, 426811, 426812, 426813, 426940, 428100, 428988, 428991, 428992, 428993, 428994), 1 synsacrum (388652), 3 sterna (427001, 427006, 427007), 3 ribs (426543, 427046, 428887), 8 furculae (388655, 388767, 388832, 426332, 426924, 427226, 428984, 428996), 4 coracoids (427130, 428875, 428995, 429002), 3 scapulae (388842, 426339, 429003), 6 humeri (388670, 426892, 427136, 428672, 428872, 428998), 2 ulnae (428873, 429007), 7 radii (388653, 426338, 428876, 428986, 429001, 429004, 429005), 3 carpometacarpi (388669, 388841, 426321), 2 manus phalanges (428999, 429000), 1 femur (428719), 5 tibiotarsi (338559, 388654, 426275, 428944, 428997), and 1 tarsometatarsus (417071). Within the total number of specimens are 13 bones that, because of their fragmentary nature, are identified as Phaethon cf. rubricauda, and 3 bones as Phaethon sp. None of these is distinguishable from P. rubricauda.

REMARKS: Phaethon rubricauda is common through much of the tropical Pacific and on all islands in the Pitcairn Group. Previous archeological records include Mangaia, Cook Islands (Steadman 1985) and Henderson (Steadman and Olson 1985).

Family FREGATIDAE

Fregata minor

Great Frigatebird

MATERIAL: NISP = 2, MNI = 2; 1 jugal (426519), 1 quadrate (426547).

REMARKS: Fregata minor is widespread in the tropical Pacific, including all four islands in the Pitcairn Group.

Order CHARADRIIFORMES

Family LARIDAE

Anous stolidus

Brown Noddy

MATERIAL: NISP = 12, MNI = 4; 1 rostrum (428703), 5 coracoids (426236, 426237, 426336, 428696, 428853), 1 scapula (426654), 1 humerus (428706), 2 ulnae (426918, 427222), 2 tibiotarsi (388859, 426952).

REMARKS: This species breeds nearly throughout the tropical Pacific, including all islands in the Pitcairn Group. Anous stolidus occurs commonly in archeological sites from many islands in Polynesia.

Gygis alba

Common Fairy-Tern

MATERIAL: NISP = 151, MNI = 16; 4 crania, 2 rostra, 1 pterygoid, 10 quadrates, 9 mandibles, 6 synsacra, 9 sternae, 14 furculae, 28 coracoids, 22 scapulae, 8 humeri, 9 ulnae, 5 radii, 7 carpometacarpi, 6 manus phalanges, 8 tibiotarsi, and 3 tarsometatarsi. Included are 7 bones identified as cf. Gygis alba.

REMARKS: This distinctive bird is found nearly throughout the tropical Pacific, including all islands in the Pitcairn Group. The bones of Gygis alba from Henderson are slightly larger overall than modern specimens from the Cook Islands. Bones of G. alba are common in archeological sites from almost all regions of Polynesia.

Family SCOLOPACIDAE

Heteroscelus incanus

Wandering Tattler

MATERIAL: NISP = 1, MNI = 1; 1 ulna (428635).

REMARKS: Heteroscelus incanus breeds in Alaska and northwest Canada and migrates to the tropical Pacific, including most of Polynesia. It has been recorded on Ducie, Oeno and Henderson in the Pitcairn Group. Tattlers are most commonly found along shorelines, especially where fringing reefs are present.

Numenius tahitiensis
Bristle-thighed Curlew

MATERIAL: NISP = 2, MNI = 1; 1 scapula (426516), 1 synsacrum (388797).

REMARKS: Numenius tahitiensis ranges widely in the Pacific as it migrates from breeding grounds in Alaska to spend the fall, winter, and spring on tropical Pacific islands, especially those of eastern and central Polynesia. This curlew has been recorded on all islands in the Pitcairn Group. It prefers open habitat such as shallow reefs, beaches, fields, and airport runways.

Order GRUIFORMES
Family RALLIDAE
Porzana atra
Henderson Island Rail

MATERIAL: NISP = 6, MNI = 2; 1 coracoid (428717), 3 tibiotarsi (428276, 428832, 428857), 2 tarsometatarsi (426530, 436396).

REMARKS: This flightless rail is found only on Henderson Island. The only other rail known from the Pitcairn Group is the widespread and volant Porzana tabuensis (Spotless Crake), which has been recorded on Oeno and Ducie. Porzana atra inhabits the forest floor where it rustles through the leaves searching for food and making a "peet" call resembling that of an American Woodcock (Scolopax minor). Rails were fairly common on Henderson in 1987.

Order COLUMBIFORMES
Family COLUMBIDAE
Gallicolumba sp.
Unknown Ground-dove

MATERIAL: NISP = 1, MNI = 1; 1 tarsometatarsus (proximal end) (388744).

REMARKS: This fragmentary specimen represents a species of Gallicolumba rather than Ducula or Ptilinopus because of these characters: tuberositas musculo tibialis cranialis abuts medial foramen vascularium proximalium (located more distad in Ducula and Ptilinopus); medial foramen vascularium proximalium smaller; in medial aspect, proximal margin of shaft thinner; in plantar aspect, medial margin of shaft more smoothly recurved; sulcus flexorius longer, sharper.

USNM 388744 is larger than the tarsometatarsus of Gallicolumba erythroptera, which occurs in the Tuamotu Group today and has been extirpated in the Cook and Society Islands. The Henderson specimen is much larger than in G. rubescens of the Marquesas, but smaller than in the extinct Gallicolumba new species 2 of the Marquesas, Society, and Cook Islands (Steadman 1989). USNM 388744 resembles the tarsometatarsus of G. erythroptera and G. rubescens more than that of G. new species 2 in the smoothly curved, shallow proximo-medial margin of the shaft, the presence of a lateral foramen vascularium proximalium, and the shallower fossa infracotylaris dorsalis (Steadman in press).

This is the southeasternmost record for any species of Gallicolumba. The nearest congener is G. erythroptera, which occurs on certain islands in the southeast portion of the Tuamotu Group, about 1000 km west-northwest of Henderson.

Ptilinopus insularis
Henderson Island Fruit Dove

MATERIAL: NISP = 54, MNI = 11; 2 rostra (417136, 428679), 1 mandible (426533), 2 synsacra (426335, 428756), 5 sterna (426595, 427008, 427009, 428166, 428760), 17 coracoids (417155, 426407, 426408, 426527, 426535, 426727, 426728, 426850, 426932, 426933, 427227, 428156, 428652, 428680, 428763, 428767, 428855), 5 scapulae (426525, 426526, 426930, 428681, 428762), 3 humeri (417106, 426289, 428945), 4 ulnae (426596, 426597, 428678, 428764), 3 radii (388799, 426962, 428806), 1 pelvis (428650), 2 femora (388681, 428615), 7 tibiotarsi (426961, 428472, 428757, 428758, 428759, 428765, 428766), 1 tarsometatarsus (426849), and 1 pedal phalanx (428761).

REMARKS: This species is regarded as endemic to Henderson because it has never been recorded elsewhere. In light of the numerous range extensions of other Polynesian columbids based upon archeological specimens (Steadman 1989), we would not be surprised if P. insularis once occurred on islands other than Henderson, especially Pitcairn Island. Fruit-doves were fairly common on Henderson in 1987.

Order PSITTACIFORMES
Family PSITTACIDAE
Vini stepheni
Henderson Island Lorikeet

MATERIAL: NISP = 2, MNI = 1; 1 scapula (417131), 1 tibiotarsus (426966).

REMARKS: This small parrot is found only on Henderson Island. As with Ptilinopus insularis, whether it is truly endemic to Henderson can be tested through the collection and analysis of archeological avifaunas from adjacent islands. Lorikeets were fairly common on Henderson in 1987.

Order PASSERIFORMES
Family SYLVIIDAE
Acrocephalus vaughani taiti
Henderson Island Reed-Warbler

MATERIAL: NISP = 1, MNI = 1; 1 rostrum (428718).

REMARKS: This subspecies of the Pitcairn Island Reed-Warbler is endemic to Henderson, where it was common in 1987. No warblers are found on Ducie or Oeno.

Aves sp.
Indeterminate birds

MATERIAL: NISP = 33. These fragmentary bones are undiagnostic at any level.

DISCUSSION

The 1987 excavations on Henderson Island demonstrate that a very large sample of bird bones might be needed if the goal is to represent the prehistoric avifauna as completely as possible. The sample analyzed by Steadman and Olson (1985) included 303 identifiable bird bones representing 12 species. Our sample of nearly 2800 bones represents 16 species, seven of which were not in the smaller sample (Tables 1, 2). Likewise, the sample of 303 bones included three species not present in the larger sample.

Sampling artifacts are especially significant in recording rare species, whether seabirds or landbirds. Each of the seven species recorded in the larger but not in the smaller sample is represented by only one to four bones. The three species that occurred in the smaller but not the larger sample are represented by three to nine bones each. This relatively larger representation is related to the heavier exploitation of landbirds (6.9% versus 2.3% of all bones; Table 1) by the people responsible for the smaller sample. In spite of the great numbers of Pterodroma alba bones in both samples, this petrel still survives on Henderson. Conversely, the seemingly low numbers of bones of most landbirds reflect the loss of three species of pigeons on Henderson. Landbirds, being less transient, tend to be more vulnerable to local overexploitation. The interior of Henderson is characterized by jagged, crevassed limestone (see Kirch 1988). Despite the harsh terrain Polynesians undoubtedly ranged over the entire island seeking food and water. The lack of tillable soil on Henderson would have prevented the development of agriculture, while the steep, narrow reef and scarcity of reef passages would have made fishing a dangerous, undependable activity. All of this points to a heavy dependence upon birds for food.

Whether the depletion of birds was a primary factor in the eventual abandonment or collapse of Henderson culture, we cannot be sure. We are certain, however, that the Polynesians were involved in the loss of certain populations of seabirds and landbirds on their island. At a minimum, the Polynesian hunters reduced some bird populations to a point where the birds became more difficult to obtain. The absence of basalt for adzes and pearlshell for fishhooks (Sinoto 1983) as well as the depletion of indigenous birds contributed to the harsh existence led by the prehistoric inhabitants of Henderson Island.

ACKNOWLEDGMENTS

This research was supported by National Science Foundation Grant BSR-8607535 and the Smithsonian Institution, including private funds generously provided by S. Dillon Ripley. We thank the government and people of Pitcairn Island for permission, cooperation, and friendship. Logistical support and assistance given by the Captain and crew of R/V RAMBLER are gratefully acknowledged. We appreciate comments on the manuscript by N.G. Miller, S.L. Olson and W.N. Mathis. For access to modern specimens, we thank the staff of USNM and UWBM. Figures 1 and 2 are by D.S. Pahlavan. Figures 3-4 (Appendix) are by Virginia C. Steadman. This is contribution number 605 of the New York State Museum and Science Service.

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Table 1. Archeological avifaunas from Henderson Island. Data of Steadman and Olson (1985) are based upon bones collected by Y.H. and A. Sinoto in 1971. M = migrant. NISP = number of identified specimens. % = % of NISP in entire sample of bird bones.

	Steadman & Olson (1985)		Schubel & Steadman (herein)	
	NISP	%	NISP	%
Pterodroma alba Phoenix Petrel	165	54.4	1961	70.1
Pterodroma externa Juan Fernandez Petrel	-	-	2	0.07
Pterodroma sp. (small) Unknown petrel	-	-	4	0.14
Puffinus nativitatis Christmas Shearwater	8	2.6	1	0.07
Procellariidae sp. Unknown petrel/shearwater	-	-	457	16.4
Nesofregetta fuliginosa White-throated Storm-Petrel	3	1.0	1	0.04
Phaethon rubricauda Red-tailed Tropicbird	20	6.6	104	3.7
Sula sula Red-footed Booby	3	1.0	-	-
Fregata minor Great Frigatebird	9	3.0	2	0.07
Anous stolidus Brown Noddy	4	1.3	12	0.4
Gygis alba Common Fairy-Tern	70	23.1	151	5.4
Heteroscelus incanus (M) Wandering Tattler	-	-	1	0.04
Numenius tahitiensis (M) Bristle-thighed Curlew	-	-	2	0.07
Porzana atra Henderson Island Crake	8	2.6	6	0.2
Gallicolumba sp. Ground-Dove	-	-	1	0.07
Ptilinopus insularis Henderson Island Fruit-Dove	1	0.3	54	1.9
Ducula cf. *aurorae* Polynesian Pigeon	9	3.0	-	-
Ducula cf. *galeata* "Nuku Hiva" Pigeon	3	1.0	-	-
Vini stepheni Henderson Island Lorikeet	-	-	2	0.07
Acrocephalus vaughani taiti Henderson Island Warbler	-	-	1	0.04
Aves sp. Unknown bird	-	-	33	1.2
Totals	303	100.0	2795	100.0
% landbirds		6.9	2.3	

Table 2. Modern and prehistoric birds of Henderson Island. Modern records are derived from Williams (1960), Bourne and David (1983), and Fosberg et al. (1983). ? = recorded from Henderson, but breeding status uncertain. M = migrant (not included in landbird totals). COMBINED TOTALS = modern + prehistoric.

		PREHISTORIC RECORDS	
	MODERN RECORD	Steadman & Olson (1985)	Schubel & Steadman (herein)
SEABIRDS			
Pterodroma ultima Murphy's Petrel	X	-	-
Pterodroma neglecta Kermadec Petrel	X	-	-
Pterodroma alba Phoenix Petrel	X	X	X
Pterodroma arminjoniana Herald Petrel	X	-	-
Pterodroma externa Juan Fernandez Petrel	-	-	X
Pterodroma sp. (small) Unknown petrel	-	-	X
Puffinus nativitatis Christmas Shearwater	?	X	X
Puffinus pacificus Wedge-tailed Shearwater	X	-	-
Nesofregetta fuliginosa White-throated Storm-Petrel	-	X	X
Phaethon rubricauda Red-tailed Tropicbird	X	X	X
Sula dactylatra Masked Booby	X	-	-
Sula sula Red-footed Booby	?	X	-
Sula leucogaster Brown Booby	?	-	-
Fregata minor Great Frigatebird	X	X	X
Anous stolidus Brown Noddy	X	X	X
Anous minutus Black Noddy	?	-	-
Procelsterna cerulea Blue-gray Noddy	X	-	-
Gygis alba Common Fairy-Tern	X	X	X
LANDBIRDS			
Heteroscelus incanus Wandering Tattler	M	-	M
Numenius tahitiensis Bristle-thighed Curlew	M	-	M
Calidris alba Sanderling	M	-	-
Egretta sacra Reef Heron	?	-	-

Table 2 (continued)

	MODERN RECORD	PREHISTORIC RECORDS Steadman & Olson (1985)	Schubel & Steadman (herein)
Porzana atra Henderson Island Crake	X	X	X
Gallicolumba sp. Ground-Dove	-	-	X
Ptilinopus insularis Henderson Island Fruit-Dove	X	X	X
Ducula cf. *aurorae* Polynesian Pigeon	-	X	-
Ducula cf. *galeata* "Nuku Hiva" Pigeon	-	X	-
Vini stepheni Henderson Island Lorikeet	X	-	X
Acrocephalus vaughani taiti Henderson Island Warbler	X	-	X
TOTALS			
Seabirds	10-15	8	9
Landbirds	4-5	4	5
All birds	14-23	12	16
COMBINED TOTALS			
Seabirds	16-18		
Landbirds	7-8		
All birds	23-29		

Table 3. Measurements (in mm) of the tibiotarsus of Pterodroma, with range and sample size. F = female. M = male. U = sex unknown.

	Length without crista cnemiali	Length from crista fibularis to distal end
P. externa Lone Frigate Cave, Henderson Island (2U)	62.6, 62.6	42.3, 42.4
P. externa Modern specimens taken at sea, Central Pacific (3F)	59.8-62.8 3	42.2-44.1 3
P. externa Modern specimens taken at sea, Central Pacific (3M)	62.9-66.7 3	42.2-46.8 3
P. alba Lone Frigate Cave, Henderson Island (11U)	53.8 52.1-55.5 11	38.8 37.3-40.0 11

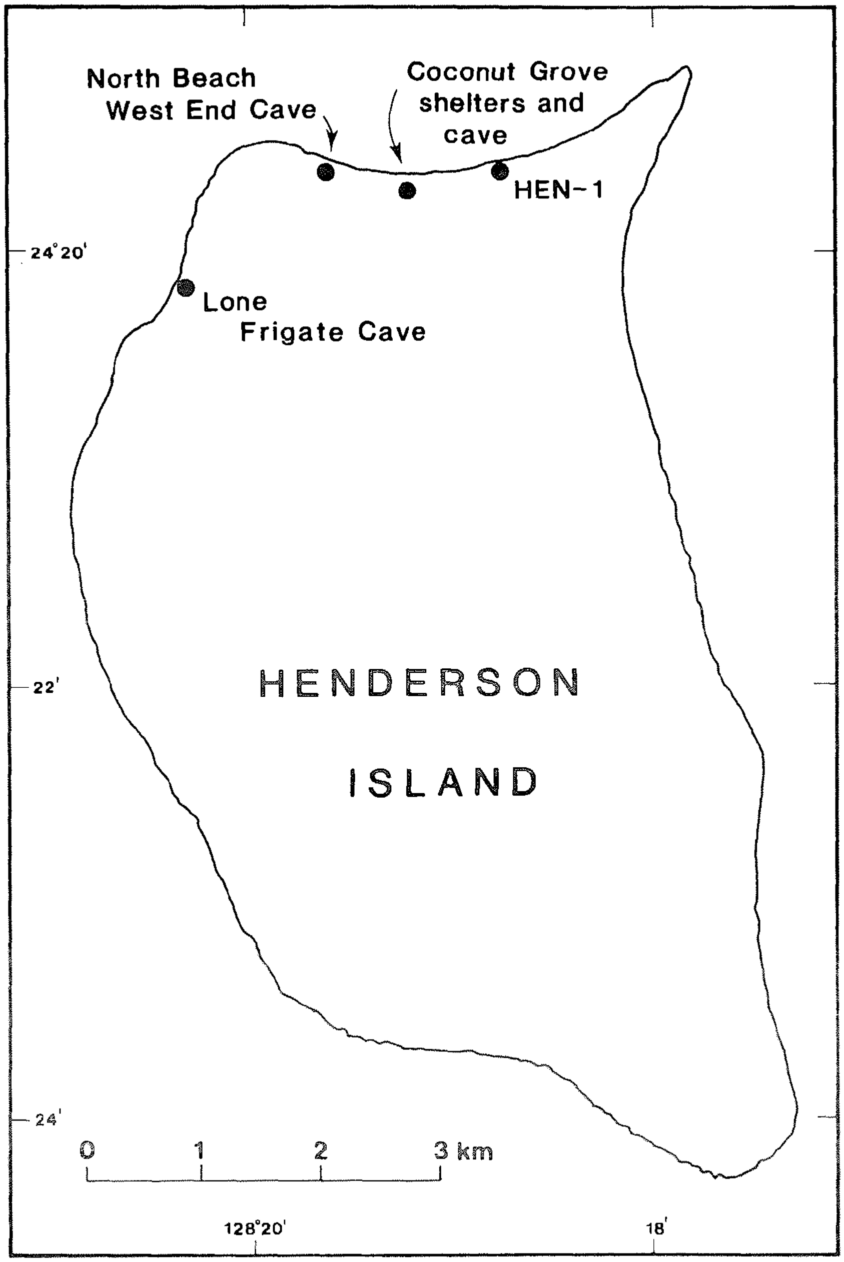

Figure 1. Henderson Island, showing localities where bird bones have been found.

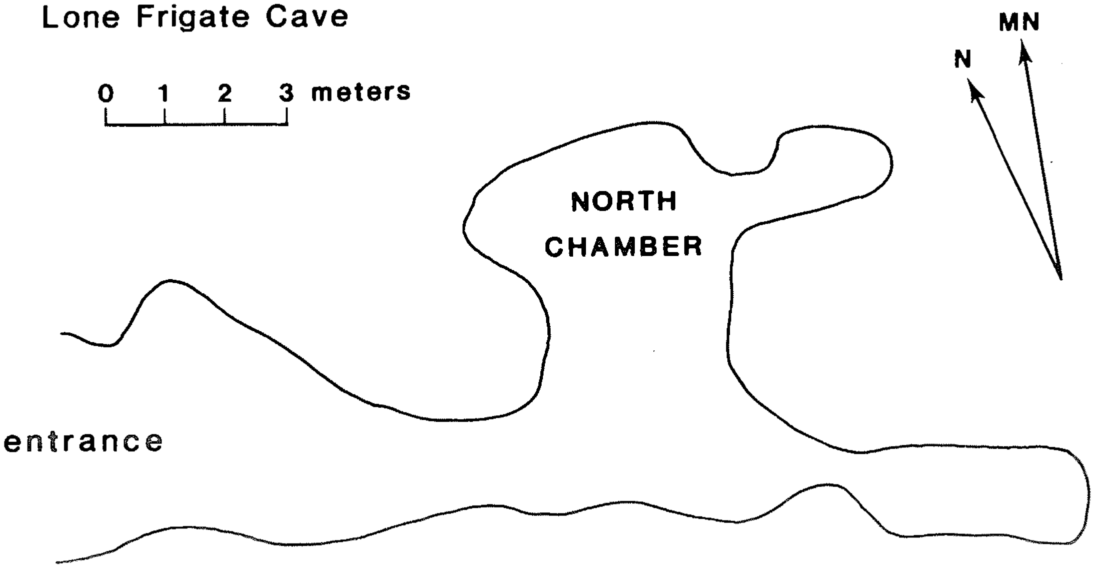

Figure 2. Plan view of Lone Frigate Cave, Henderson Island.

APPENDIX
ARTIFACTS FROM 1987 EXCAVATIONS ON HENDERSON ISLAND

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Eight potential artifacts were recovered during the May 1987 excavations at Lone Frigate Cave and West End Cave, Henderson Island. They are described below, with accompanying illustrations by Virginia Carter Steadman. The specimens will be deposited in the collections of the Department of Anthropology, National Museum of Natural History, Smithsonian Institution.

Some of the coral objects, although not culturally modified, must have been transported to the cave by humans. This is suggested both by the distance of the caves from the coast, 45 m in the case of Lone Frigate Cave and 60 m for West End Cave, and their elevation above sea level, 18 m for Lone Frigate Cave and 17.3 m for West End Cave. In addition, the sediments in both caves are predominantly terrigenous. In Lone Frigate Cave, modern human activity was indicated by matches and a few pieces of plastic. Surficial hearths in both caves also appear to be recent.

None of the Henderson artifacts recovered in 1987 is temporally diagnostic or shows affinity with any other particular East Polynesian island group. The several hundred artifacts recovered in 1971 by Sinoto (1983:59-61) on the northern coast of the island suggested a close affiliation with the Marquesas. His excavation also revealed a sequence of gradual change from predominantly exotic raw materials (i.e., pearlshell for fishhooks and basalts for adzes) to principally locally available ones, such as hammer oysters and Tridacna. The significantly greater number of bird bones and much lower concentration of artifacts in Lone Frigate and West End Caves suggest that both localities were used primarily for food processing and consumption. This contrasts with Sinoto's findings on the north shore where tool production was also an important activity.

Specimen 1 (Figure 3A, B): Unfinished fishhook. Lone Frigate Cave, surface association, 7-8 m from entrance (north side).

This unfinished fishhook is 48 mm long by 42 mm wide. It is flat and thin in cross-section with a maximum thickness of 3 mm. The bend is U-shaped and 18 mm wide. Although unfinished, it probably was going to be a jabbing form of hook. The raw material is Pinctada, as indicated by the pearly surface and the exterior shell coloration. It appears to be from one of the smaller species of pearlshell, such as Pinctada maculata, although an immature specimen of Pinctada margaritifera is also possible. The area of muscle attachment has been cut away and the edge abraded, while the exterior edge is cut, but not further finished.

Specimen 2 (Figure 3C, D): Modified limpet shell (cf. Cellana). Lone Frigate Cave, 8-10 m from entrance, rubble pile (0-10 cm).

The top of the shell has been cut away, leaving a ring 9 to 11 mm in width. One end of the ring has also been broken off. The cut edges have not been abraded or smoothed, nor have the exterior edges been modified. The intended function of the object is unclear.

Specimen 3 (Figure 3E, F): Fragment of Tridacna shell. Lone Frigate Cave, Test Pit at entrance, (0-10 cm).

This fragment, from the distal end of a Tridacna valve, is 33 mm long, 24 mm wide, and 8 mm deep. It is not possible to tell if the specimen was fractured from the rest of the valve by a cultural or natural agent. The specimen could be debitage from the production of Tridacna shell adzes such as those reported from Henderson by Sinoto (1983).

Specimen 4 (Figure 4A-C): Porites coral cobble. Lone Frigate Cave, 8-10m from entrance, North side, in rubble, (0-10 cm).

This specimen measures 60 by 46 by 24 mm. One end is broken off and it is cracked and discolored by fire. No wear facets were identified. Given its provenience Schubel thought that this specimen may have been a recent introduction to the cave.

Specimen 5 (Figure 4D, E): Porites coral cobble. Lone Frigate Cave, Test Pit at entrance, (0-10 cm).

This specimen measures 65 by 21 by 15 mm and is water-rounded. No wear facets were identified. The "stem" at one end may be the result of cultural modification, although there are no definite areas of grinding or abrasion. The specimen is of the same general shape as the coral abraders reported from Henderson by Sinoto (1983:60).

Specimen 6 (Figure 4F): Porites coral cobble. Lone Frigate Cave, Test Pit at entrance, (0-10 cm).

There are no definite wear facets on this specimen to suggest that it was used as an abrader. One end is battered, however, indicating that it may have been used in some other fashion. It measures 66 by 20 by 15 mm.

Specimen 7 (Figure 4G, H): Porites coral abrader (?). West End Cave, East wall, (0-10 cm), hearth area.

One side of this specimen is fractured and rough. The other side is smooth, suggesting its possible use as an abrader. There are, however, no definite wear facets. It measures 83 by 26 by 18 mm.

Specimen 8 (Figure 4I, J): Porites coral cobble. West End Cave, East wall, (0-10 cm), hearth area.

One end of this water-rounded cobble is broken off. There are no wear facets, although the intact end is battered as in Specimen 6. Possibly it was used as a hammerstone. It measures 55 by 35 by 22 mm.

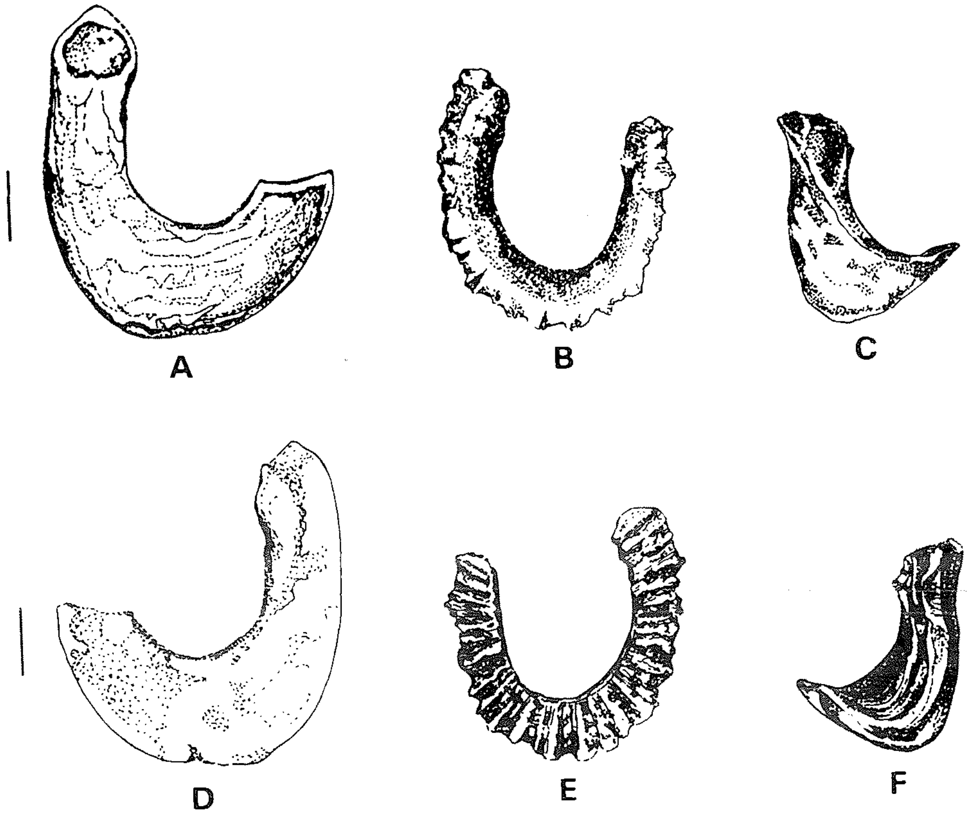
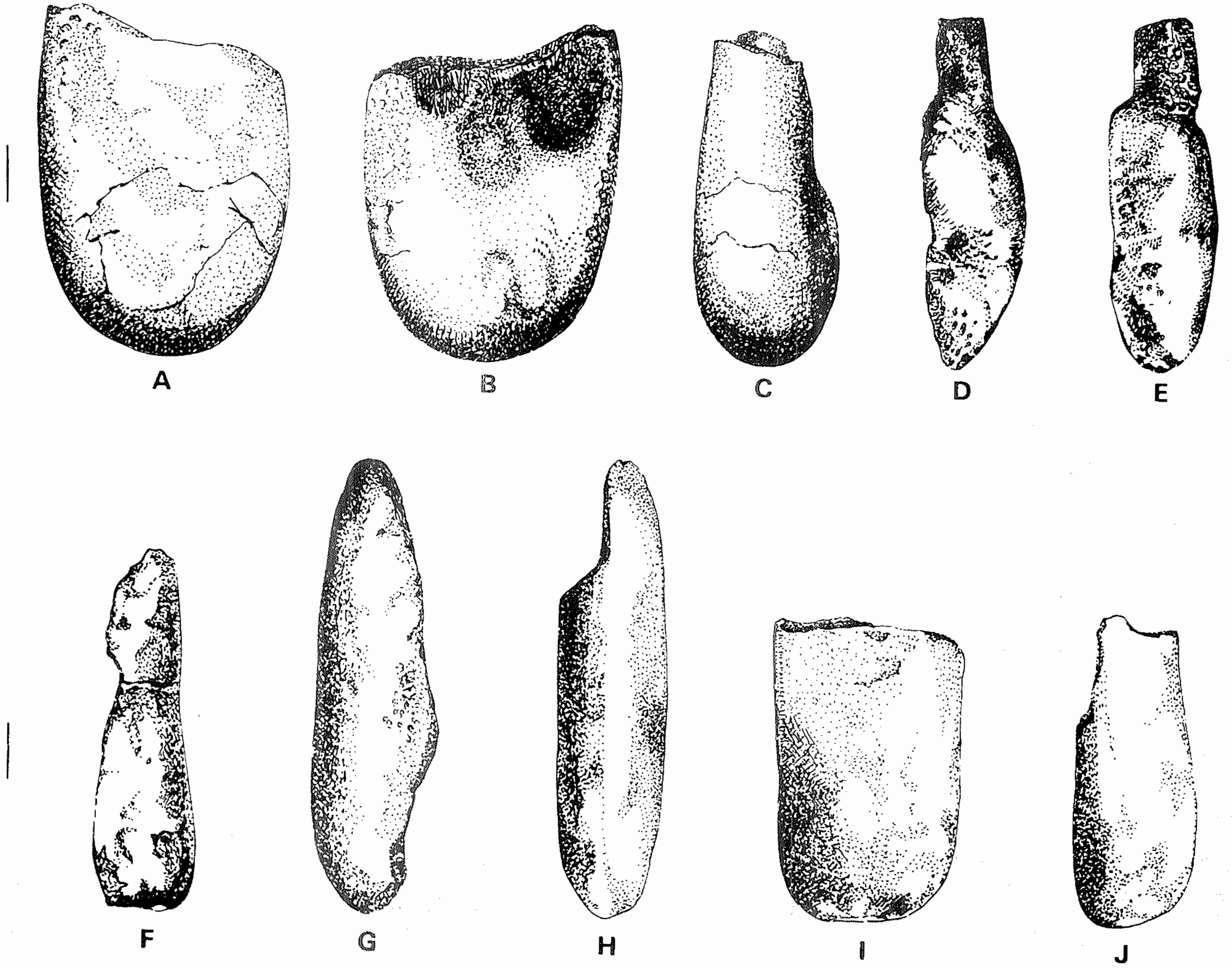


Figure 3 (above). Shell artifacts from Henderson Island. A,D. Unfinished fishhook. B,E. Modified limpet shell. C,F. Fragment of Tridacna shell. See text for detailed description. Scale bars = 1 cm.

Figure 4 (next page). Porites Coral artifacts from Henderson Island. A-C. Specimen 4. D,E. Specimen 5. F. Specimen 6. G,H. Specimen 7. I,J. Specimen 8. See text for detailed description. Scale bars = 1 cm.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NO. 326

MARINE INVERTERBRATES OF THE PITCAIRN ISLANDS: SPECIES COMPOSITION AND BIOGEOGRAPHY OF CORALS, MOLLUSCS, AND ECHINODERMS

BY

GUSTAV PAULAY

ISSUED BY
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MARINE INVERTERBRATES OF THE PITCAIRN ISLANDS: SPECIES COMPOSITION AND BIOGEOGRAPHY OF CORALS, MOLLUSCS, AND ECHINODERMS

BY

GUSTAV PAULAY

ABSTRACT

The marine invertebrate fauna of the Pitcairn Islands consists of a depauparate assemblage of Indo-West Pacific species; 54 corals, 198 molluscs, and 58 echinoderms are recorded. I discuss the physiography and marine communities of each island and the origin and characteristics of the fauna. There is considerably variation in species composition among islands as well as through time, indicating that these peripheral islands have an unstable, dynamic fauna.

INTRODUCTION

The marine fauna of the Pitcairn Group is of particular biogeographic interest because of the group's isolation, peripheral location, and unusual physiography. Located at the southeastern edge of the Indo-West Pacific province, the Pitcairns are 390 km east of their nearest neighbor, Temoe Atoll in the Tuamotu-Gambier Islands, and 1570 km west of Easter Island. They are the easternmost islands on the Pacific plate and indeed within the Indo-West Pacific province, with the exception of faunistically depauperate and unusual Easter Island and Sala y Gomez. Situated between 24-25°S, the Pitcairns are also more austral than most other tropical Pacific islands. Two of the Pitcairn Islands have a physiography that is uncommon for the Central Pacific: Henderson is an uplifted atoll, whereas Pitcairn is a precipitous Pleistocene volcano with very little reef development. The remaining islands, Ducie and Oeno, are small atolls. Of further interest is that except for Pitcairn, the islands in the group are uninhabited and have been so for hundreds of years; they thus provide a rare glimpse of insular marine ecosystems essentially unaltered by human activities.

PAST WORK

Studies on the marine fauna of the Pitcairn Group have been infrequent. Hugh Cuming made the first collections in the archipelago, visiting Ducie, Henderson, and Pitcairn in 1827, and Pitcairn again in 1828 (Dance 1980). Although his stay was brief (11 days total, St. John 1940), several new molluscs were described from specimens he collected in the group. The next significant marine collection, again of molluscs, was made on Henderson by JR Jamieson and DR Tait in 1912; their collections were described by EA Smith (1913). The natural history expeditions that followed in the first half of this century - the Whitney South Sea Expedition in 1922, the Mangarevan Expedition in 1934, and the Templeton Crocker Expedition in 1935 - focused largely on the terrestrial biota.

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Since the 1960's, the marine fauna of the Pitcairns has received more attention. In 1964, HA Rehder collected molluscs on Pitcairn Island. In 1967 the *Pele* with HA Rehder, DM Devaney and BR Wilson on board, spent 5 days on Pitcairn and 2 on Oeno. They made 33 dredge hauls on Pitcairn, collecting in depth zones little studied elsewhere in Polynesia (Rehder 1974). In 1970-1971, the schooner *Westward*, with JE Randall and HA Rehder, spent most of its one-month stay in the group on Pitcairn, but also visited Henderson, Ducie and Oeno briefly (for <3 days each) (Randall 1973, 1978, Devaney & Randall 1973). All 3 above expeditions focused on Pitcairn within the archipelago, and the greatest collecting efforts concentrated on molluscs (Rehder in 1964, 1967, 1970-1; Wilson in 1967), echinoderms (Devaney in 1967) and fish (Randall in 1970-1), although other invertebrates were routinely taken. Results on ophiuroids and asteroids were published by Devaney (1973, 1974), Devaney & Randall (1973) and Marsh (1974). Rehder & Wilson (1975) described 3 new gastropods from Pitcairn, while Rehder & Randall (1975) and Fosberg *et al.* (1983) listed the known malacofauna of Ducie and Henderson respectively. Although most of the large collections of molluscs from Pitcairn have yet to be studied, several systematic revisions on various gastropod taxa include material from the Pitcairn Group (see table 2). Rehder & Randall (1975) provided a brief list and comments on some crustaceans, echinoderms, and corals, and Fosberg *et al.* (1983) mentioned a lobster and an echinoid. A series of papers have also been published discussing the fish fauna, including a species list for Ducie (Rehder & Randall 1975).

PRESENT WORK

The 1987 Smithsonian Expedition visited Ducie on 10 May 1987, Henderson on 12-21 May, Pitcairn on 22-26 May, and Oeno for a brief 2 hours on 28 May. On both Ducie and Henderson we collected most intensely on the fore reef using SCUBA, while reef flat and lagoonal (on Ducie) habitats were sampled less intensely. Collections on Pitcairn were limited to a few specimens brought by divers. On Oeno we landed briefly on the E end of the main islet, and I collected on the adjacent shoreline and lagoon. Accordingly, my most extensive collections are from Henderson and Ducie, while those from Pitcairn and Oeno are very limited.

Corals (Milleporina & Scleractinia), molluscs, and echinoderms were the focus of my collecting efforts, and are the taxa considered here. All species encountered are listed in tables 1-3, with the exception of a few molluscs and corals that remain unidentified. Coral collections made by Devaney in 1967 (USNM portion only) and by the *Westward* crew in 1971 (Bishop Museum, reported on by Rehder & Randall 1975) were also (re-) examined. Other invertebrates collections from the Pitcairns at the USNM and Bishop Museum were not consulted. Literature records are included from papers concentrating on the Pitcairn Group fauna and from several recent taxonomic monographs (see tables 1-3 for citations). All collections from the 1987 expedition are deposited in the National Museum of Natural History (USNM). A list of USNM catalogue numbers for all species here referred to will, once available, be deposited in the USNM Mollusc library.

PHYSIOGRAPHY AND MARINE HABITATS

Ducie: Rehder & Randall (1975) and Devaney & Randall (1973) described the physiography and marine habitats of Ducie in some detail; only a few noteworthy features will be mentioned here. The outer reef slope was investigated only off the western tip of Acadia Islet, where it forms a wide shelf, sloping gently until a break at

25-30 m depth, steepening thereafter. Rehder & Randall (1975) reported similar wide shelves off at least the NW, NE, and SW sides, most extensive (270 m wide to the break at 30 m depth) off the small SW passage. Such wide fore reef terraces appear to be common on the southernmost Polynesian islands: they are found on Rarotonga, Mangaia (Cook Islands), Rimatara, Tubuai, Raivavae, and areas of Rurutu (Austral Islands), and may represent reefs unable to reach the surface due to slower growth rates at these colder latitudes (Paulay & McEdward submitted).

An unusual feature of the fore reef area investigated is the complete absence of sands or finer sediments. Only a few pockets of coral rubble interrupt the undulating reef pavement, which is lightly dissected by a spur and groove topography best developed at depths of <10 m. The fore reef grades imperceptibly into the outer reef flat, a reef crest is entirely lacking. The reef flat investigated at the W end of Acadia Islet has minimal sand deposits, lacks live corals, and has dense populations of the sea cucumber *Holothuria atra* and the giant vermetid *Dendropoma maximum.*

The lack of fine sediments on the fore reef and reef flat is further reflected in the composition of Acadia Islet, composed entirely of storm-tossed coral and mollusc rubble, with shells of the gastropod *Turbo argyrostomus* dominating the latter. On the lagoon side, this rubble mound ends abruptly in a steep bank, ending ca. 10 m from shore at a depth of 8-9 m, uncomformably overlying the flat lagoon bottom of fine, white sand. Many irregular, heavily eroded patch reefs rise from the lagoon floor, reaching within 2-5 m of the surface. Several species of *Montipora* and *Astreopora* cf. *myriophthalma* dominate the sparse coral cover, and the sea urchin *Diadema savignyi* is common. The lagoon floor has an abundance of *Holothuria atra* and occasional *Holothuria nobilis.*

Rehder & Randall (1975) noted a large coral kill on the Ducie fore reef in January 1971, and estimated that it occurred at least a year before their visit:

> "Everyone diving at Ducie came up in wonderment at the obvious mass mortality of the corals in all areas investigated. ... At one time in the not-too-distant past, the outer reef of Ducie ... was nearly completely covered with live coral, particularly an *Acropora* with branches of only a few inches in length. The coralline red alga has not grown to the extent of bridging over the tips of the branches of this coral, whereas it completely covers the plate-like or encrusting species." (p. 16)

In contrast, we found prolific live coral cover in some of the same areas as surveyed by the *Westward.* Live coral cover was high throughout the fore reef shelf investigated: at 17 m it was 58%, decreasing abruptly above 8 m to ca. 20-30%. Colonies of several corymbose *Acropora* species, up to 40 cm across, and thin whorled plates of *Montipora aequituberculata,* up to 70 cm in diameter, dominated cover. Other common corals included *Pavona* sp. 1, *Plesiastrea versipora,* and *Cyphastrea* cf. *serailia.* The largest corals seen were ca. 1 m wide colonies of *Favia stelligera.* Unlike on Henderson where they dominate coral cover, *Pocillopora* species were not common on Ducie. In contrast to the great changes that occured in the fore reef coral community between 1971 and 1987, the lagoon fauna appears to have remained stable, in both 1971 and 1987 supporting a low cover of mostly *Montipora* species.

I reexamined all but one (*Pocillopora* sp. cf. *P. modumanensis,* a likely synonym of *P. eydouxi*; see Veron & Pichon 1976) of the 14 coral species collected in 1971 (Rehder & Randall 1975 pp. 37-38) (table 1). All 3 species collected in 1971 but not in 1987 were found solely in the lagoon by the *Westward,* a habitat we sampled very cursorially. All coral species collected on the fore reef in 1971 were well established there in 1987. The 1987 coral community, dominated by *Acropora* species and *Montipora aequituberculata*, appears also to be similar to the pre-kill (pre-1971) fauna. Rehder & Randall (1975) noted *Acropora* to dominate among the recently killed coral species of 1971, and I found the plate coral *M. aequituberculata* to have been a dominant constituent of the reef in the recent past, its colonies clearly visible where eroded surge channels expose the reef framework.

Rehder & Randall (1975) argued that the observed pattern of mass mortality may be due to the intrusion of cold water masses, considering the southern position of the island (Ducie is the southernmost atoll in the world); *Acanthaster*, of which only a single individual was found in the lagoon, was considered a less likely cause. Their hypothesis is supported by the pattern of mortality: very high on the fore reef, while the lagoon retained a considerable, although sparse, cover of mostly *Montipora* species. While *Montipora* is favored by *Acanthaster*, its lagoonal habitat would be isolated from short term intrusions of cold water flowing over the fore reef.

The two most conspicuous invertebrates noted in 1971 on the fore reef (Rehder & Randall 1975), the urchins *Diadema savignyi* and *Heterocentrotus mammillatus*, were also very common during our visit. The maintenance of dense sea urchin populations through this time period is of interest not only because it contrasts with corals, but also because *D. savignyi* abundance varies greatly among islands in Polynesia. On certain islands, e.g. Mangaia, Mauke (Cooks, in 1984), and Henderson (in 1987), these nocturnal animals occur spine-to-spine in dense populations, exposed during the day, due to a lack of sufficient crevices to hide in; in contrast, on some neighboring islands (e.g. Rarotonga in the Cooks), they are not noticeably abundant. The question arises whether the very large populations are stable or the result of occasional outbreaks. The present data from Ducie supports the former hypothesis. The presence of such large densities of diademids in the oligotrophic waters of several uplifted islands (Mangaia, Mauke, Henderson) that lack runoff does not support Birkeland's (1989) hypothesis that dense echinoid populations are due to successful larval recruitment in areas of high nutrient input.

Unexpectedly for an uninhabited atoll, fish are not abundant on the fore reef at Ducie. This was also noted by the *Westward* Expedition (Devaney & Randall 1973, Rehder & Randall 1975). Most conspicuous in 1987 were several larger predators: schools of *Caranx lugubris* and *Seriola lalandi* were ubiquitous, and the grouper *Variola louti* was common. In <0.5 m water on the reef flat, however, large serranids (*Epinephelus* sp.) and scarids were common.

It is tempting to speculate that the great abundance of invertebrate grazers (sea urchins and the gastropod *Turbo argyrostomus*) and the relative paucity of herbivorous fish on Ducie are causally related, and that such a scenario may have been more widespread in Polynesia prior to the advent of man. Human predation is usually intense on large invertebrates, including echinoids and *Turbo*, throughout Polynesia and can render such species uncommon on heavily harvested reefs. Further, predatory fish are especially susceptible to overfishing, as they are often territorial and can be readily taken by angling as well as by spears, nets, and other methods. Thus by decreasing the abundance of both the potential competitors (invertebrate grazers) and principal predators of herbivorous fish, human habitation may result in an ecosystem that is more dominated by fish herbivores, as seen on many densely settled islands today. The balance between invertebrate and vertebrate grazers can also be tipped in the other direction by human occupation, however: in heavily fished reefs in the Caribbean, populations of *Diadema antillarum* are an order of magnitude higher than elsewhere, due to reduced competition from herbivorous fish, reduced predation by balistids (Hay 1984), and presumably little human predation on the urchins themselves.

Henderson: A brief description of the reefs of Henderson Island is given by Spencer & Paulay (1989). In contrast to Ducie, the fore reef on Henderson is relatively narrow, has abundant soft sediments, and supports low coral cover. Spur and groove topography is well developed; the grooves are filled with sands that support an abundant infauna.

An algal turf covers much of the fore reef surface and is dominated by *Microdictyon boergesenii* Setchell, with *Lobophora variegata* (Lamour.) Womersley, and *Stypopodium zonale* (Lamour.) Papenfuss being also common. Coral cover was 6% at 11 m depth off the N Beach. In shallow waters, coral cover is dominated by *Millepora*, which becomes uncommon by 12 m depth; deeper waters are dominated by *Pocillopora* sp. 1, *Pocillopora woodjonesi*, and *Porites* cf. *lobata*. In contrast to Ducie as well as to the uplifted Pleistocene reefs of Henderson, acroporids are uncommon. All corals listed from Henderson (table 1) were collected on the fore reef.

The most conspicuous invertebrates on the fore reef are several sea urchins; *Diadema savignyi* is very abundant (see below), while *Echinostrephus aciculatus* and, in shallow (<10 m) water, *Echinometra oblonga*, are common. The large sea cucumber *Holothuria nobilis* is also common, especially at <15 m depths. Like on Ducie, fish are not abundant on Henderson. The black jack, *Caranx lugubris*, is most conspicuous.

The fringing reef flat that surrounds Henderson on the E, N, and NW sides lacks a reef crest and slopes gently seaward. The flat bordering the North Beach was investigated by snorkeling. Although it is banked by a beach, little loose sediment is found on the hard reef flat pavement, and the little that occurs lies underneath the few loose rocks near the landward margin of the reef.

The reef flat has a rich malacofauna. The bivalves *Arca avellana, Lima vulgaris, Chama asperella,* and especially *Isognomon perna* are common, as are several species of muricids and cones, especially *Drupa morum, Drupa clathrata, Thais armigera,* and *Conus rattus*, but also *Drupa ricinus, Morula uva, Conus miliaris, Conus nanus, Conus lividus,* and *Conus retifer*. Additional common gastropods include *Patella flexuosa, Cypraea schilderorum, Nassarius gaudiosus,* and *Strombus maculatus*. The echinoid *Heterocentrotus trigonarius* is abundant in patches along the outer reef flat, while *Echinometra oblonga* is abundant scattered across the reef. Under rocks are large populations of the irregular echinoid *Echinoneus cyclostomus* as well as occasional *Holothuria arenicola*. The only corals seen were a few colonies of *Favia rotumana*.

Pitcairn: A brief description of the underwater topography and habitats of Pitcairn are given by Devaney & Randall (1973). Coral reefs are small and isolated, most being confined to depths of over 20 m.

Oeno: Devaney & Randall (1973) give a brief description of the Oeno lagoon and fore reef. Our visit was brief and confined to the lagoon. The SE outer reef flat is strongly dissected by spur and groove topography and lacks a reef crest. The lagoon seen is uniformly shallow, ca. 1.5-3 m deep, and has an undulating bottom of rubble and sand, with scattered reefs. In the small area investigated at the eastern tip of the larger islet several species of *Montipora* dominate coral cover, with *Acropora humilis,* *Acropora secale, Pavona varians, Montastrea curta,* and *Cyphastrea* cf. *serailia* being also common. *Tridacna maxima* appears to be abundant throughout the lagoon.

MARINE FAUNA

The recorded coral, mollusc, and echinoderm species of the Pitcairn Islands are listed in tables 1-3. Noteworthy observations on the taxonomy, distribution, or ecology of selected species are presented below.

Corals:

Corals exhibit considerable geographic variation in morphology (Veron 1981), and it may be difficult to determine whether unusual forms at peripheral locations are due to genetic or ecophenotypic differences. Several species in the Pitcairn Group do not fit well into the described species they were assigned to, further collecting in the Pitcairn and Tuamotu Islands is necessary to interpret such differences. The Pitcairn fauna exhibits considerably more such odd geographic variation than the Cook Islands' fauna. Some striking examples are discusses below.

Stylocoeniella guentheri Bassett-Smith 1890

A large clump of arborescent *S. guentheri* was dredged at 37 m off Henderson Island; colonies of similar form were dredged by the *Pele* off Pitcairn from 47-63 m and 72-108 m. The fine branches characteristic of these colonies differ from the encrusting or massively columnar growth form usually exhibited by this species (Veron & Pichon 1976).

Pocillopora sp. 1

This was the most common pocilloporid seen in the Pitcairn group. It is similar to ***P. verrucosa***, but differs in possessing hood-like ramifications over the calices as in *Stylophora*. I have also seen 2 colonies of this form on Aitutaki in the Cook Islands, where *P. verrucosa* is prevalent.

Pocillopora woodjonesi Vaughan 1918

Colonies of *P. woodjonesi* are fairly common on Henderson. They are reminescent of a thin *P. eydouxi*, a growth form recently also recognized off Australia as being more typical for this species than the irregular form originally described (CC Wallace pers. comm. 1988).

Montipora aequituberculata Bernard 1897

Montipora aequituberculata is one of the most common corals on the Ducie fore reef today. Its large, whorled, thin plates are also conspicuous in exposed reef sections there; it was clearly an important contributor to Holocene reef development on Ducie. While *M. aequituberculata* is uncommon on Henderson today, fossil colonies lacking surface features but exhibiting its classic growth form are locally common on the Pleistocene limestone buttresses above the North Beach (Spencer & Paulay 1989).

Porites sp. aff. *P. annae* Crossland 1952

This unusual *Porites* occurs throughout the Pitcairn Group. It is closest to ***P. annae***, but is much more heavily calcified; septa and walls are very thick, and an incomplete endotheca-like blanket of aragonite often envelops calices near the top of septa such that only the septal denticles project above it. Colonies are small, and subarborescent or massive with large, projecting knobs.

Porites sp. cf. *P. lobata* Dana 1846

Instead of the typical massive growth form of *P. lobata*, most colonies from the Pitcairns have subarborescent or columnar skeletons. All specimens have well-developed pali on all 8 septa, although pali are often at a lower level than septal denticles. *Porites* cf. *lobata* is common on Henderson and occasional on Ducie.

Pavona sp. 1

This columnar *Pavona* is common throughout Southeastern Polynesia, occuring westward at least to the Cook Islands. It is intermediate in form between *P. maldivensis* and *P. clavus* / *P. minuta*. It has a columella, small calices (ca. 2 mm), few (6-9 primary) and markedly unequal septocostae with primary septocostae frequently bearing prominent septal lobes, and either a fine (1-3 cm diameter) digitate or a wide, flat-sided-columnar (cf. *P. minuta*) growth form. Colonies are usually small, but can grow to considerable size, e.g. a 4-5 m diameter colony was found on the Henderson fore reef.

Goniastrea australiensis (Edwards & Haime 1857)

Goniastrea australiensis appears to have a sporadic distribution in the Pacific, and is best represented at high latitudes; it is known from Japan, Philippines, Formosa, Great Barrier Reef, Kermadecs (Veron *et al.* 1977), Niue (Paulay 1988), Rapa (Faure 1985), and the Pitcairns. Within Polynesia it appears to be restricted to a southern, subtropical band.

Plesiastrea versipora (Lamarck 1816)

Although *P. versipora* has been recorded from several localities in the Central Pacific, most literature records are based on misidentified *Montastrea curta* (Dana 1846), a species incorrectly considered a synonym (Veron et al. 1977). Actually *P. versipora* has a sporadic distribution in Polynesia, and is known only from a few Tuamotu atolls (a specimen from Raroia is at the USNM) and from the Pitcairn Group, where it is common both living and as a Pleistocene fossil. This eastern Polynesian population appears to be isolated; the species is not known from the intensively surveyed Niue or Cook Islands (Paulay 1988), nor from other French Polynesian archipelagoes (Chevalier 1981). Its success in the Pitcairn Group is further accentuated by its persistence there since the mid-Pleistocene, despite the tremendous turnover in the coral fauna of the group since then (Paulay & Spencer 1989).

Molluscs:

Modiolus matris Pilsbry 1921

Described from the Hawaiian Islands, this colorful mytilid has a curious distribution; it is also known from the Marquesas, Raivavae (Austral), Pitcairn, Henderson, and Easter Islands (Rehder 1980, USNM collections) and thus appears to be restricted to the easternmost fringe of the Indo-West Pacific. It has a wide depth range; although usually found at 5-8 m in Hawaii (Kay 1979) specimens from the Marquesas (USNM) have been dredged as deep as 128-141 m.

Barbatia parva (Sowerby 1833)

The type locality of this species is Ducie, where it was originally collected by Cuming in 1827 (Rehder & Randall 1975). On Ducie it is abundant in crevices in the lagoonal patch reefs, and is also found attached to the undersides of slabs on the reef flat. In contrast to its habitats on Ducie, *B. parva* is known mostly from outer reef slopes elsewhere in Polynesia (Paulay 1988).

Chama "spinosa" Broderip 1835 *sensu* Lamy 1906

Closely related to *Chama asperella*, or possibly a variant of that species, *C. "spinosa"* differs in having a violet interior. Rehder (in Fosberg *et al.* 1983) listed this species as a possible variety of *C. asperella*, noting its peculiar color. It is widespread in Southeastern Polynesia (Paulay 1987).

Chama sp. 2

An apparently undescribed species with fine, honeycombed sculpture, and a yellow interior. It is also known from the Niue, Cook, Society, and Gambier Islands (Paulay 1987).

Tridacna squamosa Lamarck 1819

Tridacna squamosa was known previously eastward to the Cook Islands (Paulay 1987). We found it to be fairly common between 15-20 m on the fore reef of Ducie and occasional on Henderson. In the Cooks as in the Pitcairns it is known only from fore reef habitats (Paulay 1987). Whether its apparent absence in French Polynesia is real, or due to its somewhat inaccessible habitat is not clear.

Tridacna maxima (Roding 1798)

As *T. maxima* is intensively harvested on inhabited islands, its abundance in undisturbed settings is of interest. While *T. maxima* is abundant in the Oeno lagoon, on Henderson it is uncommon. On Ducie only a single live clam was seen on the reef flat, although the large numbers of shells embedded in the beachrock on Acadia Islet indicate that the species may have been much more common in the past, perhaps prior to the coral mortality noted above.

Cantharidus marmoreus (Pease 1867)

This small, rare trochid is known only from the Tuamotus (Cernohorsky 1980), Austral Islands (Raivavae, USNM 732211) and Henderson.

Turbo argyrostomus Linne 1758

In the Cook Islands *Turbo setosus* is common while *T. argyrostomus* is rare. In the Pitcairns the former is rare, while the abundance of *T. argyrostomus* on Ducie was phenomenal, its shells forming a significant portion of Acadia Islet. Perhaps the rarity of *T. setosus* is in part responsible for the abundance of *T. argyrostomus*.

Pseudovertagus clava (Gmelin 1791)

The abundance of this large cerithiid in the Pitcairn Group and some Tuamotu Atolls has been noted (Rehder & Randall 1975, Houbrick 1978), and is especially interesting considering its sporadic distribution and relative rarity elsewhere. *Pseudovertagus clava* appears to be restricted to a southern subtropical band from ca. 15-35°S in the Indo-Pacific (Houbrick 1978).

Recluzia johni (Holten 1802)

Two specimens found in beach drift on Henderson Island appear to be the first records for this widespread janthinid from Southeastern Polynesia.

Polinices simiae (Deshayes 1838)

Although distributed from East Africa to Easter Island, *P. simiae* is rare in most localities except along the margins of its range, at Easter, the Kermadecs, and Hawaii (Cernohorsky 1972, Rehder 1980). It is similarly common on Henderson Island.

Coralliophila latilirata Rehder 1985

The hosts of this Southeastern Polynesian endemic were previously unrecorded. I collected 2 specimens on the plate coral *Montipora aequituberculata*, and 1 on *Leptastrea* sp..

Engina fuscolineata E.A. Smith 1913

This small buccinid, originally described from Henderson, where it is common in beach drift, is also known from the Society Islands (Richard 1985).

Echinoderms:

Diadema savignyi (Audouin 1826)

Diadema savignyi is abundant on both Ducie and Henderson. I found more than one urchin per m^2 in the crevices that riddle the fore reef on Ducie. They are much less common on the Ducie reef flat, but again common in the lagoon; lagoonal urchins are larger (20-25 cm) than those on the fore reef (<15 cm). On Henderson, *D, savignyi* is so abundant that there are not sufficient crevices for them to occupy, so many remain in the open and aggregate into herds, probably for protection, carpeting large reef areas spine to spine in depths of ca. 8-30 m. I have seen similar aggregations of this species on Mangaia and Mauke in the Cook Islands.

Echinometra species-complex

Recent molecular studies on Indo-Pacific *Echinometra* have shown that at least 4 species are represented in what used to be called *E. mathaei* and *E. mathaei oblonga* (Palumbi & Metz in prep.). In the Pitcairn Group *E. oblonga* is by far the most common species; it was occasional on the reef flat on Ducie, and common on the reef flat and shallow fore reef (0-9 m) on Henderson. Two additional forms that fit 2 of Palumbi & Metz's (in prep.) species were also collected; *E.* sp. 1 with white-tipped spines, and the species tentatively assigned to *E. mathaei* (S.R. Palumbi pers. comm. 1989) with unicolored spines and abundant rod-shaped gonadal spicules packed together in bundles.

Heterocentrotus trigonarius (Lamarck 1816)

This widely distributed urchin is common throughout Polynesia, living in the surf zone on reef fronts and on outer reef flats. Populations in the Pitcairn Group are unusually dense, and consist of very large individuals having a different color pattern and shape than those in Central Polynesia. They are uniformly dark blue violet, have elongate, tapering, sharp spines (if unbroken), and grow up to 25-30 cm in diameter spinetip to spinetip. On Ducie, Henderson, and Oeno, they occur in waters up to 3 m deep on the fore reef, are abundant in the surf zone, and extend onto the outer reef flat, which, lacking a reef crest, receives considerable wave action. On Ducie, in the center of this zone, their density was estimated at up to 1-2 urchins m^{-2}. The population on Oeno is similarly dense, which together with their unusually sharp spines, made this "slate-pencil urchin" an unlikely landing hazard; several people in our landing party had spines driven into their feet through tennis shoes while crossing the reef edge. It is probably to this species and not to *Diadema* that Beechey referred to as "numerous *echini*" on the Henderson reef flat that were capable of inflicting "painful wounds" on landing (Fosberg *et al.* 1983, p. 27). The abundance of this species in the Pitcairns is at least in part the result of lack of human predation, as the species is frequently harvested by Polynesians elsewhere.

Heterocentrotus mammillatus (Linne 1758)

While *Heterocentrotus trigonarius* is ubiquitous in southern Polynesia, the only verified records of *H. mammillatus* in the region are from the Pitcairn Group and Raroia (USNM E8525) in the Tuamotus. Morthensen (1943) records this species east only to Fiji in the South Pacific, albeit it extends to Hawaii in the northern hemisphere. Thus the population in the Pitcairns and Eastern Tuamotus appears to be isolated. Within the Pitcairn Group it is very common on Ducie, rare on Henderson (we did not find any, but Randall (1978) illustrates the species from 1971), and again apparently common on Pitcairn. *H. mammillatus* lives in crevices on the fore reef between 10-20+ m depths and does not overlap with *H. trigonarius*. An excellent illustration of the urchin *in situ* is provided by Randall (1978 fig. 4), depicting the characteristic habitat and hinting at the color pattern of the Pitcairns' populations: primary spines are reddish-orange, while secondary spines are white, often with a slight suffusion of red.

Metalia spatagus (Linne 1758)

A relatively dense population of this spatangoid was found on the fore reef of Henderson Island between 10-18 m depths.

Echinoneus cyclostomus Leske 1778

Although tests of this irregular echinoid are not uncommon in Polynesia, I have rarely seen live animals before. On the north reef flat on Henderson, however, *E. cyclostomus* is common, with 10-15 huddling under occasional, loose, dead coral slabs; the animals being at most partly buried in the little sand found under the rock. They are beige with red tubefeet.

Allostichaster peleensis Marsh 1974

Described from Pitcairn on the basis of a single specimen dregded from 101-119 m, I collected another specimen of this species on the Henderson fore reef at 12-18 m depth. While the type has all arms intact, the present specimen has 4 regenerating arms, indicating, that like other members of the genus (Emson 1977), it may be fissiparous. As noted by Marsh (1974), "*Allostichaster* is a genus of southern temperate waters, Australia, New Zealand and South America so *A. peleensis* may add a temperate element to the otherwise tropical asteroid fauna of Pitcairn Island."

Actinopyga palauensis Panning 1944

Described from Palau, this large, black holothurian has since been recorded only from New Caledonia (Guille *et al.* 1986). I found it to be not uncommon on the fore reef between 10-20 m on Henderson as well as on Niue Island. In the intervening Cook Islands I have never seen it despite an intensive survey of the holothurian fauna there. Pierre Laboute (pers. comm., 1988) recalls collecting what was likely this species on Scilly Atoll (Society Iss.), however. Apparently it has a very patchy distribution.

Holothuria (Halodeima) signata Ludwig 1875

Until recently *H. (H.) signata* was thought to be a synonym of *H. (H.) edulis*, but Frank Rowe (pers. comm. 1987) concluded that the name applies to a distinctive chestnut brown *Halodeima* with cream spots covering the dorsum. I have collected it on Niue, and throughout the Cook as well as Pitcairn Islands.

Holothuria (Lessonothuria?) sp. 3

This small (5 cm), cryptic holothurian is apparently undescribed (Frank Rowe pers. comm. 1986). I have collected it in the Cooks, Niue, and Henderson Island.

DISCUSSION

The distribution of a species reflects, to varying degrees 1) the speciation event that established its original range, 2) its dispersal ability, which sets its potential range, 3) its ecology, which determines the habitats and thus areas in which it is capable of living, and 4) its changing environment, which determines the distribution of suitable habitats. I will first look at the fauna of the Pitcairn Group from the perspective of these 4 factors; then I will briefly investigate variation in species composition and abundance among the four islands that constitute the group.

1) Endemicity: Isolated islands or archipelagoes may produce endemic species by allopatric speciation. Isolation may be at the island (group) level, if the island (group) is physically isolated from its neighbors by wide areas of open ocean. Alternatively, it can be at the habitat level, as uncommon habitats can be isolated even if the islands on which they are situated on are not. At the insular level, the Pitcairn Group is not particularly isolated, its nearest neighbor, Temoe Atoll, is only 390 km distant. On the habitat level however, the terrigenous and largely reefless marine environments of Pitcairn are without parallel in the area except for Easter Island, Rapa, and the Marquesas. Thus while endemics distributed throughout the Pitcairn Group are unlikely, endemics restricted to the unusual habitats of Pitcairn Island may be expected.

A paucity of endemics was noted for the fish fauna by Randall (1978), who judged that about 2% of the fish species are restricted to the group. Among the invertebrates studied 7 of 310 (2.2%) species or subspecies are known only from the Pitcairn Group: the asteroid *Allostichaster peleensis*, the ophiuroids *Amphilimna tanyodes* and *Amphiura bountyia*, the coral *Porites* aff. *annae*, and the gastropods *Engina rosacea*, *Fusinus galatheae bountyi*, and *Ziba cernohorskyi*. Five of the 7 are known only from Pitcairn Island. Although the predominance of potential endemics on Pitcairn fits the expectations outlined above, such a conclusion is weak, as all 5 species were taken only by dredging on Pitcairn, mostly in fairly deep water (40-100 m), a habitat minimally sampled in Polynesia.

2) Dispersal limitations: The Pitcairn Group lies at the eastern edge of the Indo-West Pacific province, yet its fauna recorded herein appears to be entirely derived from the west, lacking East Pacific components. As prevailing surface currents are from the north-east, the islands lie upstream of potential Indo-Pacific source areas, making dispersal to the Pitcairns especially difficult. Similarly, continued survival of established populations may be difficult because there are no upstream islands to contribute propagules; thus populations may be more ephemeral in the Pitcairns than on islands further west (see faunal turnover below).

A direct effect of dispersal limitations is the low diversity of the Pitcairns' marine life, part of the well known trend of eastwardly-decreasing diversity through the Pacific basin (e.g. Wells 1954, Stehli et al. 1967). Although our collections are limited and many species remain to be recorded from the group, species diversity in the Pitcairns is clearly considerably less than in archipelagoes westward. Thus, while 1159 species of molluscs (Richard 1985) and 168 species of scleractinians (Pichon 1985) have been reported from French Polynesia, only 198 molluscs and 54 corals are recorded from the Pitcairns. Similarly diminished diversities were noted for the fish fauna (Randall 1978, Rehder & Randall 1975).

3) Ecological limitations: Some interesting biogeographic trends in the Pitcairn Group result from ecological limitations. Both physical limitations, such as temperature and light intensity, and biotic limitations appear to be important in structuring the marine fauna.

The cooler waters around the Pitcairns likely prevent many Indo-West Pacific species from establishing, contributing to the impoverishment of the fauna discussed above, but may also permit the survival and success of other species on the islands. A widespread faunule restricted to subtropical latitudes, spanning the Pacific from Easter Island and Sala y Gomez, through the Pitcairns, Rapa, Marotiri, Kermadecs, Lord Howe and Norfolk Islands, with some species reappearing in northern subtropical areas (especially Hawaii), has been well documented (Randall 1976, Rehder 1980, Briggs 1987). Among the invertebrates studied, 8 species appear to be restricted to this subtropical faunule (table 4). Species with such a narrowly subtropical yet longitudinally widespread distribution are not as common in the Pitcairn Group as on islands located further south: 2.6% of the Pitcairns' (24-25°S) compared with 42.5% (53 species) of Easter Islands' (27°10'S) malacofauna is so restricted latitudinally.

Such distributions may reflect physical or biotic limitations. If subtropical endemic species are so distributed because of temperature or light limitations, their restriction to so narrow a latitudinal band (24-33°) indicates considerable stenotopy with regards to those physical factors. Biotic limitations for southern endemic and amphitropical taxa has found more support (Briggs 1987, Newman & Foster 1987).

Biotic factors - predators, parasites or competitors - may exclude some species from areas they could otherwise occupy. Species so excluded may survive in other areas unoccupied by their foes. Both the variety and intensity (Vermeij 1978) of biotic interactions increases with increasing diversity, thus species are more likely excluded because of biotic interactions from high than from low diversity areas. Habitats or islands that are physically stressful or isolated and thus have low diversity faunas may serve as refuges for stress tolerant and well dispersing species susceptible to biotic limitations (Diamond 1974, Grime 1977, Briggs 1987). Coral reefs and their associated faunas are limited to a latitudinal band roughly between 30°N and 30°S. Between the tropics of Cancer and Capricorn diversity does not appear to be affected by latitude, but falls abruptly toward higher latitudes due to decreasing temperature and light intensity (Rosen 1984). Thus the southern subtropical faunule discussed coincides with this marginal band of low diversity reefs. The eastern edge of the Indo-West Pacific also has low diversity due to dispersal limitations, and in the Pitcairn fauna, at least one species, the mussel *Modiolus matris*, is restricted to it; it is known only from the Hawaiian, Marquesas, Austral, Pitcairn, and Easter Islands.

In depauparate areas species may also have access to resources unavailable to them in more diverse areas due to biotic interactions. Such ecological release may result in a greater abundance of a species or in an expansion of the resources it uses. Several species that are rarely encountered in more central Indo-West Pacific localities are strikingly common in the Pitcairn Group, including the coral *Plesiastrea versipora,* and the gastropods *Pseudovertagus clava,* and *Polinices simiae. Polinices simiae* has also been noted to be unusually common at other marginal Pacific localities: in Hawaii, Easter Island and the Kermadecs (Rehder 1980). Veron (1986) notes that while *Plesiastrea versipora* is common at high latitudes in Australia, it is relatively rare and restricted to shaded environments at low latitudes. While the pelecypod *Barbatia parva* is largely confined to outer reef slopes on most Pacific islands, on Ducie it is abundant in a variety of lagoonal and reef flat habitats. An excellent study of similar ecological release on neighboring Easter Island is given by Kohn (1978).

4) Environmental change and faunal turnover: The uplifted atoll of Henderson provides a well preserved Pleistocene fauna to compare with the living biota of the same area. Paulay & Spencer (1989) showed that since the Pleistocene there has been a greater turnover (extinction and subsequent recolonization of different species) in the coral fauna of Henderson than recorded for any other Pacific island, and that this turnover was not associated with habitat alterations implicit in Henderson's uplift or due to sea level fluctuations. The high faunal turnover is instead likely due to the marginal location of these islands and accompanying physical and dispersal limitations (Paulay & Spencer 1989).

Inter-island variation: There appears to be considerable variation among the Pitcairn Islands in species composition and community structure, reflecting in part the diverse geological history and physiography of the group (Spencer 1989), but also due to the group's peripheral location and attendant instability of its fauna (Paulay & Spencer 1989). The likely unusual marine biota of reef-poor Pitcairn Island cannot yet be compared due to lack of study. The two islands studied in most detail, Henderson and Ducie, show remarkable differences between their faunas. Among the 45 species of corals collected on the two islands, only 16 (36%) are shared. In comparison, Rarotonga and Aitutaki (Cook Islands), separated by about the same distance as Henderson and Ducie, share 78% of their combined fauna of 73 species (Paulay 1988, a study which does not include acroporids) ($G=21.5$, $p<0.001$). Although the large differences between the Ducie and Henderson faunas are certainly due in part to undersampling, considerable qualitative differences are also apparent between them. On Ducie fore reef coral cover is over 50% (although cover has undergone marked fluctuations, see above) and is dominated by *Acropora* and *Montipora* species with *Pocillopora* being occasional. On Henderson, coral cover is <10% and *Millepora* and *Pocillopora* dominate cover, while acroporids are rare. Acroporids are also significantly more diverse on Ducie (16 species, 55% of total) than on Henderson (9 species, 28% of total) ($G=4.7$, $p<0.05$). Further, the echinoid *Heterocentrotus mammillatus* is abundant on Ducie, while it is rare on Henderson.

SUMMARY

Most of the Pitcairns' marine invertebrates are widespread species distributed through several Pacific archipelagoes or the Indo-West Pacific. The location of these islands at the southeastern margin of the Indo-West Pacific province makes both the survival (due to latitudinal, climatic limitations) and continued re-establishment (due to longitudinal, dispersal limitations) of species difficult. Species diversity is therefore relatively low and the fauna appears to be somewhat unstable. Faunal instability is reflected in large short term changes in coral cover on Ducie, large temporal changes in species composition on Henderson, and considerable differences between the faunas of neighboring Ducie and Henderson.

The resulting low species diversity creates a more benign biotic environment than possible in high diversity areas, as many potential predators, parasites, and competitors are absent. This allows the survival of several species restricted to (or most common in) such marginal environments around the Indo-West Pacific fringe. There are few if any endemics restricted to the Pitcairn Group; Pitcairn Island is predicted to be most likely to support possible endemics due to its unusual physiography and habitats.

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Table 1
Pitcairn Group corals

*) 1987 collections; A) Rehder & Randall 1975; B) USNM collections (1967, Devaney coll.); +) species names preceded by a "+" are junior synonyms or misidentifications of the preceding species in the table, their source is given in parantheses; 1) These species are discussed in more detail in the text. Duc: Ducie, Hen: Henderson, Pit: Pitcairn, Oen: Oeno.

MILLEPORINA	**Duc**	**Hen**	**Pit**	**Oen**
Milleporidae				
Millepora spp.		*		
SCLERACTINIA				
Astrocoeniidae				
Stylocoeniella guentheri Bassett-Smith 1890[1]		*	B	
Pocilloporidae				
Pocillopora damicornis (Linne 1758)			B	
Pocillopora eydouxi Edwards & Haime 1860	*A?	*?		
+?*Pocillopora* sp. cf. *modumanensis* Vaughan 1907 (A)				
Pocillopora sp. 1[1]	*A	*	B	*
+*Pocillopora elegans* Dana 1846 (A)				
Pocillopora woodjonesi Vaughan 1918[1]		*	B	*B
Acroporidae				
Montipora aequituberculata Bernard 1897[1]	*A	*?		
+*Montipora composita* Crossland 1952 (A)				
Montipora aff. *bilaminata* Bernard 1897	A			
Montipora caliculata (Dana 1846)	A	*		
Montipora cf. *capitata* (Dana 1846)		*		
Montipora complanata (Lamarck 1816)	A			
Montipora foveolata (Dana 1846)	*	*		*
Montipora grisea Bernard 1897				*
Montipora incrassata (Dana 1846)	*A			B
+*Montipora* sp. cf. *venosa* (Ehrenberg 1834) (A)				
Montipora tuberculosa (Lamarck 1816)				*
Montipora venosa (Ehrenberg 1834)				*
Montipora cf. *verrucosa* (Lamarck 1816)	*			*?
Acropora acuminata (Verrill 1864)	*		B?	B
Acropora cytherea (Dana 1846)				B
Acropora digitifera (Dana 1846)		*		
Acropora cf. *glauca* (Brook 1893)		*		
Acropora humilis (Dana 1846)	*	*		*
Acropora latistellata (Brook 1892)	*			
Acropora cf. *lutkeni* Crossland 1952	*			
Acropora cf. *microclados* (Ehrenberg 1834)	*			
Acropora nasuta (Dana 1846)	*A	*		
Acropora secale (Studer 1878)			B?	*
Acropora cf. *solitaryensis* Veron & Wallace 1984	*			
Acropora valida (Dana 1846)	*			
Astreopora myriophthalma (Lamarck 1816)	*?A		B	
Astreopora cf. *moretonensis* Veron & Wallace 1984		*		

Poritidae	**Duc**	**Hen**	**Pit**	**Oen**
Porites aff. *annae* Crossland 1952[1]	*	*	B	*
Porites australiensis Vaughan 1918	*A	*		
Porites cf. *lobata* Dana 1846[1]	*	*	B	
Siderastreidae				
Psammocora haimeana Edwards & Haime 1851		*	B	*
Psammocora obtusangula (Lamarck 1816)	*	*		
Agariciidae				
Pavona sp. 1[1]	*A	*		
+*Pavona* sp. cf. *pollicata* (Wells 1954) (A)				
Pavona maldivensis (Gardiner 1905)		*		
Pavona varians Verrill 1864		*		*
Leptoseris hawaiiensis Vaughan 1907			B	
Leptoseris incrustans (Quelch 1886)	*A	*		
Fungiidae				
Cycloseris vaughani (Boschma 1923)			B	
Fungia scutaria Lamarck 1801	*A			
Mussidae				
Scolymia cf. *vitiensis* Bruggemann 1877		*	B	
Faviidae				
Caulastrea cf. *furcata* Dana 1846			B	
Favia mathaii Vaughan 1918		*	B	
Favia rotumana (Gardiner 1899)		*		
Favia stelligera (Dana 1846)	*			
Goniastrea australiensis (Edwards & Haime 1857)[1]		*	B	
Montastrea curta (Dana 1846)	*	*		*
Plesiastrea versipora (Lamarck 1816)[1]	*A	*		*
Leptastrea purpurea (Dana 1846)		*	B?	*
Leptastrea ?transversa Klunzinger 1879		*		*
Cyphastrea cf. *serailia* (Forskal 1775)	*	*		*

Table 2
Pitcairn Group molluscs

*) 1987 collections; A) Rehder in Fosberg et al. 1983, this list includes previous records from Smith 1913; B) Rehder & Randall 1975; C) Rehder 1980; D) Paulay 1988; E) Wilson & Tait 1984; F) Rehder & Wilson 1975; G) USNM collections; H) Powell 1973; I) Emerson & Cernohorsky 1973; J) Cernohorsky 1976; K) Rosewater 1970; L) Houbrick 1986; M) Houbrick 1978; +) species names preceded by a "+" are junior synonyms or misidentifications of the preceding species in the table, their source is given in parantheses; [1]) These species are discussed in more detail in the text. Duc: Ducie, Hen: Henderson, Pit: Pitcairn, Oen: Oeno.

BIVALVIA	**Duc**	**Hen**	**Pit**	**Oen**
Mytilidae				
Modiolus auriculatus Krauss 1848				D
Modiolus matris Pilsbry 1921[1]		*	G	
Botula fusca (Gmelin 1791)			E	
Arcidae				
Arca avellana Lamarck 1819		*A		D
Barbatia parva (Sowerby 1833)[1]	*B	*A		*
Barbatia plicata (Dillwyn 1817)		*A		*
+*Acar divaricata* (Sowerby 1833) (A)				
Pinnidae				
Streptopinna saccata (Linne 1758)		*		
Pteriidae				
Pinctada ?maculata (Gould 1850)	*B			*
Pinctada margaritifera (Linne 1758)	B	*		
Isognomonidae				
Isognomon anomioides (Reeve 1858)		*		
Isognomon perna (Linne 1767)	*B	*		*
Isognomon rupella (Dufo 1840)	*B		D	
+*Isognomon dentifera* (Krauss 1848) (B)				
Pectinidae				
Chlamys coruscans (Hinds 1845)		*	D	
Chlamys sp.			D	
Excellichlamys 'parva' (Sowerby 1835)		*		
Gloripallium pallium (Linne 1758)				*
Mirapecten mirificus (Reeve 1853)		*		
Mirapecten sp.		*		
Semipallium sp.		*		
Spondylidae				
Spondylus hystrix Roding 1798		*		
Spondylus tenebrosus Reeve 1856		*		*
Spondylus sp.	B	A		
Limidae				
Lima bullifera Deshayes 1863		A	D	
Lima vulgaris (Link 1807)		*A		
+*Lima lima* (Linne 1758)				
Ostreacea				
"Ostrea" sp.	B			
Gryphaeidae				
Hyotissa hyotis (Linne 1758)			D	

Chamidae	**Duc**	**Hen**	**Pit**	**Oen**
Chama asperella Lamarck 1819	*	*		
Chama limbula Lamarck 1819	*B	*		*
+*Chama iostoma* Conrad 1837 (B)				
*Chama "spinosa"*Broderip1835 *sensu* Lamy 1906[1]		*A		*
+?*Chama asperella* Lamarck 1819 (A)				
Chama sp. 2[1]		*		
Chama sp.		*		
Lucinidae				
Codakia bella (Conrad 1837)	*B	*A		*
Codakia tigerina (Linne 1758)				*
Anodontia edentula (Linne 1758)		*		*
Cardiidae				
Trachycardium orbitum (Sowerby 1833) - D				
Fragum mundum (Reeve 1845)		*		
Corculum dionaeum (Broderip & Sowerby 1829)	*			
Tridacnidae				
Tridacna maxima (Roding 1798)[1]	*B	*A		*
Tridacna squamosa Lamarck 1819[1]	*	*A?,D		
Mesodesmatidae				
Ervilia cf. *bisculpta* Gould 1861		*		
Tellinidae				
Tellina ?bougei (G.B.Sowerby III 1909)				*
Tellina crucigera Lamarck 1818				*
Tellina scobinata Linne 1758		*A		*
+*Arcopagia scobinata* (Linne 1758) (A)				
Loxoglypta rhomboides (Quoy & Gaimard 1835)				D
Semelidae				
Semele australis (Sowerby 1832)	*B	*A		*
Semelangulus crebrimaculatus (Sowerby 1868)	B			
+*S. nebulosus* Dall, Bartsch & Rehder 1938 (B)				
Trapeziidae				
Trapezium oblongum (Linne 1758)		*A		*
Veneridae				
Venus toreuma Gould 1850			D	
Periglypta reticulata (Linne 1758)		*		
GASTROPODA				
Haliotidae				
Haliotis pulcherrima Gmelin 1791	B	*A		*
Patellidae				
Patella flexuosa Quoy & Gaimard, 1834		*A		*
Cellana taitensis (Roding 1798)			H	
Acmaeidae				
Patelloida conoidalis (Pease 1868)		*A		
Patelloida sp.aff.*chamorrorum* Lindberg&Vermeij 1985		*		
Trochidae				
Cantharidus marmoreus (Pease 1867)[1]		*A		
Stomatellidae				
Broderipia iridescens (Broderip 1834)		A		
Pseudostomatella speciosa (A. Adams 1850)		A		
Turbinidae				
Turbo argyrostomus Linne 1758[1]	*B	*A	G	G

	Duc	Hen	Pit	Oen
Turbo petholatus Linne 1758	B	*A		
Turbo setosus Gmelin 1791	*	*		
Astralium confragosum (Gould 1849)	B			
Neritidae				
Nerita morio (Sowerby 1833)	BC	*AC	C	C
+*Nerita haneti* Recluz 1841 (B)				
Nerita plicata Linne 1758	*B	*A		*
Littorinidae				
Littoraria coccinea (Gmelin 1791)		*AK	K	K
Nodilittorina pyramidalis pascua Rosewater 1970		*AC	C	C
Cerithiidae				
Pseudovertagus clava (Gmelin 1791)[1]	BM		M	*M
Rhinoclavis sinensis (Gmelin 1791)	BM	*A	M	*M
Cerithium ?alveolus Hombron & Jaquinot 1852		*		
Cerith. atromarginatum Dautzenberg&Bouge1933		*A		
Cerithium columna Sowerby 1834		*		
Cerithium echinatum (Lamarck 1822)	*B	*A		*
+*Cerithium rubus* Deshayes 1843 (A)				
+*Cerithium tuberculiferum* Pease 1869 (B)				
Cerithium egenum Gould 1849		A		
Cerithium sandvichense Sowerby 1865	B	*		
Royella sinon (Bayle 1880)		*A	L	
Planaxidae				
Planaxis brasiliana Lamarck 1822			C	
Vermetidae				
Dendropoma maximum (Sowerby 1825)	B	A		
Epitoniidae				
Epitonium torquatum (Fenaux 1943)		A		
Janthinidae				
Janthina janthina (Linne 1758)		*A		*
Recluzia johni (Holten 1802)[1]		*		
Cypraeidae				
Cypraea ?bistrinotata(Schilder&Schilder1937)		*		
Cypraea caputserpentis Linne 1758	*B	A		*
Cypraea childreni Gray 1825		A		
Cypraea cicercula Linne 1758		A		
Cypraea cumingii Sowerby 1832		*A		
Cypraea dillwyni Schilder 1922		*A		
Cypraea fimbriata Gmelin 1791		A		
Cypraea goodalli Sowerby 1832		*A		
Cypraea helvola Linne 1758	B	*A		*
Cypraea irrorata Gray 1828		*A		
Cypraea isabella Linne 1758		*A		*
Cypraea kingae Rehder & Wilson 1975			F	
Cypraea lynx Linne 1758		*		
Cypraea maculifera (Schilder 1932)	*B	*?,A		
Cypraea mappa Linne 1758		A		
Cypraea moneta Linne 1758	*			
Cypraea poraria Linne 1758	*	*A		
Cypraea schilderorum Iredale 1939	*B	*A		*
Cypraea scurra Gmelin 1791		A		

	Duc	Hen	Pit	Oen
Cypraea subteres Weinkauff 1881		A		
Cypraea testudinaria Linne 1758	*B	*		
Cypraea ventriculus Lamarck 1810		*A		
Triviidae				
Trivia edgari Shaw 1909		A		
Vanikoridae				
Vanikoro ?acuta (Recluz 1844)		*		
Vanikoro plicata (Recluz 1844)		A		
Vanikoro sp.		*		
Hipponicidae				
Sabia conica (Schumacher 1817)	*?,B	*		
Calyptraeidae				
Cheilea equestris (Linne 1758)		*		*
Strombidae				
Strombus maculatus Sowerby 1842	*	*		*
Lambis chiragra (Linne 1758)		A		
+*Lambis rugosa* (Sowerby 1842) (A)				
Lambis truncata (Lightfoot 1782)		A		
Naticidae				
Polinices simiae (Deshayes 1838)[1]		*A		
Natica gualteriana Recluz 1844		A		
Natica ochrostigmata Rehder 1980		*	G	
Tonnidae				
Tonna perdix (Linne 1758)		*		*
Malea pomum (Linne 1758)				*
Cassidae				
Casmaria erinaceus (Linne 1758)	B	*A		*
Cymatiidae				
Cymatium nicobaricum (Roding 1798)		*		
Bursidae				
Bursa granularis (Roding 1798)		*A		
Muricidae				
Maculotriton serriale (Deshayes 1834)		*A		
+*Maculotriton serrialis* (Laborde 1838) (A)				
Phyllocoma convoluta (Broderip 1833)		A		
Drupa clathrata (Lamarck 1816)		*A	I	
Drupa elegans (Broderip & Sowerby 1829)	B	A		
Drupa grossularia Roding 1798	*B	*A		
Drupa morum Roding 1798	B	*A	I	
Drupa ricinus (Linne 1758)	*B	*A	I	
Drupa speciosa (Dunker 1867)				I
Drupella cornus (Roding 1798)	B	*		
+*D. elata* (Blainville 1832) (B)				
Morula dealbata (Reeve 1846)		A		
Morula granulata (Duclos 1832)	B	*A		
Morula "parva" (Pease 1868)		*		
Morula uva Roding 1798	*B	*A		
Thais armigera Link 1807		*A		
+*Thais affinis* (Reeve 1846) (A)				
Thais intermedia (Kiener 1835)		A		
Nassa serta (Bruguiere 1789)	*B	*A		
Vexilla vexillum (Gmelin 1791)		A		

Coralliophilidae	**Duc**	**Hen**	**Pit**	**Oen**
Coralliophila latilirata Rehder 1985[1]	*	*		
Coralliophila violacea (Kiener 1836)	*	*		
Quoyula monodonta (Blainville 1832)		*A		
Magilopsis cf. *lamarckii* (Deshayes 1863)		*		
Rapa rapa (Linne 1758)		*		
Buccinidae				
Engina fuscolineata E.A.Smith 1913[1]		*A		
Engina rosacea (E.A. Smith 1913)		A		
Prodotia iostoma (Gray, 1834)		*A		
+*Tritonidea difficilis* E.A. Smith 1913 (A)				
Pisania decollata (Sowerby 1833)		*		
Caducifer decapitata (Recluz 1844)		*A		
Nassariidae				
Nassarius gaudiosus (Hinds 1844)		*A		
Nassarius papillosus (Linne 1758)		A		
+*Alectrion papillosa* (Linne 1758) (A)				
Fasciolariidae				
Fusinus galatheae bountyi Rehder&Wilson 1975			F	
Latirus nodatus (Gmelin 1791)	B	*A		
Peristernia nassatula (Lamarck 1822)		*		
Columbellidae				
Euplica loisae Rehder 1980			C	
Euplica turturina (Lamarck 1822)	B	*A		
+*Euplica palumbina* (Gould 1845) (A,B)				
Euplica varians (Sowerby 1834)		*A		
Pyrene flava (Bruguiere 1789)		*A	G	
+*Pyrene obtusa* (Sowerby 1832) (A)				
Colubrariidae				
Colubraria nitidula (Sowerby 1833)		A		
Colubraria sp.		*		
Vasidae				
Vasum armatum (Broderip 1833)		A		
Harpidae				
Morum ponderosum (Hanley 1858)		A		
Mitridae				
Mitra auriculoides Reeve 1845		A		
Mitra coffea Schubert & Wagner 1829		A		
Mitra colombelliformis Kiener 1838			J	
Mitra coronata Lamarck 1811			J	
Mitra litterata Lamarck 1811	*B	A		
Mitra pele Cernohorsky 1970			J	
Mitra stictica (Link 1807)		A		
Mitra testacea Broderip 1836			J	
Ziba cernohorskyi Rehder & Wilson 1975			F	
Vexillidae				
Vexillum cancellarioides Anton 1838		*		
Turridae				
Daphnella flammea (Hinds 1943)		*		
Conidae				
Conus chaldeus (Roding 1798)	*B	*A		
Conus ebraeus Linne 1758	B	*A		*
Conus flavidus Lamarck 1810	*			

	Duc	Hen	Pit	Oen
Conus geographus Linne 1758	*B	*		
Conus litoglyphus Hwass 1792		*		
Conus lividus Hwass 1792	B	*A		*
Conus magnificus Reeve 1843		*		
Conus miliaris Hwass 1792	*B	*A		
Conus nanus Sowerby 1833	*B	*A		
Conus pennaceus Born 1778		A		
Conus rattus Hwass 1792	B	*A		
Conus retifer Menke 1829	B	*A		
Conus sanguinolentus Quoy & Gaimard 1834		A		
Conus sponsalis Hwass 1792		A		
Conus tenuistriatus Sowerby 1856		A		
Conus tessullatus Born 1778		*A		
Conus textile Linne 1758		*		*
Conus tulipa Linne 1758	B	*A		
Terebridae				
Terebra affinis Gray 1834		*		
Terebra crenulata (Linne 1758)				*
Terebra maculata (Linne 1758)				*
Terebra subulata (Linne 1767)	B			
Hastula penicillata (Hinds 1844)		*		
Elobiidae				
Melampus flavus (Gmelin 1791)		*A		
Bullidae				
Bulla cf. *punctulata* A.Adams 1850		*		
Bulla sp.		A		
Aplysiidae				
Dolabrifera cf. *fusca* Pease 1868	B			
Phyllidiidae				
Phyllidia sp. *?pustulosa* Cuvier 1804				*
Glaucidae				
Glaucus atlanticus Forster 1777		*		

Table 3
Pitcairn Group echinoderms

*) 1987 collections; x) 1987 sight records, not collected; A) Randall & Rehder 1975; B) Marsh 1974; C) Devaney 1974; D) Randall 1978; [1]) These species are discussed in more detail in the text. Duc: Ducie, Hen: Henderson, Pit: Pitcairn, Oen: Oeno.

ECHINOIDEA	**Duc**	**Hen**	**Pit**	**Oen**
Diadematidae				
Diadema savignyi (Audouin 1826)[1]	*A?	*		x
Echinothrix calamaris (Pallas 1774)		*		
Toxopneustidae				
Tripneustes gratilla (Linne 1758)		*		
Echinometridae				
Echinometra mathaei (de Blainville 1825)[1]		*		
Echinometra oblonga (de Blainville 1825)[1]	*	*		
Echinometra sp. 1[1]	*			*
Echinostrephus aciculatus A. Agassiz 1863	*	*		
Heterocentrotus mamillatus (Linne 1758)[1]	*A	D	*	
Heterocentrotus trigonarius (Lamarck 1816)[1]	*A	*		x
Echinoneidae				
Echinoneus cyclostomus Leske 1778[1]		*		*
Clypeasteridae				
Clypeaster sp. ?*reticulatus* (Linne 1758)		*		
Fibulariidae				
Mortonia australis (Desmoulins 1835)		*		*
Brissidae				
Brissus latecarinatus (Leske 1778)	*			
Metalia spatagus (Linne 1758)[1]		*		
ASTEROIDEA				
Astropectinidae				
Astropecten polyacanthus Mueller & Troschel 1842			B	
Oreasteridae				
Culcita novaeguineae Mueller & Troschel 1842			*B	
Ophidiasteridae				
Dactylosaster cylindricus (Lamarck 1816)		*		
Linckia guildingi Gray 1840			*B	
Linckia laevigata (Linne 1758)			B	
Linckia multifora (Lamarck 1816)		*	B	*
Neoferdina cumingi (Gray 1840)		*		
Ophidiaster lorioli Fisher 1906			B	
Acanthasteridae				
Acanthaster planci (Linne 1758)	AB		B	
Asteriidae				
Allostichaster peleensis Marsh 1974[1]		*	B	
OPHIUROIDEA				
Ophiacanthidae				
Amphilimna tanyodes Devaney 1974			C	
Amphiuridae				
Amphiura bountyia Devaney 1974			C	
Ophiactidae				
Ophiactis sp.	*			

Ophiotrichidae	**Duc**	**Hen**	**Pit**	**Oen**
Macrophiothrix demessa (Lyman 1861)			C	C
Macrophiothrix sp.		*		
Ophiothrix purpurea Martens 1867			C	
Ophiocomidae				
Ophiocoma bervipes Peters 1851			C	C
Ophiocoma dentata Mueller & Troschel 1842		*	C	*C
Ophiocoma cf. *doderleini* Loriol 1899		*		
Ophiocoma erinaceus Mueller & Troschel 1842		*	C	C
Ophiocoma longispina HL Clark 1917			C	
Ophiocoma macroplaca (HL Clark 1915)			C	
Ophiocoma pica Mueller & Troschel 1842		*	C	C
Ophiocoma pusilla (Brock 1888)			C	
Ophiocomella sexradia (Duncan 1887)			C	C
Ophionereidae				
Ophionereis aff. *dubia* (Mueller & Troschel 1842)		*		
Ophionereis porrecta Lyman 1860			C	
Ophiodermatidae				
Ophiarachna megacantha erythema Devaney 1974			C	
Ophiopeza kingi Devaney 1974			C	
HOLOTHUROIDEA				
Holothuriidae				
Actinopyga mauritiana (Quoy & Gaimard 1833)		*		
Actinopyga palauensis Panning 1944[1]		*		
Holothuria (Halodeima) atra Jaeger 1833	*	*		x
Holothuria (Halodeima) signata Ludwig 1875[1]		*	*	*
Holothuria (Lessonothuria) sp. 3[1]		*		
Holothuria (Microthele) nobilis (Selenka 1867)	*	*	*	x
Holothuria (Platyperona) difficilis Semper 1868	*			*
Holothuria (Semperothuria) cinerascens (Brandt 1835)	*			
Holothuria (Thymiosycia) arenicola Semper 1868		*		
Holothuria (Thymiosycia) hilla Lesson 1830				*
Holothuria (Thymiosycia) impatiens (Forskal 1775)				*
Labidodemas semperianum Selenka 1867		*		
Synaptidae				
Euapta godeffroyi (Semper 1868)	*	*		
Chiridotidae				
Chiridota hawaiiensis Fisher 1907				*
Chiridota sp.		*		

Table 4
Species in Pitcairn Group that are known only from subtropical areas

Other islands from which species[1] is recorded: Eas: Easter & Sala y Gomez, Rap: Rapa & Marotiri, Aus: Australs, Gam: Gambiers, Ker: Kermadecs, LoH: Lord Howe and Norfolk, Aus: Australian subtropics and N New Zealand, Haw: Hawaiian Islands.

Species	Eas	Rap	Aus	Gam	Ker	LoH	Aus	Haw
Nerita morio	*	*	*	*				
Nodilittorina pyramidalis pascua	*							
Planaxis brasiliana					*	*	*	
Euplica loisae	*	*						
Fusinus galatheae[1]					*			
Mitra pele								*
Allostichaster peleensis[1]							*	
Ophiarachna megacantha erythema		*						

[1] Represented by related subspecies or sister species outside the Pitcairns.

ATOLL RESEARCH BULLETIN

NO. 327

DIPTERA (INSECTA) OR TRUE FLIES OF THE PITCAIRN GROUP (DUCIE, HENDERSON, OENO, AND PITCAIRN ISLANDS)

BY

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ABSTRACT

An annotated checklist of the Diptera or true flies of the Pitcairn Group (southeastern Polynesia) with emphasis on the fauna of Henderson Island is presented. Although 59 species of Diptera are reported here, which is a substantial increase in the number of species that was known earlier, the fauna must still be considered depauparate. As is typical of oceanic islands of eastern Polynesia, the Pitcairn-Group fauna lacks many taxonomic groups. Most of the species apparently dispersed to the Pitcairn Group from other islands to the west and north, primarily within Polynesia. Only five species are apparently endemic to the Pitcairn Group, and with better sampling, even these may be found elsewhere. Two species, an otitid and a calliphorid, were known previously only from the neotropics.

INTRODUCTION

Remote and exotic, the islands of the Pitcairn Group are poorly known, especially their natural history. Our meager knowledge of them is due largely to their remoteness, which, ironically, now makes them inviting to study because their fauna and flora are relatively undisturbed. Only Pitcairn, of *Mutiny on the Bounty* fame, has been inhabited in recent times, and of the four islands comprising the Group, it alone bears the lasting imprint of human disturbance. The Pitcairn Group lies in the South Pacific along the southern boundry of Polynesia between 23-25° south latitude and 124-131° west longitude. Besides Pitcairn, which is a geologically recent volcanic island, the other islands of the Pitcairn Group are Ducie and Oeno, both low-lying atolls, and Henderson, a raised atoll.

Although remote and poorly known, the Pitcairn Group has not been totally bypassed by man, least of all Pitcairn. During the past decade, for example, an American millionaire attempted first to buy and then to lease Henderson Island, the largest island of the Group. The intent of the procurement was to establish a small settlement and construct an airfield among other developments. Through the lobbying efforts of the Royal Society of England and the Smithsonian Institution, the procurement of Henderson Island was thwarted, and Henderson has now been proposed as a world heritage site to better preserve its unique geological features and depauparate fauna and flora. A history of Henderson Island, including a summary of all previous work on the natural history of the island, was recently published by Fosberg, et al. (1983).

To better document the unique natural history of the Pitcairn Group, a Smithsonian-sponsored expedition visited these islands in 1987. The purposes of the expedition were: to conduct biological and geological reconnaissance of the islands and to gather data that are needed to determine the feasibility of more long-term research on the islands. The efforts of the Smithsonian team were primarily focused on Henderson Island because of recent threats to its conservation, its unique geology, and its much larger size.

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Because of complex logistics, limited budgets, and tight schedules, the reconnaissance work was restricted to brief stays on each of the islands. Our visits to Ducie and Oeno atolls were for a few hours on the afternoons of May 10th and 28th respectively. Nine days were devoted to Henderson (May 12-21), and four days were spent on Pitcairn (May 22-26).

As documented in Fosberg, et al., the insects of Henderson Island are virtually unknown. Less than 35 species in five orders had been recorded prior to our survey, and of these, only two were dipterans, *Dacus setinervis* Malloch and *Atherigona hendersoni* Malloch. The Diptera of the other islands are no better known. Thus, the purpose of this paper is to report on the Diptera or true flies of the Pitcairn Group that were collected on the Smithsonian expedition.

Although only two dipterous species had been reported previously from Henderson Island, we anticipated the discovery of many more. Herein, nearly 60 species are treated, and although this represents a major increase in the number of species recorded for these islands, many additional species will undoubtedly be discovered as these islands are further sampled for longer periods of time, at different seasons, and using different collecting techniques. We collected Diptera with an aerial net and a Malaise trap that was sometimes baited.

For each species treated, the following information is provided: the name of the species plus its author, year, and page of publication; immediately following these data and continuing on the same line is the name of the person who made the species determination (the author made the identification if no one is noted) and major references to the species. Thereafter as information is available are sections on "Specimens Examined" (distribution on islands of the Pitcairn Group, including the number and gender of the specimens; specimens are deposited in the USNM unless noted otherwise) and "Distribution" (generalized account of a species distribution). Information on the natural history and other comments as available and appropriate are included under a "Remarks" section.

Gustav Paulay and I were the two entomologists on the Smithsonian team, and most of the insects, including all of the Diptera, were collected by us. Determinations of species are as authoritative as possible short of revising each group to which a species belongs. For a few species, primary types were examined, but for most identifications, I relied on the expertise of specialists.

On Henderson Island, we sampled two primary sites as follows: the NW Beach from May 12-20 and the North Beach from May 17-20. From these two beaches, we made short excursions inland to a few more sites, but even the more productive of these were within the vicinity of the beaches. The inland sites will be noted more specifically in the "Specimens Examined" section for each species.

Two primary sites were sampled on Pitcairn Island. The first, and by far the more extensively collected, was Adamstown, the only settlement on the island. The settlement occupies nearly one-fourth of the island and includes a number of different habitats from the rocky shores of Bounty Bay, the only harbor of the island, to garden plots and orchards near the homes. Where appropriate, Adamstown has been annotated with the specific habitat in the listing under the "Specimens Examined" section. The second site on Pitcairn was the beach at Down Rope. Down Rope is the only sandy beach of Pitcairn, is approximately 150 meters in length, and is only accessible from a steep trail down a cliff face on the southeast side of the island.

Because of their small size, essentially all of the main islet of both Oeno and Ducie were surveyed, although very hurriedly and superficially.

In accordance with the editorial policy of this publication series, new taxa are not described herein; these will be published elsewhere.

TREATMENT OF TAXA

SUBORDER NEMATOCERA

Family Sciaridae

1. **Bradysia** sp. (det. R.J. Gagné).
   Specimens Examined.--Pitcairn Island. Adamstown (2♀).
   Remarks.--The genus *Bradysia* comprises numerous species, and recognition of most are based on sexually dimorphic characters of males. Thus the two female specimens that we collected cannot be distinguished at the species level.

Family Psychodidae

2. **Psychoda** sp. (det. R.V. Peterson).
   Specimens Examined.--Henderson. NW Beach (4♂, 7♀).
   Remarks.--All specimens were collected in a Malaise trap during the night.

Family Culicidae

3. **Aedes (Stegomyia) aegypti** (Linnaeus, 1762:470; det. Y.M. Huang).
   Specimens Examined.--Pitcairn Island. Adamstown (9♂, 1♀).
   Distribution.--Pantropical, mostly within the 10° C. isotherms.
   Remarks.--The literature on this species is voluminous, especially as it pertains to its vectoral capacity of numerous diseases of man. This species is the common man biter on Pitcairn, and its potential there as a vector of diseases should not be overlooked.

4. **Culex (Culex) quinquefasciatus** Say, 1823:10 (det. Y.M. Huang).
   Specimens Examined.--Pitcairn Island. Adamstown (1♀).
   Distribution.--Cosmopolitan.
   Remarks.--This species, like the preceding one, is the vector of several diseases, mostly arboviruses, of man. Caution, therefore, should be exercised to avoid establishment of these diseases on Pitcairn.

Family Chironomidae

5. **Chironomus** s.l. sp. (det. P. Cranston).
   Specimens Examined.--Henderson. North Beach (1♀).

Family Ceratopogonidae

6. **Dasyhelea pacifica** Macfie, 1933:99 (det. W.W. Wirth).
   Specimens Examined.--Henderson. North Beach (9♂, 3♀).
   Distribution.--Oceania: Common on Marquesas and Society Islands and the Pitcairn Group.

7. **Dasyhelea fulvicauda** Macfie, 1933:101 (det. W.W. Wirth).
   Specimens Examined.--Henderson. North Beach (1♀).
   Distribution.--Oceania: Common on Marquesas and Society Islands and the Pitcairn Group; Oriental: Taiwan.

8. **Dasyhelea** n. sp. (in *mutabilis* group)(det. W.W. Wirth).
   Specimens Examined.--Henderson. North Beach (5♂, 5♀).
   Distribution.--Oceania: The Pitcairn Group.

9. **Forcipomyia (Euprojoannisia) sauteri** Kieffer, 1912:27 (det. W.W. Wirth).
   Specimens Examined.--Henderson. North Beach (6♂, 5♀).
   Distribution.--Oceania: The Pitcairn Group; Oriental: Taiwan.

SUBORDER BRACHYCERA

Family Dolichopodidae

10. **Chrysosoma n.** sp. (det. D.J. Bickel).

Specimens Examined.--Henderson. NW Beach (12♂, 11♀); North Beach (4♀).

Distribution.--Oceania: Society Islands and the Pitcairn Group.

Remarks.--Most of the specimens taken from the NW Beach were collected individually from the broad leaves of a shrub that was growing on top of the escarpment just above the beach.

11. **Chrysotus denticornis** Lamb, 1932:233 (det. D.J. Bickel).

Specimens Examined.--Pitcairn Island. Adamstown (4♂, 5♀).

Distribution.--Oceania: Society and Marquesas Islands and the Pitcairn Group.

12. **Cymatopus** n. sp. (det. D.J. Bickel).

Specimens Examined.--Pitcairn Island. Adamstown (14♂, 6♀).

Distribution.--Oceania: Cook Islands and the Pitcairn Group.

Family Phoridae

13. **Chonocephalus** sp. A. (det. H. Disney).

Specimens Examined.--Henderson Island. NW Beach (5♂).

14. **Chonocephalus** sp. B. (det. H. Disney).

Specimens Examined.--Henderson Island. NW Beach (4♂).

15. **Megaselia (Megaselia) scalaris** (Loew, 1866b:53; det. H. Disney).

Specimens Examined.--Pitcairn Island. Adamstown (1?, abdomen missing).

Distribution.--Pantropical.

Remarks.--*Megaselia* has hundreds of species of which most are difficult to distinguish even when the male genitalia are intact. Hence the determination of this species must be considered tentative (Disney, in litt.).

16. **Dohrniphora cornuta** (Bigot, 1857:348; det. H. Disney).

Specimens Examined.--Henderson Island. NW Beach (2♂).

Distribution.--Pantropical.

Remarks.--This species, which was originally described from Cuba, is common throughout the tropics.

Family Syrphidae

17. **Ischiodon scutellaris** (Fabricius, 1805:252; det. F.C. Thompson).

Specimens Examined.--Henderson Island. NW Beach (5♂).

Distribution.--Orient: SE Asia and Japan; Australasian: Australia; Oceania: Hawaii, Micronesia, and the Pitcairn Group.

Remarks.--This species was attracted to flowers of *Pemphis acidula* Forst. that appeared to be in the last stages of flowering in May. *Pemphis acidula* is common on Henderson as a shrub or tree between the beach and cliff face.

Family Otitidae

18. **Perissoneura diversipennis** Malloch, 1932:207.

Specimens Examined.--Henderson Island. NW Beach (60♂, 45♀); North Beach (6♂, 5♀). Oeno Atoll (7♂, 9♀).

Distribution.--Oceania: Marquesas (Fatu Uku and Hatu Tu) and the Pitcairn Group.

Remarks.--The wings of this species demonstrate considerable sexual dimorphism. Those of the male bear a pattern, whereas the female's are hyaline. This species is fairly abundant, especially on Henderson, and occurred mostly on low-lying vegetation in the shade. Adults were also attracted to human feces.

19. **Acrosticta apicalis** (Williston, 1896:375; det. G.C.Steyskal).--Malloch, 1932:206 (list, Marquesas).

Specimens Examined.--Pitcairn Island. Adamstown (1♀).

Distribution.--Widely distributed from the Neotropics, Africa, several islands of Oceania (Fiji, Samoa, Society Islands, Marquesas, Hawaii) and now the Pitcairn Group.

Remarks.--This species was collected while randomly sweeping vegetation.

20. **Euxesta stigmatias** Loew, 1868:310 (det. G.C. Steyskal).

Specimens Examined.--Pitcairn Island. Adamstown (1♂, 1♀).

Distribution.--Neotropics: Mexico and the West Indies, south to Brazil and Bolivia; Oceania: The Pitcairn Group.

Remarks.--This species was collected while randomly sweeping vegetation. Our collections on Pitcairn are the first records outside of the Neotropical Region.

Family Platystomatidae

21. **Scholastes lonchifera** Hendel, 1914:253.--Malloch, 1932:206 (list, Marquesas).

Specimens Examined.--Henderson Island. NW Beach (45♂, 40♀); North Beach (12♂, 7♀). Oeno Atoll (5♂, 5♀). Pitcairn Island. Adamstown (2♀).

Distribution.--Oceania: Society Islands (Tahiti), Cook Islands, Marquesas (Hiva Oa, Fatu Hiva, Ua Huka, Ua Pou), and the Pitcairn Group.

Remarks.--This species occurs commonly on shaded, low-lying vegetation, especially beneath coconut palms on Henderson and Oeno. The larvae of *Scholastes* breed in rotting vegetable matter, and at least one species, *S. bimaculatus* Hendel, breeds in rotting coconuts (Swezey, 1924:389-390). Adults are also attracted to human feces.

22. **Pseudorichardia flavitarsis** Macquart, 1850:121.--Malloch, 1932:206 (list, Marquesas).

Specimens Examined.--Henderson Island. NW Beach (1♂, 26♀); North Beach (1♂, 1♀). Oeno Atoll (2♂). Pitcairn Island. Adamstown (1♂, 1♀).

Distribution.--Oceania: Widespread from Fiji to the Society Islands (Tahiti), the Marquesas (Hiva Oa), and the Pitcairn Group.

Remarks.--This species is the type species of *Pseudorichardia.* Nearly all of the specimens from Henderson were taken from the sides of a tent or on vegetation near the site where birds were being prepared as museum specimens. Numerous bird skins and carcasses were usually hung or laid out to dry and apparently attracted this species.

Family Tephritidae

23. **Dacus setinervis** Malloch, 1938:112.

Specimens Examined.--Henderson Island. NW Beach (1♀). Pitcairn Island. Adamstown (2♂, 3♀).

Distribution.--This species is apparently endemic to the Pitcairn Group, where it is known from the type locality, Henderson Island, and now from Pitcairn.

Remarks.--Our previous knowledge of the Diptera of Henderson Island was limited to this and a species of Muscidae, both of which were thought to be endemic to this island. This species is now known from Pitcairn, where most specimens were collected on vegetation that had overgrown an old shed in Adamstown.

24. **Dioxyna sororcula** (Wiedemann, 1830:509; det. A.L. Norrbom).

Specimens Examined.--Pitcairn Island. Adamstown (3♂, 3♀).

Distribution.--Widespread in tropical and subtropical areas of the Old World and now the Pitcairn Group.

Remarks.--This species was originally described from specimens collected on the Canary Islands and has since been discovered to be widespread in tropical areas of the Old World. It was probably introduced to Pitcairn Island. This species lives in seeds of *Bidens*.

Family Lonchaeidae

25. **Lamprolonchaea metatarsata** (Kertész, 1901:83).

Specimens Examined.--Oeno Atoll (4♂, 4♀). Pitcairn Island. Adamstown (2♂, 4♀).

Distribution.--Widespread in Southeast Asia and Oceania.

Remarks.--This species was probably introduced to Oeno and Pitcairn, perhaps in infested fruit.

Family Lauxaniidae

26. **Homoneura hawaiiensis** (Grimshaw, 1902:84).--Hardy and Delfinado, 1980:134-135 (description and figures).

Specimens Examined.--Henderson Island. NW Beach (27♀). Oeno Atoll (11♂, 10♀). Pitcairn Island. Adamstown (2♂, 13♀).

Distribution.--Oceania: Marquesas, Society Islands, Samoa, Solomon Islands, Hawaii, and the Pitcairn Group.

Remarks.--This species was fairly common and was swept from low-lying, shaded vegetation. On the NW Beach of Henderson, most specimens were collected by sweeping ferns.

Family Milichiidae

27. **Leptometopa beardsleyi** Hardy and Delfinado, 1980:358 (det. C.W. Sabrosky).

Specimens Examined.--Henderson Island. NW Beach (2♀); North Beach (1♀). Oeno Atoll (5♂).

Distribution.--Oceania: Hawaii and the Pitcairn Group.

Remarks.--The specimen from North Beach was collected from guano-covered vegetation that was growing next to the nesting area of a masked booby (*Sula dactylatra* Lesson). In addition to the specimens noted above, a female from Oeno that is possibly a variety of *beardsleyi* was collected. Because intraspecific variation within *beardsleyi* has not been assessed and as the specimen in question is in poor condition, it is not specifically listed as this species.

28. **Desmometopa inaurata** Lamb, 1914:363 (det. C.W. Sabrosky).--Sabrosky, 1983:33 (revision).

Specimens Examined.--Pitcairn Island. Adamstown (2♂, 2♀).

Distribution.--Widespread throughout the world except for the Oriental Region. Oceania: Fiji, Samoa, Hawaii, Marquesas, and the Pitcairn Group.

Remarks.--This species was probably introduced to Pitcairn Island.

29. **Milichiella lacteipennis** (Loew, 1866a:185; det. C.W. Sabrosky).

Specimens Examined.--Pitcairn Island. Adamstown (3♀).

Distribution.--Cosmopolitan.

Remarks.--Like the previous species, this was probably introduced to Pitcairn Island.

Family Sphaeroceridae

30. **Coproica hirtula** (Rondani, 1880:38; det. A.L. Norrbom).

Specimens Examined.--Pitcairn Island. Adamstown (11♂, 9♀).

Distribution.--Cosmopolitan.

Remarks.--This is undoubtedly an introduction to Pitcairn Island.

Family Xenasteiidae

31. **Xenasteia palauensis** Hardy, 1980:218.

Specimens Examined.--Henderson Island. NW Beach (10♂, 14♀). Pitcairn Island. Adamstown (1♀).

Distribution.--Oceania: Palau and the Pitcairn Group.

Remarks.--This species was moderately common on low-lying vegetation that was growing immediately next to an open-air latrine, the contents of which apparently attracted it.

The identification of this species as *X. palauensis* must be considered tentative. When Hardy (1980:219-220) described this species he noted that several specimens other than the type series may represent this species or form a species complex of closely related species. The issue remains unresolved.

Family Chyromyidae

32. **Nannodastia horni** Hendel, 1930:70.--Sabrosky and Wirth, 1958:109-110.

Specimens Examined.--Henderson Island. North Beach (4♂, 9♀); NW Beach (6♂, 3♀).

Distribution.--Orient: Taiwan; Oceania: Hawaii and the Pitcairn Group.

Remarks.--Specimens of this species are tiny, usually less than 2 mm in length, and were collected in caves and under overhangs by sweeping a fine-meshed net just above the soil or debris on the floor. The caves and overhangs we sampled were 15-20 m above the beach on the cliff face.

Family Chloropidae

33. **Cadrema pallida** variety **bilineata** (Meijere, 1904:113; det. C.W. Sabrosky).

Specimens Examined.--Henderson Island. NW Beach (18♂, 70♀). Pitcairn. Adamstown (9♂, 15♀).

Distribution.--Widespread in the Orient and Oceania (extending to the Marquesas and south to the Pitcairn Group).

Remarks.--This species is moderately common on the beach at the high tide mark where debris had accumulated.

34. **Cadrema nigricornis** (Thomson, 1869:607; det. C.W. Sabrosky).

Specimens Examined.--Henderson Island. NW Beach (40♂, 46♀); North Beach (19♂, 8♀). Oeno Atoll (16♂, 1♀). Pitcairn Island. Adamstown (1♀).

Distribution.--Widespread in SE Asia and the Pacific islands to Hawaii, the Marquesas, and the Pitcairn Group.

Remarks.--Like the previous taxon, this species is also moderately common on the beach at the high tide mark where debris had accumulated.

35. **Cadrema samoaensis** (Malloch, 1930:246; det. C.W. Sabrosky).

Specimens Examined.--Pitcairn Island. Adamstown (3♂).

Distribution.--Oceania: Samoa (Salailua and Safune) and the Pitcairn Group.

36. **Tricimba adamsoni** Malloch, 1933:29 (det. C.W. Sabrosky).

Specimens Examined.--Pitcairn Island. Adamstown (2♀).

Distribution.--Oceania: Marquesas and the Pitcairn Group.

37. **Gaurax bicoloripes** (Malloch, 1933:30; det. C.W. Sabrosky).

Specimens Examined.--Henderson Island. NW Beach (1♀). Oeno Atoll (1♂, 1♀). Pitcairn Island. Adamstown (10♂, 4♀).

Distribution.--Oceania: Marquesas and the Pitcairn Group.

38. **Gaurax** n. sp. (det. C.W. Sabrosky).

Specimens Examined.--Henderson Island. NW Beach (24♂, 4♀). Pitcairn Island. Adamstown (1♂, 1♀).

Distribution.--Oceania: The Pitcairn Group.

Family Tethinidae

39. **Dasyrhiconoessa lasiophthalma** (Malloch, 1933:17).--Sasakawa, 1974:2 (figure of male genitalia).

Specimens Examined.--Oeno Atoll (6♂, 6♀). Pitcairn Island. Adamstown (harbor area) (17♂, 6♀); Down Rope (20♂, 5♀).

Distribution.--Afrotropical: Seychelles; Oriental: China (Hong Kong), Philippines; Oceania: Marquesas south to the Pitcairn Group.

Remarks.--The habitat for this species is beaches where debris has accumulated at or above the high tide mark. On Oeno and Pitcairn, the species occurred commonly in this habitat.

Family Canacidae

40. **Nocticanace** n. sp.

Specimens Examined.--Oeno Atoll (30♂, 11♀). Pitcairn Island. Adamstown (harbor area) (33♂, 11♀); Down Rope (2♂, 5♀).

Distribution.--Oceania: The Pitcairn Group.

Remarks.--I found this species commonly on all beaches of Pitcairn and Oeno that had large rocks (rock diameter of 0.5 m or larger) or exposed coral.

Family Ephydridae

41. **Placopsidella marquesana** (Malloch, 1933:13).--Tenorio, 1980:270-271, 350-351 (figures and description of larva and puparium).--Mathis, 1986:11-13 (revision).

Specimens Examined.--Pitcairn Island. Adamstown (harbor area) (11♂, 3♀); Down Rope (8♂, 9♀).

Distribution.--Oceania: Widespread in Oceania between the Solomon Islands and the Pitcairn Group and as far north as Hawaii.

Remarks.--This species was moderately abundant on the rocky beach of Bounty Bay, especially among larger rocks (0.5 m in diameter or larger) that offered some protection from the direct action of waves and the sun. Discovery of this species on Pitcairn is a major extension to its distribution; previously its farthest known locality southward was the Society Islands (Bora Bora and Tahiti)(Mathis, 1986).

42. **Hecamede granifera** Thomson, 1869:594.

Specimens Examined.--Henderson Island. NW Beach (88♂, 11♀); North Beach (56♂, 10♀). Oeno Atoll (34♂, 9♀). Pitcairn Island. Adamstown (7♂, 3♀); Down Rope (9♂, 6♀).

Distribution.--Oceania: The Marquesas (Nuku Hiva) and the Pitcairn Group.

Remarks.--The genus *Hecamede* needs revision before many of the available names can be validly applied. For the present, I am using *H. granifera* for this species in accordance with the recent catalog of Australasian and Oceanian Diptera (Mathis, 1989). A junior synonym, *H. inermis* Malloch, was used previously for the common species of *Hecamede* that occurs in the South Pacific.

This species was abundant on the beach, especially where debris had accumulated at the high tide mark. It was also common on specimens of corals and bird preparations that we had set out to dry.

43. **Atissa** sp.

Specimens Examined.--Pitcairn Island. Down Rope (1♂).

44. **Paratissa pollinosa** (Williston, 1896:414).

Specimens Examined.--Pitcairn Island. Adamstown (harbor area) (20♂, 7♀); Down Rope (7♂).

Distribution.--Neotropics: Dominica to St. Vincent and Panama; Oceania: Hawaii (Oahu and Maui) and the Pitcairn Group.

Remarks.--This species was collected on the rocky beach of Bounty Bay (Adamstown). Seaweed and other organic debris had accumulated at the specific site where the specimens were collected.

45. **Nostima striata** (Lamb, 1912:326; det. J. Edmiston).

Specimens Examined.--Oeno Atoll (11♂, 1♀).

Distribution.--Oceania: The Marquesas (Hiva Oa) and the Pitcairn Group.

Remarks.--Toward the northern end of Oeno are occasional patches of moss on the moist, mostly shaded soil beneath some of the larger trees. The patches of moss were no more than a meter or two in diameter, and the specimens seemed to be very specific to these patches.

Family Drosophilidae

46. **Drosophila (Sophophora) simulans** Sturtevant, 1919:153 (det. D.A. Grimaldi).

Specimens Examined.--Henderson Island. NW Beach (1♂, 1♀); North Beach (1♀). Pitcairn Island. Adamstown (1♂).

Distribution.--Cosmopolitan.

Remarks.--This species was probably introduced to Henderson and Pitcairn islands.

47. **Drosophila (Sophophora) melanogaster** species group (det. D.A. Grimaldi).

Specimens Examined.--Pitcairn Island. Adamstown (10♂, 14♀).

Distribution.--Cosmopolitan.

Remarks.--This species was undoubtedly introduced to Pitcairn Island.

48. **Phorticella** n. sp. (det. D.A. Grimaldi).
Specimens Examined.--Pitcairn Island. Adamstown (5♂, 3♀).
Distribution.--Oceania: The Pitcairn Group.
Remarks.--The genus *Phorticella* Duda includes eight species (Wheeler, 1981), all of which have Oriental distributions. Thus this species would be the first from Oceania.

49. **Scaptomyza (Bunostoma) australis** Malloch, 1923b:618 (det. D.A. Grimaldi).
Specimens Examined.--Henderson Island. NW Beach (1♂, 1♀).
Distribution.--Australasian: Australia; Oceania: The Pitcairn Group.
Remarks.--This is the first record of this genus in Polynesia except for numerous species on the Hawaiian Islands.

Family Agromyzidae

50. **Liriomyza** sp. (det. A. Freidberg).
Specimens Examined.--Pitcairn Island. Adamstown (1♂, 1♀).

51. **Pseudonapomyza** sp. (det. A. Freidberg).
Specimens Examined.--Pitcairn Island. Adamstown (1♀).

Family Muscidae

52. **Atherigona hendersoni** Malloch, 1923a:184 (det. A.C. Pont).
Specimens Examined.--Henderson Island. NW Beach (40♀). Oeno Atoll (4♀). Pitcairn Island. Adamstown (17♀).
Distribution.--Oceania: Fiji, Hawaiian Islands, Pitcairn Group, Tonga, Western Samoa.
Remarks.--This is one of the more common species of Diptera to occur on these and other islands of the South Pacific.

Family Fanniidae

53. **Fannia pusio** (Wiedemann, 1830:437; det. A.C. Pont).
Specimens Examined.--Henderson Island. NW Beach (1♂, 14♀). Oeno Atoll (9♂, 3♀). Pitcairn Island. Adamstown (1♂, 1♀).
Distribution.--Oceania: Easter Islands, Fiji, Guam, Hawaiian Islands, Kiribati (Gilbert I), Pitcairn Group, Wake I, Western Samoa, New Caledonia, Afrotropical, Nearctic, Neotropical.
Remarks.--Females were collected mostly by sweeping vegetation. An occasional specimen was captured in the Malaise trap. The single male from Henderson was part of a hovering swarm between three and four m above the ground.

Family Calliphoridae

54. **Phaenicia sericata** (Meigen, 1826:53; det. N.E. Woodley).
Specimens Examined.--Henderson Island. NW Beach (11♂, 9♀). Oeno Atoll (4♀). Pitcairn Island. Adamstown (7♂, 3♀).
Distribution.--Widespread throughout most of the Old World except for Africa and now the Pitcairn Group.
Remarks.--Nearly all of the specimens we collected were taken from areas where dead animals were being prepared as museum specimens or for food.

55. **Cochliomyia macellaria** (Fabricius, 1775:776; det. N.E. Woodley).
Specimens Examined.--Pitcairn Island. Adamstown (4♂, 8♀).
Distribution.--Southern USA south to Argentina and Chile and the Pitcairn Group.
Remarks.--This species was common around chicken coops and tables where dead fish were cleaned and prepared for cooking. It is almost surely an introduction and is known by the vernacular name of primary screw-worm.

56. **Hemipyrellia** sp. (det. N.E. Woodley).
Specimens Examined.--Henderson Island. NW Beach (8♀).

Family Sarcophagidae

57. **Sarcophaga (Liosarcophaga) dux** (Thomson, 1869:534; det. T. Pape).

Specimens Examined.--Henderson Island. NW Beach (26♂, 9♀).

Distribution.--Oriental: India, Sri Lanka, Java, Philippines, China; Palearctic: S. Korea, Japan; Oceania: Guam, Hawaiian Islands, Mariana Islands, Henderson I, Samoa, Caroline Islands, Wake, Marshall Islands, Gilbert Islands; Australasian: Australia.

Remarks.--This species was attracted to bird preparations that we had laid out to dry. Females were especially common and many deposited first-instar larvae on the preparations.

Family Hippoboscidae

58. **Ornithoica pusilla** (Schiner, 1868:384; det. R.V. Peterson).--Maa, 1966:94-97 (revision).

Specimens Examined.--Henderson Island. NW Beach (2♀); North Beach (on a masked booby, *Sula dactylatra* Lesson) (10♂, 4♀).

Distribution.--Oceania: Christmas Island, Marshall Islands, Tokelau Island, Tuamotu Archipelago, Society Islands (Tahiti), and the Pitcairn Group.

Remarks.--We collected specimens of this species directly from a nesting pair of masked boobies.

59. **Olfersia aenescens** Thomson, 1869:610 (det. R.V. Peterson).

Specimens Examined.--Ducie Atoll (on a red-tailed tropicbird, *Phaethon ribricauda* Boddaert) (6♂). Henderson Island. NW Beach (1♂, 1♀); North Beach (2♂).

Distribution.--Nearly cosmotropical over tropical seas as a parasite on various species of birds.

Remarks.--Most of the specimens that we collected on Henderson were taken as they would land on us. The specimens from Ducie Atoll were taken from a nesting red-tailed tropicbird. This is one of the few widespread species that probably occurs naturally on islands of the Pitcairn Group.

DISCUSSION

This study should only be considered within the limited perspective of two weeks of intensive field work and subsequent study of the resultant collections and observations. With more extensive collecting, including rearing of adults from immatures, more specialized collecting techniques (e.g. baits, Berlese funnels), and sampling at different seasons, the fauna of Diptera will undoubtedly be found to be more diverse. The same kind of sampling artifacts apply to attempts to determine the provenance of the fauna occurring on the Pitcairn Group.

Despite these qualifications, certain patterns are apparent from the available evidence. The evidence is summarized into tables (Tables 1-4) in which the islands of the Pitcairn Group are listed with the following abbreviations: DA = Ducie Atoll; HI = Henderson Island; OA = Oeno Atoll; PI = Pitcairn Island. For data in the tables that is cited under "Distribution Elsewhere," I have depended on the information provided by the specialist who identified the species and/or the forthcoming catalog of Diptera from the Australasian and Oceanian Regions (Evenhuis, 1989). Species determined simply as "sp." in the preceding section are not listed in the tables as we know nothing about their distribution.

The most apparent pattern is that the majority of Diptera from the Pitcairn Group probably dispersed there from other islands of Polynesia, and, moreover, that the Polynesian provenance reflects the overall pattern for Oceania in general, i.e., the Polynesian fauna of Diptera came mostly from the west, primarily from other islands but also from the Orient and Australia, including New Guinea. This is particularly evident from the data presented in Table 1. The species in this table, which constitute about two-thirds of the known fauna of the Pitcairn Group, are found elsewhere in Oceania, primarily Polynesia, or continental areas to the west. Most of these species either infiltrated from the west or they have sister groups occurring on islands or continents to the west.

The next largest category of Diptera are frequently referred to as "weeds" (Table 2). These species, numbering 11 on the Pitcairn Group, are pantropical or cosmopolitan, and for the most part, their occurrence reflects man's impact on these islands. The majority of these species occur only on Pitcairn Island, which is highly disturbed and where there is fairly regular commerce by which these flies could easily have been introduced.

Table 1. Distribution of Oceanian, Australian, and/or Oriental Diptera of the Pitcairn Group

	DA	HI	OA	PI	Distribution Elsewhere
Dasyhelea pacifica		X			Marquesas, Society
Dasyhelea fulvicauda		X			Marquesas, Society, Taiwan
Forcipomyia sauteri		X			Taiwan
Chrysosoma n. sp.		X			Society
Chrysotus denticornis				X	Marquesas, Society
Cymatopus n. sp.				X	Cook Islands
Ischiodon scutellaris		X			Oceania, widespread Asian
Perissoneura diversipennis		X			Marquesas
Acrosticta apicalis				X	Oceania, widespread tropics
Scholastes lonchifera		X	X	X	Widespread Oceanian
Pseudorichardia flavitarsis		X	X	X	Oceania east of Fiji
Lamprolonchaea metatarsata			X	X	Oceania, SE Asian
Homoneura hawaiiensis		X	X	X	Widespread Oceanian
Leptometopa beardsleyi		X	X		Hawaii
Desmometopa inaurata				X	Widespread Oceanian
Xenasteia palauensis		X		X	Oceanian
Nannodastia horni		X			Hawaii, Taiwan
Cadrema pallida bilineata		X		X	Oceanian, widespread Oriental
Cadrema nigricornis		X	X	X	Oceanian, SE Asian
Cadrema samoaensis				X	Samoa
Tricimba adamsoni				X	Marquesas
Gaurax bicoloripes		X	X	X	Marquesas
Dasyrhiconoessa lasiophthalma			X	X	Oceanian, Seychelles, China
Placopsidella marquesana				X	Widespread Oceanian
Hecamede granifera		X	X	X	Marquesas
Paratissa pollinosa				X	Hawaii, Caribbean
Nostima striata				X	Marquesas
Scaptomyza australis		X			Australia
Atherigona hendersoni		X	X	X	Polynesian
Fannia pusio		X	X	X	Polynesian, New Caledonia
Sarcophaga dux		X			Oceanian, Oriental
Ornithoica pusilla		X			Widespread Oceanian

Endemism among Diptera from the Pitcairn Group is surprisingly low, with only five potential species (Table 3). Although these five are known thus far only from the Pitcairn Group, I would not be surprised to learn of their occurrence elsewhere. This potential is exemplified by the taxonomic history of *Atherigona hendersoni.* This species was originally described from specimens collected on Henderson Island (Malloch, 1923a) but has now been found as far west as Fiji and to the north as far as Hawaii (Adrian Pont, personal communication).

The neotropical otitid and calliphorid species (Table 4) that were unknown previously from Oceania are interpreted to be "baggage" that has accompanied man's arrival in recent times. The calliphorid is the primary screw worm of large mammals in the Western Hemisphere and could have arrived on Pitcairn Island with the various introductions of feral goats.

Table 2. Distribution of Cosmopolitan or Pantropical Diptera found on the Pitcairn Group

	DA	HI	OA	PI	Distribution Elsewhere
Aedes aegypti				X	Pantropical
Dohrniphora cornuta		X			Pantropical
Olfersia aenescens	X	X			Pantropical
Dioxyna sororcula				X	Old World tropics
Phaenicia sericata		X	X	X	Widespread Old World
Culex quinquefasciatus				X	Cosmopolitan
Megaselia scalaris				X	Cosmopolitan
Milichiella lacteipennis				X	Cosmopolitan
Coproica hirtula				X	Cosmopolitan
Drosophila simulans		X		X	Cosmopolitan
Drosophila melanogaster				X	Cosmopolitan

Table 3. Distribution of Endemic Diptera of the Pitcairn Group

	DA	HI	OA	PI	Distribution Elsewhere
Dasyhelea n. sp.		X			Pitcairn Group
Dacus setinervis		X		X	Pitcairn Group
Gaurax n. sp.		X		X	Pitcairn Group
Nocticanace n. sp.			X	X	Pitcairn Group
Phorticella n. sp.				X	Pitcairn Group

Table 4. Distribution of Neotropical Diptera found on the Pitcairn Group

	DA	HI	OA	PI	Distribution Elsewhere
Euxesta stigmatias				X	Widespread neotropics
Cochliomyia macellaria				X	Widespread neotropics

CONCLUSIONS

This study of the Diptera from the Pitcairn Group reveals a much richer fauna than was reported previously. The results were largely expected, however, as insects are the dominant terrestrial group on most oceanic islands, especially those of the Pacific. The order Diptera, in turn, is one of the major components of the Insecta. Furthermore, these islands had not been visited previously by a specialist on Diptera, and the use of specialized knowledge and collecting techniques would normally result in additional finds.

Despite the substantial increase in the number of known species, from two to nearly 60, the dipterous fauna of the Pitcairn Group must still be considered depauperate and very disharmonic (lacking major lineages within the groups represented). These two conditions were likewise predictable. Nearly 30 years ago, Gressitt (1961) wrote that "..the fauna of southeastern Polynesia is a poor one, both in the sense of great disharmony and in general poverty of species." This study essentially corroborates Gressitt's ovservations.

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It is with special pleasure that I dedicate this paper to Dr. S. Dillon Ripley, Secretary Emeritus of the Smithsonian Institution. His unflagging interest in all aspects of the natural history and conservation of these islands has directly resulted in their preservation and our expedition to them.

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VEGETATION OF HENDERSON ISLAND

BY

GUSTAV PAULAY AND T. SPENCER

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VEGETATION OF HENDERSON ISLAND

BY

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ABSTRACT

On the basis of field surveys from the north and north-west beaches, the vegetation of Henderson Island can be classified into 11 vegetation communities: 2 in littoral environments with sandy substrates, 4 on rocky coasts and 5 associated with the limestone plateau. Apart from the cutting of 'miro' wood by Pitcairn islanders, the communities are remarkably undisturbed, with only 5 adventive species recorded. Whereas the littoral communities are clearly differentiated into well-defined zones from shore to plateau, the island interior limestone forests (canopy 5-8m, with an understorey of herbs and shrubs) show many combinations of species, resulting in a complex mosaic of forest types. 9 species or varieties are presently recognised as endemic to Henderson and all are primarily plants of the island's interior.

INTRODUCTION

The study of the vegetation communities of Henderson Island is of both great interest and importance. Henderson's vegetation is of interest in a regional context, first, biogeographically, because of the island's remoteness in the south-east Pacific Ocean (Fosberg 1984) and secondly, because its floristic composition reflects a relatively rare stage in the continuum of vegetation types, controlled by increasing elevation above sea level, from the *motus* of sea-level atolls to the 'high' islands of Polynesia constructed from both volcanic rocks and limestones (Sachet 1985). In addition, Henderson's vegetation is of great significance to the wider debate on the structure and function of island ecosystems both past and present. As a result of the island's isolation, unsuitability for sustained human habitation and lack of economic phosphate deposits, the vegetation of Henderson Island has survived Polynesian and successive Western impacts (with only 5 introduced plant species) and provides an almost unique glimpse of the natural vegetation cover of a former atoll and lagoon well-raised above present sea level (for classification of different emergent reef surfaces see Figure 1; Fosberg 1985a). Furthermore, the continued removal of the natural vegetation communities of fragile tropical island ecosystems makes the field study of locations such as Henderson doubly important (Fosberg et al. 1983, Fosberg 1985b).

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Uplifted islands are also important because they offer a rare analogue for what Pacific atolls may have been like during the low sea stands that characterised much of the Pleistocene. As tectonic uplift took place in the relatively recent past (< 1.0 my ago, Spencer and Paulay, this volume) at Henderson, the island is especially appropriate as a model for atoll environments during low sea stands (mean duration of Pleistocene low sea levels ~ 100 kyr; Shackleton and Opdyke 1976). Thus, for example, soil development on Henderson has been poor by comparison with other uplifted islands such as Niue, S.W.Pacific (Wright and van Westerndorp 1965) or the makatea islands of the Southern Cook Islands (Wood and Hay 1970). Meagre soil development has likely been the result of both the recency of uplift and the lack of source minerals other than those available in limestone and humus. By contrast, fluvial inputs from the central volcanic highlands on Mangaia, S.Cook Islands (Wood and Hay 1970) and atmospherically-sourced volcanic particles (likely to be ash; Fieldes et al. 1960, Wright and van Westerndorp 1965) on Niue have contributed considerably to pedogenesis on these islands. Henderson's lack of soil accumulation and the coarse coral rubble (see Spencer and Paulay, this volume) which covers most of the island, probably explain the low stature of the vegetation, which rarely exceeds 10m in height. This contrasts with much taller mature forests on other uplifted islands: thus, for example, the canopy of the primary forest of Niue is 20-30m high (Sykes 1970, pers. obs. G.P.).

In this paper we consider aspects of vegetation (i) structure; (ii) function and adaptation; (iii) physiognomy; and (iv) floristic composition and ecological interactions. As such, it complements the published checklists of the island's flora (St John and Philipson 1962, Fosberg et al. 1983, this volume).

CLASSIFICATION OF VEGETATION COMMUNITIES

Vegetation units on Henderson Island can be broadly equated with topographic units and/or sedimentary environments. The following classification is proposed.

A. LITTORAL VEGETATION

(a) Sandy substrates

1. Strand pioneer vegetation and seaward beachridge slope community
2. Beachridge crest and back-barrier swale community

(b) Rocky substrates

3. Limestone platform community
4. 'Miro' woodland community
5. Limestone buttress and cliff face community
6. Fern slopes community

B. LIMESTONE PLATEAU MARGIN AND ISLAND INTERIOR VEGETATION

7. Cliff top and plateau margin community
8. Pinnacled-pitted limestone community
9. Timonius scrub community
10. Limestone glade woodland community
11. Lagoonal patch reef community

It should be stressed, however, that this classification is empirical and strictly only applies to those areas of the island, primarily the north and north-west coasts, visited by the 1987 expedition (for locations; see Spencer and Paulay, this volume). It is interesting to note that 3 species (*Asplenium lobulatum*, *Fimbristylis cymosa* and *Lycium carolinense* var. *sandwichense*) only collected on one occasion, by D R Tait in 1912, are indicated by St John and Philipson (1972) as being restricted to the South Point region. Whilst coral ledges and a reef flat dissipate wave attack on the north-western, northern and eastern shores, waves break directly onto the undercut cliffs of the south-western and south coasts with sea spray being thrown to heights above that of the cliff margin under even moderate sea conditions. Thus different ecological conditions prevail at the southern end of Henderson by comparison with the northern coasts. Even within the latter region field observations suggest that there may be micro-climatic differences between neighbouring coasts; for example, the cliff face and plateau margin environments above the north-west beach appear to be moister than the corresponding areas on the north coast. One reflection of these differences may be the apparently much poorer epiphytic flora on the northern plateau; further differences are considered below.

One of the great problems in delimiting the different vegetation communities on Henderson Island is that not only are they floristically diverse but also that many species are present in more than one, and often several, different communities. The following species lists by community document all the species seen by us in each community; the accompanying text indicates which species make each community recognizable and adds information from the work of previous plant collectors. Nomenclature follows Fosberg et al. (1983, and see also this volume).

DESCRIPTION OF VEGETATION COMMUNITIES

A. LITTORAL VEGETATION

The littoral vegetation, defined as seaward of the plateau margin, has more diverse and clearly differentiated communities than the interior vegetation. This diversity and differentiation is the result of a greater variation from shore to cliff top in elevation, substrate type, exposure to sea spray, and other microclimatic factors than are found in the island interior. The arrangement of most of this variation is normal to the coast, producing well-defined zones from shore to plateau.

The most seaward community may be either on sandy substrates (1. Strand pioneer and seaward beachridge community: see below) especially along the north coast, or on solid limestone (3. Limestone platform community: see below) depending on local physiography. These shoreward communities consist of a few salt tolerant species. In their shelter follow more diverse woodland communities on gently sloping or level ground on sand (2. Beachridge crest and back-barrier swale community: see below) or on limestone rock and rubble (4. 'Miro' woodland community: see below). These latter communities include the most disturbed areas on Henderson. They serve as camp-sites to visiting parties on the north and northwest beaches, most coconuts grow here, and miro (*Thespesia populnea*) is frequently cut. The transition from this littoral terrace to the plateau is via a mosaic of steep slopes and cliff faces that bear low-lying, dense, species-rich covers (5. Limestone buttress and cliff face community; and 6. Fern slopes community: see below).

1. Strand pioneer and seaward beachridge community

The beaches of Henderson are of two types: the long, relatively broad beaches of the northern and eastern shores and small pocket beaches, typified by the north-west beach and the eastern sections of the north beach. The pocket beaches are characteristically backed by a bevelled limestone ramp and flanked by low limestone outcrops (see Spencer and Paulay, this volume); they support few plants. The north beach can be divided into a lower foreshore dominated by beachrock and poorly-sorted sands and an upper, planar beach, 15 - 25m in width. At the western end of this beach the limestone cliffs come right down to the shore and only locally are incipient, small sand dunes present between the limestones and the beach sands. These low sand sheets are characterised by clumps of the grass *Lepturus repens*. In the central section of the north beach a beachridge fronts a broad embayment in the limestone cliffs (see Spencer and Paulay, this volume for north beach plan). The dominant colonist on the seaward face of this beachridge, at ~3.0 - 4.5m above sea level, is *Scaevola sericea* (Plate 1) with *Heliotropium anomalum* and *Pemphis acidula* being locally present.

Shrubs:	*Pemphis acidula* *Scaevola sericea* var. *tuamotuensis*
Herb:	*Heliotropium anomalum* var. *argenteum*
Creeper:	*Triumfetta procumbens*
Grass:	*Lepturus repens*

2. Beachridge crest and back-barrier swale community

At the Pitcairner's campsite on the north beach, the dominant vegetation on the beachridge crest is coconut plantation. To the west of this locality the beachridge supports an extensive cover of *Tournefortia argentea* both as a bushy ground cover and as gnarled trees, 3 - 4m high. *Tournefortia* is an opportunistic species characteristic of marginal and disturbed ground (Fosberg 1953) and is restricted to the littoral vegetation on Henderson. Beneath the latter may be an understorey of *Polypodium* sp(p).

The area between the beachridge crest and the base of the limestone cliffs, reaching ~30m in width on the central north beach, is clearly a zone of transition of both micro-climate and substrate. *Pemphis acidula* , common along the seaward margin, becomes noticeably absent as this zone is traversed. In the moist, shaded localities at some distance from direct marine influence, *Procris pedunculata* and the endemic *Peperomia hendersonensis* are particularly characteristic of this shrub-dominated community.

Trees:	*Cocos nucifera* *Pandanus tectorius* *Thespesia populnea* *Tournefortia argentea*
Shrubs:	*Guettarda speciosa* *Scaevola sericea* var. *tuamotuensis* *Timonius polygama* *Tournefortia argentea*

Herbs:	*Peperomia hendersonensis* *Procris pendunculata*
Creeper:	*Ipomoea macrantha*
Grass:	*Thuarea involuta*
Ferns:	*Asplenium nidus* *Polypodium* sp(p).

3. Limestone platform community

The limestone platform environment is dominated at its seaward margin by dense, monospecific stands of *Pemphis* (Plates 2 and 3), in a band usually less than 5m wide, and locally festooned by orange-green strings of *Cassytha filiformis*. The '*Pemphis* forest' is a characteristic and permanent community of rocky shores on Central Pacific atolls (Fosberg 1953), as well as on other uplifted islands (pers. obs.; S.Cooks, Niue). The creeper *Triumfetta procumbens* is also found on the seaward margin of this community.

Tree:	*Cocos nucifera* *Tournefortia argentea*
Shrub:	*Pemphis acidula*
Creepers:	*Cassytha filiformis* *Triumfetta procumbens*

4. 'Miro' woodland community

Inland from the *Pemphis* zone, trees become established on the last interglacial limestone unit. At the southern end of the north-west beach and particularly at the eastern end of the north beach the 3 - 5m high canopy is dominated by miro, *Thespesia populnea*, with an understorey of *Polypodium* sp(p). Gaps in the canopy and the presence of numerous logs on the limestone substrate attest to the management of this community by the Pitcairn Islanders who crop miro for wood carving. The *Thespesia* logs are surrounded by a thick litter layer of *Pandanus* leaves and *Polypodium* fronds. Under the densest miro canopy, near the foot of the limestone buttress, *Peperomia hendersonensis* appears and becomes an abundant ground cover. At the same location occasional *Timonius polygama* and *Procris pendunculata* give their first appearance. The large coconut grove on the northwest beach dominates the canopy of the seaward half of this community.

Trees:	*Cocos nucifera* *Cordia subcordata* *Guettarda speciosa* *Pandanus tectorius* *Thespesia populnea* *Tournefortia argentea*
Shrub:	*Timonius polygama*

Herbs: *Peperomia hendersonensis*
Procris pedunculata

Grass: *Thuarea involuta*

Creeper: *Cassytha filiformis*

Ferns: *Asplenium nidus*
Polypodium sp(p).

5. Limestone buttress and cliff face community

Although there are individual trees of *Celtis* sp., *Pisonia grandis* and, particularly at higher levels, *Pandanus tectorius,* the steep limestone faces are dominated by a close ground cover. At lower levels this may consist of low *Timonius* (Plate 4) tangle but at greater heights the cliffs are characterised by creeping herbs. Particularly noticeable is the way in which *Sesuvium portulacastrum* covers the outer floor of the highest (20.2 - 21.5m; see Spencer and Paulay, this volume), deepest and most laterally extensive of the marine notches on the limestone buttresses of the north shore, an association clearly seen from the north beach (Plate 2). The change from a low shrub to a herb assemblage appears to be correlated with a change in substrate from poorly sorted, sandy coral rubble to solid limestone.

Trees: *Celtis* sp.
Pandanus tectorius
Pisonia grandis
Thespesia populnea

Shrubs: *Eugenia rariflora*
Timonius polygama
Tournefortia argentea

Herbs: *Euphorbia sparrmannii*
Heliotropium anomalum var. argenteum
Lepidium bidentatum
Sesuvium portulacastrum

Creepers: *Boerhavia tetrandra*
Cassytha filiformis
Ipomoea macrantha

Ferns: *Asplenium nidus*
Nephrolepsis hirsutula
Polypodium sp(p).

6. Fern slopes community

Above the vegetation communities of the immediate coastal fringe and in between the high angle cliffs and limestone buttresses are slopes of 25 - 30^{0} in angle up to the cliff top. This topographic unit is dominated by extensive stands of the ferns *Polypodium* sp(p). and *Nephrolepsis hirsutula*. Alternating and mixed with this fern cover, especially on the lower parts of the slope, are thickets of *Timonius* , forming a dense canopy ~ 1.5m high, draped with the parasitic *Cassytha* , and with the occasional emergent *Eugenia rariflora* reaching 2m.

Shrubs:	*Eugenia rariflora* *Pisonia grandis* *Timonius polygama*
Creeper:	*Cassytha filiformis*
Ferns:	*Nephrolepsis hirsutula* *Polypodium* sp(p).

B. LIMESTONE PLATEAU MARGIN AND ISLAND INTERIOR VEGETATION

In the simplest terms, the plateau interior of Henderson Island supports a limestone forest of large individual trees with a canopy at 5 - 8m and a wide variety of herbs and shrubs beneath that canopy, the most remarkable being the tall *Bidens hendersonensis* (Fosberg 1984). However, the way in which different species combine varies considerably across the island's surface. Some of these differences seem to be controlled by local geology. The island's interior is underlain by either jagged, pinnacled exposures of limestone or by flatter depressions, with fields of corals or areas of fragmented coral sticks, thought to represent a former atoll lagoon floor (Spencer and Paulay, this volume). Some areas of limestone bedrock may have no forest cover (8. Pinnacle-pitted limestone community: see below) or a low, tangled scrub vegetation (9.*Timonius* scrub community: see below). Similarly, a thick litter layer and pocket soils have developed over some lagoonal deposits, producing a distinctive limestone woodland (10. Limestone glade woodland: see below). It seems likely, therefore, that local changes in geology will be reflected in changes in forest floristic composition. Whereas on the northwest plateau there is an abrupt change from limestone island rim to lagoonal interior, on the northern plateau there is an alternation of bedrock exposures with lagoonal depressions (Spencer and Paulay, this volume); these differences might be expected to be echoed in forest type. Superimposed on geological constraints is the possibility of micro-climatic variation across the island top. Broad differences between the seemingly wetter north-western plateau and the drier northern plateau have already been alluded to: perhaps these differences explain the greater abundance of *Asplenium nidus* and *Nesoluma st-johnianum* on the north-west plateau and the more frequent occurrence of *Myrsine hosakae* in the northern interior. Finally, there are clearly ecological gradients from island margin to plateau interior. The plateau edge is a transition zone from the littoral limestone cliff communities, and is the only area where *Cordyline fruticosa*, *Scaevola sericea*, *Euphorbia sparrmannii*, *Caesalpinia major* and *Ipomoea macrantha* were noted on the island top (7. Cliff top and plateau margin community: see below). Further inland, these gradients are reflected in the abundance of certain species; thus *Bidens* , *Pisonia* and *Nesoluma* become more abundant as distance increases from the coasts whereas the opposite trend is exhibited by *Pandanus* . The following list shows the variety of species found within the limestone interior forest; different combinations of these species yield a complex mosaic of forest types. The communities that follow describe those associations that stand out as recognisable units within the plateau vegetation. Except for patches of *Timonius*, no area of the interior plateau is dominated by one or a few species, but supports diverse communities. It should be noted that the following list indicates only those 22 species, from a total of 41 species, which are common across much of the interior island landscape. Unfortunately our record does not include the endemic tree *Santalum hendersonense* which St John and Philipson (1962) noted as being common on the plateau top. Opinion on Pitcairn (K. Brown pers.comm. 1987), however, suggests that the species occurs only in localised clusters.

Trees:	*Celtis* sp.
	Geniostoma hendersonense
	Guettarda speciosa
	Nesoluma st-johnianum
	Pandanus tectorius
	Pisonia grandis
Shrubs:	*Alyxia* sp.
	Bidens hendersonensis var. *hendersonensis*
	Canthium barbatum f. *calcicola*
	Canthium odoratum
	Cassia glanduligera
	Eugenia rariflora
	Glochidion pitcairnense
	Ixora fragrans
	Timonius polygama
	Xylosma suaveolens var. *haroldii*
Herbs:	*Dianella intermedia*
	Procris penduncalata
Creeper:	*Morinda umbellata* var. *forsteri*
Ferns:	*Asplenium nidus*
	Davallia solida
	Polypodium sp(p).

7. Cliff top and plateau margin community

The cliff top is characterized by a dense thicket vegetation in which *Timonius*, *Canthium odoratum, Nephrolepis* and *Polypodium* sp(p). are abundant (Plate 5). St. John and Philipson (1962; Plate 5) also show *Xylosma suaveolens* to be an important component of the cliff top community above the north-west beach; we concur with this observation. Particularly noticeable are large individuals of *Pandanus* ; their pyramidal forms often dominate the island skyline from the sea and give, perhaps, an impression of greater abundance than is actually the case (eg. Plate 4).

Away from the immediate marginal cliffs, *Eugenia* begins to decline in abundance whereas *Celtis* sp., *Ixora fragrans*, *Cassia glanduligera* and *Glochidion pitcairnense* start to appear as important constituents of the forest community on rocky substrates. At the north beach the presence of *Cocos nucifera* and *Cordyline fruticosa* at the plateau margin is clearly related to the trail leading into the island interior. Similarly, *Caesalpinia major* is only found in association with the north coast trail (curiously, the difficulties of passage produced by this species are documented by Fosberg et al. (1983) for Henderson yet the species was not collected by the Mangarevan expedition (St. John and Philipson 1962)).

Trees:	*Cocos nucifera*
	Celtis sp.
	Pandanus tectorius
	Pisonia grandis
Shrubs:	*Canthium odoratum*
	Cassia glanduligera
	Cordyline fruticosa
	Eugenia rariflora
	Glochidion pitcairnense
	Ixora fragrans
	Scaevola sericea var. *tuamotuensis*
Shrubs:	*Timonius polygama*
	Xylosma suaveolens var. *haroldii*
Herb:	*Euphorbia sparrmannii*
Creepers:	*Boerhavia tetrandra*
	Caesalpinia major
	Cassytha filiformis
	Ipomoea macrantha
Ferns:	*Davallia solida*
	Nephrolepsis hirsutula
	Polypodium sp(p).

8. Pinnacle-pitted limestone community

Inland from the north-west beach is an area of open limestone, with limestone pinnacles up to 2 m high (Plate 6; and well illustrated by Fosberg et al. 1983, Plates 11 and 12). The horrors of traversing this terrain are well described by St. John and Philipson (1962). Although we only saw a small, perhaps 50m diameter, area of this pinnacle-pitted limestone, both its unique landscape and unusual vegetation warrants its separation as a distinctive community. The fern *Nephrolepsis hirsutula* is scattered across the top of the pinnacles while *Asplenium nidus* sits in the hollows between them. Several *Hernandia stokesii* trees grow on this barren landscape, the only area where this species was observed both by the Mangarevan (Fosberg, pers.comm. 1987) and the 1987 expedition.

Tree:	*Hernandia stokesii*
Shrub:	*Eugenia rariflora*
Ferns:	*Asplenium nidus*
	Nephrolepsis hirsutula
	Polypodium sp(p).

9. *Timonius* scrub community

Locally, the limestone forest community may be replaced by a scrub vegetation dominated by monospecific thickets of *Timonius* . This comprises an almost inpenetrable low canopy up to 3m high with an intersecting mattress of brittle dead twigs and branches below. The trees and shrubs which surround these patches are typical of the cliff top and plateau margin community (see above for species list).

Shrub:	*Timonius polygama*

10. Limestone glade woodland community

The presence of pocket soils on the lagoonal deposits of the plateau is reflected in the development of a glade woodland with a more open canopy than that of the limestone forest. This community also often supports a lush fern understorey, largely composed of *Davallia solida* and *Polypodium* sp(p) but also with *Procris* and *Morinda umbellata* var. *forsteri*. Commonly found foraging through the litter layer in this community is the Henderson Island Rail, *Porzana atra*. The dominant tree species are *Pisonia* and *Nesoluma* with occasional *Pandanus* and the relatively rare *Myrsine* . *Alyxia* sp. is often entangled throughout the canopy and parasitic *Korthalsella* spp. and epiphytic *Pyrrosia serpens* are also present. Where breaks in the canopy occur, the main gap colonist is *Senecio stokesii* with *Glochidion* and *Cassia* invading at the margins.

Trees:	*Myrsine hosakae* *Nesoluma st-johnianum* *Pandanus tectorius* *Pisonia grandis*
Shrubs:	*Canthium barbatum* f. *calcicola* *Canthium odoratum* *Cassia glanduligera* *Eugenia rariflora* *Glochidion pitcairnense* *Ixora fragrans* *Premna* cf. *serratifolia* *Xylosma suaveolens* var. *haroldii*
Shrubs:	*Korthalsella platycaula* var. *vitiensis* *Korthalsella rubescens* *Procris pedunculata* *Peperomia hendersonensis* *Senecio stokesii*
Creepers:	*Alyxia* sp. *Morinda umbellata* var. *forsteri*
Ferns:	*Asplenium nidus* *Davallia solida* *Polypodium* sp(p). *Pyrrosia serpens*

11. Lagoonal patch reef community

As well as the coral heads and acroporid sticks within the lagoonal depressions, there are larger mounds of coral rubble within these depressions which we interpret as rather more extensive patch reefs. Where large, these mounds show a distinctive vegetation cover, dominated by *Eugenia* and low *Pisonia* in a bushy habit (Plate 8).

Trees:	*Guettarda speciosa* *Nesoluma st-johnianum* *Pandanus tectorius*
Shrubs:	*Eugenia rariflora* *Glochidion pitcairnense* *Ixora fragrans* *Pisonia grandis* *Xylosma suaveolens* var. *haroldii*
Creeper:	*Morinda umbellata* var. *forsteri*
Fern:	*Polypodium* sp(p).

CONCLUDING REMARKS

Remarkably, the vegetation communites described above have been almost completely unaffected by human contact. Fosberg et al. (1983) list only four adventive species: *Cocos nucifera, Cordyline fruticosa, Aleurites moluccana* and *Achyranthes aspera* var. *pubescens*. To this list we add *Setaria verticillata* based on the collections made during the 1987 expedition. Of these five species, *Achyranthes* and *Aleurites* have not been collected since 1912 and 1922 respectively. Coconut plantations, clearly associated with campsites, are restricted to the central sections of the north beach and the north-west beach. These trees have obviously matured since the observations of the Mangarevan Expedition when the coconuts of the north-west beach were described as "all young" (Fosberg et al. 1983, 18). On the plateau surface, coconuts are restricted to the trail inland; mature trees near the cliff top and recent plantings at intervals along the trail in the interior. *Cordyline* is similarly restricted to trail-side locations and is only found near the plateau margin on the north coast. Only a single example of the *Setaria* grass, which is known from Pitcairn (Fosberg et al., this volume), was seen at the north beach camp-site, and all of it was excavated. It may have been a very recent colonist.The lime and orange trees reported by Maude in 1951, and assumed to be at the north landing (St John and Philipson 1962) were not seen on the 1987 expedition. We were not able to verify the presence or absence of introduced root crops at the north east point. The cutting of *Thespesia populnea* by the Pitcairners is largely confined to the low limestone platform near the shore and does not result in the disturbance of other vegetation communities.

Although the vegetation of Henderson Island is greatly enriched compared to neighbouring atolls, several typical atoll plants that occur in the Eastern Tuamotus or even on neighbouring Oeno Atoll are absent on Henderson, e.g. *Hedyotis romanzoffiensis, Sophora tomentosa, Calophyllum inophyllum, Barringtonia asiatica* and *Nesogenes euphrasioides*. Although the absence of such littoral species may in part be due to isolation, the limited extent of beaches, the lack of much reef protection, and the encroachment of the abundant 'high island' vegetation on the littoral community may also be important. The poverty of the strand flora is further reflected in our inability to find several previously reported strand plants. Of the 13 plant species that we failed to relocate from Fosberg et al.'s (1983) floristic list, 5 (*Portulaca lutea, Capparis sandwichiana, Suriana maritima.*

Lycium carolinense var. *sandwicense*, *Fimbristylis cymosa*) are predominantly littoral plants. The other species that we did not relocate include 2 introduced plants (*Achyranthes aspera* var. *pubescens* and *Aleurites moluccana*) that may have disappeared since 1934 and *Asplenium lobulatum*, *Asplenium obtusatum*, *Pittosporum aborescens*, *Sesbania coccinea*, *Santalum hendersonense* and *Meryta brachypoda*. Several of these plants are obviously rare or localised; 8 of the 13 were also not collected by the Mangarevan Expedition.

Nine species or varieties are presently recognised as endemic to Henderson (Fosberg et al. 1983, present volume): *Peperomia hendersonensis*, *Celtis* sp., *Santalum hendersonense*, *Xylosma suaveolens* var. *haroldii*, *Myrsine hosakae*, *Nesoluma st-johnianum*, *Geniostoma hendersonense*, *Alyxia* sp. and *Canthium barbatum* f.*calcicola*. All the endemics are primarily inland plants and, with the exception of *Santalum*, which we did not find in 1987, all were noted to be common in the island interior.

It seems likely that botanical collecting trips to Henderson Island will continue to be both infrequent and brief. Clearly, however, there would be value in attempting to visit the southern area of the island, not collected since Tait in 1912, and the eastern shores which must be under-collected or possibly not even collected at all. It is certain that much remains to be learnt about the vegetation communities of Henderson Island and its remarkable flora.

ACKNOWLEDGEMENTS

We are grateful to the late George Nichols and the crew of the 'Rambler' for their hospitality and great willingness to transport us to and around Henderson Island. We thank Buck Moravec for help with trail making, Lawrence Schuster for collecting plant specimens and Ray Fosberg for identifying the collections.

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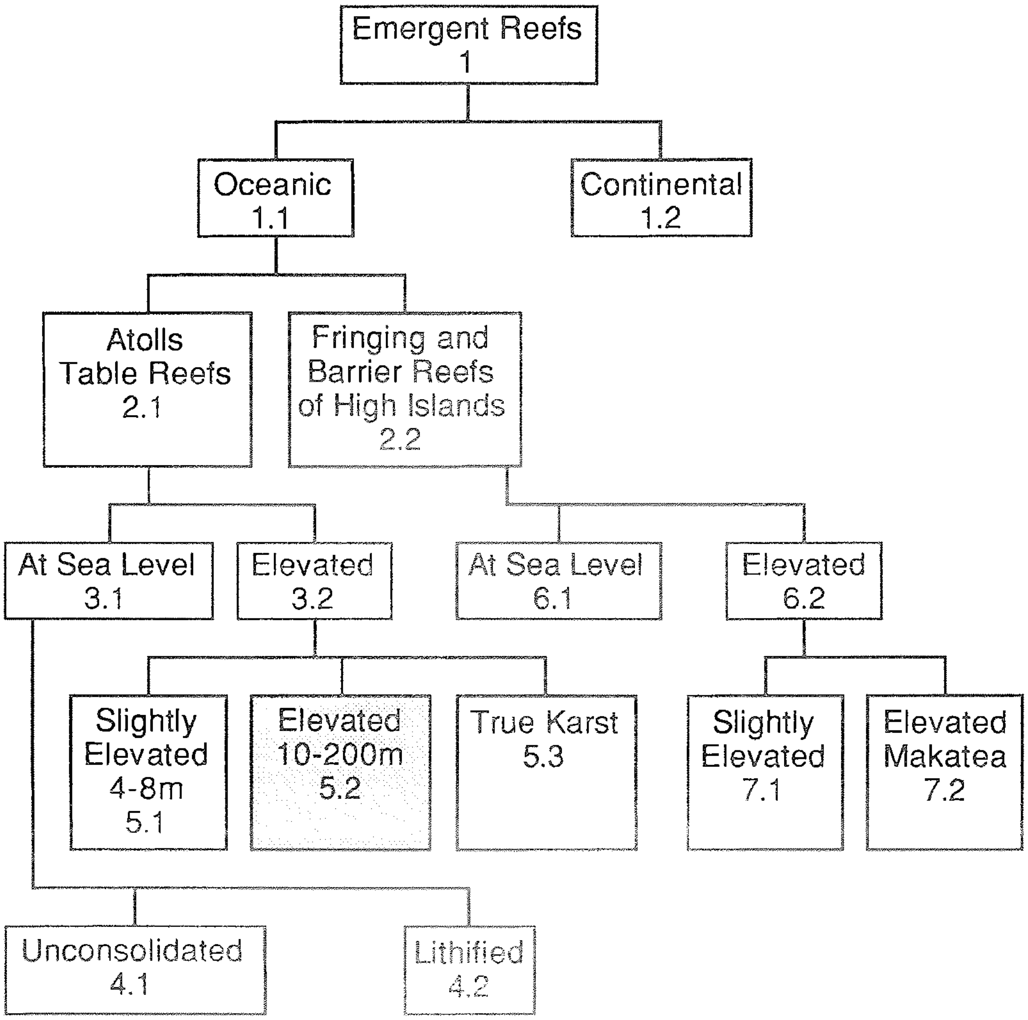

Figure 1. Diagram of classification of emerged reef surfaces (from Fosberg 1985a). Henderson Island falls within category 5.2 (Elevated 10-200m)

Plate 1. Looking west along north beach from the landing. *Scaevola sericea* var. *tuamotuensis* on seaward slope of beachridge, *Tournefortia argentea* and *Pandanus tectorius* on beachridge crest.

Plate 2. Limestone buttress, south-central north beach. Monospecific *Pemphis acidula* on low limestone platform behind beach. *Sesuvium portulacastrum* on notch floor (centre middle) of buttress.

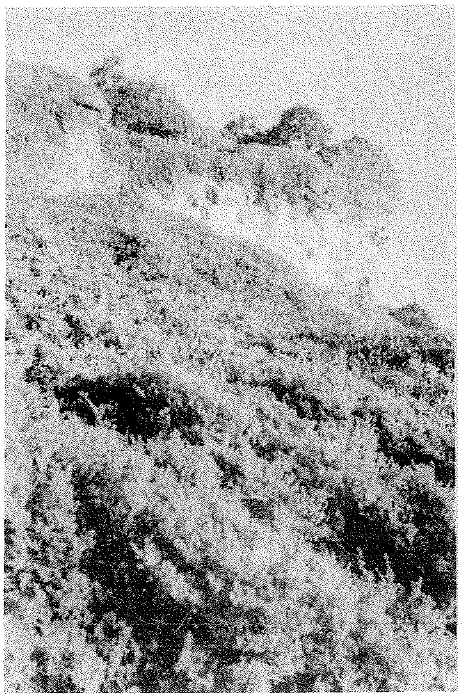

Plate 3. *Pemphis acidula* on lower limestone unit replaced by fern slopes community on higher slopes, north-west beach. Notch floor of buttress (centre right) characterized by *Sesuvium portulacastrum*, *Euphorbia sparrmannii* and *Lepidium bidentatum*.

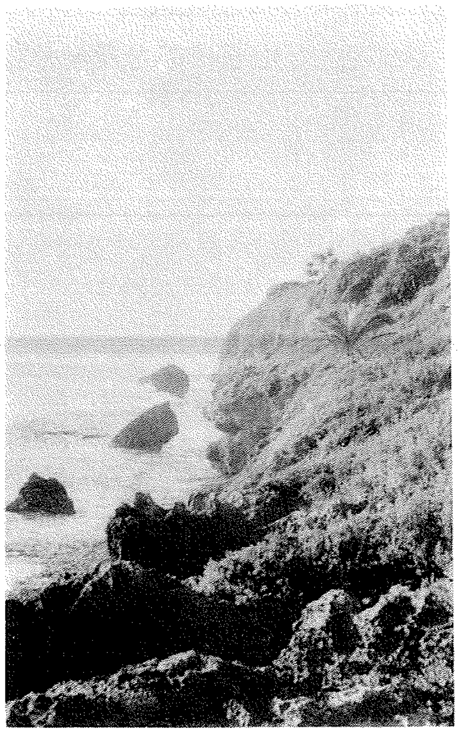

Plate 4. Looking north from end of north-west beach. *Pemphis acidula*, *Timonius polygama* and emergent *Cocos nucifera*. Skyline *Pandanus tectorius* is typical.

Plate 5. Plateau margin scrub thicket vegetation. N. beach trail

Plate 6. Pinnacle-pitted limestone, inland from north-west beach. Limestone forest in background.

Plate 7. Limestone glade woodland community, N. beach trail. *Pisonia grandis* and *Pandanus tectorius* with predominantly fern understorey.

Plate 8. Lagoonal patch reef vegetation dominated by bushy *Pisonia grandis* and *Eugenia rariflora*.

ATOLL RESEARCH BULLETIN

NO. 329

NEW COLLECTIONS AND NOTES ON THE PLANTS OF HENDERSON, PITCAIRN, OENO, AND DUCIE ISLANDS

BY

F.R. FOSBERG, GUSTAV PAULAY,

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NEW COLLECTIONS AND NOTES ON THE PLANTS OF HENDERSON, PITCAIRN, OENO, AND DUCIE ISLANDS

BY

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T. SPENCER[3], AND ROYCE OLIVER[1]

INTRODUCTION

It may seem superfluous to add another paper on the flora of Henderson Island, so soon after the account in Fosberg, Sachet and Stoddart (1983), but the Paulay and Spencer collections added several species and additional information on some others, already known. It also provides a convenient oppertunity to make needed nomenclatural adjustments and corrections, as well as comments on variability.

45 species were collected on Henderson, including one additional exotic (Setaria), and two other previously unrecorded native plants. 16 previously listed plants (Fosberg 1983) were not found. This does not necessarily mean that they have disappeared. There was no botanist on the expedition, so the plants were collected by other members of the party in addition to their other activities, so naturally the plant collecting may not be as complete as if a full-time botanist had been available. The additional notes over and above the bare list show that, even botanically, the expedition's accomplishments were significant.

In the list the parenthetical (St. J. & P.) indicates the reference to species in the 1962 paper by St. John and Philipson. The parenthetical (Fosberg et al.) indicates the

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page reference in the paper by Fosberg, Sachet, and Stoddart in 1983. The parenthetical upper case letter sympols are the Lanjouw System (Holmgren, Keuken and Schofield 1981) symbols for the herbaria where the specimens are deposited.

For completeness, we have also listed the collections from Oeno and Ducie Atolls and Pitcairn Island. Lists of previous collections from these islands have been published by Philipson and St. John (1960) for Oeno, indicated in the list by (P. and St. J.) and St. John (1987) for Pitcairn, indicated in the list by (St. J.). We also include several additional species, collected by Miss Ross, brought to our attention by Rhys Gardner, of Auckland Institute and Museum. As a matter of information, we have recently learned of a substantial collection from Pitcairn, collected by S.P. Twyford in 1955, housed in the University of the South Pacific Herbarium in SUVA. We regret that time was not available to list and check identities of these specimens.

In all of the lists the collection data were furnished by Paulay and Spencer: the identifications and comments by Fosberg, and the manuscripts were assembled by Oliver. In all three lists, all species collected by the Smithsonian Expedition are cited with pertinent synonymy and abbreviated references to previous lists. Species not found by the Expedition are only mentioned, in the main list, if we disagree with the name used earlier or if there are comments to be made on the occurrence or matters of distribution, variation or taxonomic interest. This seems sufficient since for each of the three islands there is a published modern annotated list citing collections.

The full set of Smithsonian Expedition collections are housed in the U.S. National Herbarium (US), with duplicates, if any, at Bishop Museum (BISH), occasional extra ones are at DSIR, Christchurch (CHR) and a few other herbaria. A few earlier specimens studied are cited with the herbaria indicated.

Polypodiaceae

Asplenium nidus L. (St. J. & P. 178; Fosberg et al. 29)

Common, NW beach site, Paulay and Spencer 602 (US, BISH, BM)

Generally rather common.

Davallia solida Sw. (St. J. & P. 178; Fosberg et al. 29)

Top plateau, inland of NW beach site, Paulay and Spencer 613 (US, BISH)

Nephrolepis hirsutula (Forst. f.) Presl
Nephrolepis biserrata (Sw.) Schott (Fosberg et al. 29; St. J. & P. 178).
Nephrelopis exaltata Schott (St. J. & P. 179; Fosberg et al. 29).

Common on top of cliff, NW beach Paulay and Spencer 608 (US, BISH).

This is rather atypical, though having rhizome scales with shiny, black bases. The scales on rhachis and pinnae are very sparse, some appearing glandular, reddish, but scales woolly. The sori are not as close to the margin as usual, but not as far from it as in N. biserrata, which has been reported from the island earlier. Probably only N.

hirsutula occurs on this island.

Polypodium sp.
Polypodium scolopendria "aberrant" of Copeland, non Burm. P. 179)

NW beach site, Paulay and Spencer 611 (US, BISH, BM).
S.l. St. John & Fosberg 15125 (BISH),

This species, probably endemic, will be described in a later publication.

Polypodium scolopendria Burm. f.
Phymatodes scolopendria (Burm f.) Ching (St. J. & P. 179)

Common at base of cliff NW beach site, Paulay and Spencer 601 (US).

A very large form., with 8-11 narrow lobes on a side, very acuminate, sinuses broad, rounded, sori in one row an each side of a lobe, round to elliptic, impressed in blade. Where Polypodium pitcairensis and P. sylvaticum Brack. fit into the P. scolopendria complex on Henderson can only be determined by more collections and study.

Pyrrosia serpens (Forst. f.) Ching
Cyclophorus blepharolepis C. Chr. (St. J. & P. 119; Fosberg et al. 29)

Top plateau, mid fossil lagoon, Paulay and Spencer 618 (US, BISH, BM); St. John & Fosberg 15154 (US), det Hovenkamp.

Poaceae

Lepturus repens (Forst. f.) R. Br. (St. J. & P. 179; Fosberg et al. 29)

N. beach, Paulay and Spencer 633 (US, BISH)

This species is said by St. John to be rare, found only at top of beaches. No. 633 is an unusual coarse form. The leaves are lanceolate, broad and short, crowded. Only one young spike is present. The glumes are narrowly lanceolate, not aristate.

Setaria verticillata (L.) Beauv. (det S.A. Renvoize)

N. beach, at landing Paulay and Spencer 660 (US).

This weedy grass is apparently a new record for the island; probably recently introduced. The specimen is depauperate, depressed, badly wilted, the panicles unusually narrow, 5 mm or less wide, 4-5 cm long.

Liliaceae

Cordyline fruticosa (L.) Chev. (Fosberg et al. 30)

Cordyline terminalis (L.) Kunth (St. J. & P. 179)

N. beach site, cliff top, Paulay and Spencer 626 (US, BISH, BM)

No. 626 is the large-leafed green form,usually, as in this case, sterile, probably dispersed throughout Polynesia by the Polynesians, and doubtless planted on Henderson by the Pitcairn people.

Dianella intermedia Endl.
Dianella intermedia var. gambierensis F. Br. (St. J. & P. 179; Fosberg et el. 30)

Occasional top plateau, fossil lagoon, Paulay and Spencer 617 (US).

Sterile specimen, but probably this species as the leaf margins are spinulose, but variety cannot be determined.

Piperaceae

Peperomia hendersonensis Yunker (1937; St. J. & P. 180; Fosberg et al. 30)

N. beach, inland, Paulay and Spencer 655 (US, BISH), nr. base of cliff NW beach 597 (US, BISH, BM)

Endemic to Henderson, apparently common.

A feature was noticed possibly unique to this species, or at least uncommon in the genus, occasional on # 655, stipules or stipule-like structures at or very slightly above axils of some leaves. These are very small, 1 mm long and wide or less, broadly ovate or triangular, slightly cordate at base, apex subcuspidate with glandular tip, somewhat carinate from tip, sides thin.

Ulmaceae

Celtis sp.
Celtis paniculata var. viridis F. Br. (St. J. & P. 180; Fosberg et al. 30)

N. beach trail, fossil lagoon-plateau, Paulay and Spencer 647 (US), beach just inland of coconut grove, 623 (US)

In forest on plateau. A distinctive form; probably does not belong in C. paniculata Planch.

Urticaceae

Procris pedunculata (Forst.) Wedd. (St. J. & P.180; Fosberg et al. 30)

Common , top terrace, NW beach side, Paulay and Spencer 600 (US).

Viscaceae

Korthalsella platycaula var. **vitiensis** (v. Tiegh.) Danser
Korthalsella vitiensis (v. Tiegh.) Engler (St. J. & P. 180, Fosberg et al. 30)

Korthalsella margaretae F. Br. new var. ? (F. Brown, Bish. Mus. Bull. 130: 60, 1935)
Korthalsella complanata sensu Danser, non (v. Tiegh) Engler

Paulay and Spencer 654 (US, BISH, BM))

There is little agreement on the status of this taxon. Its affinities are certainly with K. platycaula (v. Tiegh.) Engler, type from Tahiti, but what little material available from Fiji, Rurutu, Rapa and Henderson Island differs consistently from the Society Island forms in its broader, shorter elliptic segments, with strong longitudinal ridges (or veins?). A.C. Smith (Fl. Vit. Nova 3: 474, 1985) lumps this form with K. platycaula. His photos, fig. 189A and D., the above-mentioned features very well. St. John and Philipson 180, go the other way and recognize K. vitiensis as an independant species. F.B.H. Brown goes still farther and makes at least two species of it. My first impression was to treat it as K. platycaula, but after examinining all readily available material, I feel that it is at least merits varietal rank and am treating it so, as above. Certainly it has nothing to do with the Hawaiian K. complanata (v. Tiegh.) Engler, as claimed by Danser.

Korthalsella rubescens (v. Tiegh.) Engler (St. J. & P. 180); Fosberg et al. 30)

Top plateau, NW beach, Paulay and Spencer 599 (US).

We cannot distinguish this species from K. horneana v. Tiegh. (ex char.) but hesitate to combine them in absence of specimens of the latter.

Nyctaginaceae

Boerhavia tetrandra Forst. f. (Fosberg et al 32)
Boerhavia diffusa var. tetrandra (Forst. f.) Heimerl (St. J. & P. 181)

N. beach, level of cliff notch, Paulay and Spencer 639 (US), N. beach, cliff face 632 (US).

No. 639 is rather bushy and small-leafed for this species, with young buds only. No. 632 is of normal stature and habit, but with leaves rather broadly ovate and peduncles very long, in bud only.

Aizoaceae

Sesuvium portulacastrum L. (Fosberg et al. 30)

N. beach, cliff face, Paulay and Spencer 634 (US, BISH, BM).

This plant is a slender, prostrate, completely green form, with small spatulate leaves and white flowers, with perianth lobes 4 mm long. It does not have the coarse habit and conspicuously gray-green leaves of var. griseum Degener & Fosberg.

Lauraceae

Cassytha filiformis L. (St. J. & P. 181; Fosberg et al. 31)

N. beach, cliff face, Paulay and Spencer 651 (US, BISH)

Parasitic vine, attacking various shrubs and herbs.

Hernandiaceae

Hernandia stokesii (F. Br.) Kubitzki, Bot. Jahrb. 89: 141, 1969.
Hernandia ovigera var. stokesii F. Br. Fosberg et al. 31)

Local on top plateau off NW beach Paulay and Spencer 592 (US, BISH, BM)

This shrub, local on very rough pinnacled limestone on the west side of the plateau, said to be identical with the Rapa plant of this name, is neither H. ovigera L. nor H. sonora L. and not even very close to the last named. It still must be compared with the Rapa plant, which is found in a very different habitat, as the identity depends an comparison of a single Whitney Expedition specimen, lacking data. For the present it can bear this name.

Brassicaceae

Lepidium bidentatum Montin (St. J. & P. 181; Fosberg et al 31)

Nr. top of cliff face, NW beach Paulay and Spencer 598 (US, BISH, BM)

Fabaceae

Caesalpinia major (Medic.) Dandy & Excell

N. beach, cliff top, Paulay and Spencer 630 (US, BISH)

C. bonduc (L.) Roxb. has been previously recorded from the island (St. J. & P. 181), but the present specimen, though sterile, lacks stipules or even scars of stipules, so is interperted as C. major.

Cassia glanduligera St. John (St. J. & P. 181-184)

Common on top plateau off NW beach Paulay and Spencer 591 (US, BISH, BM)

The South Pacific equivalent of the Hawaiian C. gaudichaudii H. & A.

Euphorbiaceae

Euphorbia sparrmannii Boiss. (Fosberg et al. 31)
Euphorbia ramosissima H. & A. (non Loisel.) (St. J. & P. 186)
Euphorbia pitcairnensis F. Br.

N. beach cliff, Paulay and Spencer 653 (US), N. beach, limestone cliff notch, 638 (US, BISH), N. beach 631 (US), 2/3 up steep cliff, NW beach site, 607 (US, BISH

Euphorbia pitcairnensis F. Br. is certainly conspecific with E. ramosissima H. & A., an illegitimate later homonym. E. sparrmannii includes this as well as several other similar taxa in the western Pacific. Several varieties are to be recognized, but they are not completely sorted out yet. The plant is common on the cliff-tops. It is slender, prostrate, spreading from a gnarled woody caudex. F. Brown was in error in referring to a calyx in E. pitcairnensis, mistaking the involucre or cyathium for a calyx.

Sapindaceae

Allophylus sp.

N. beach, fossil lagoon-plateau, Paulay and Spencer 637 (US).

A sterile specimen, glabrous, with leaf-shape and margin not right for the widespread strand species, A. timoriensis (DC.) Bl.

Tiliaceae

Triumfetta procumbens Forst f. (St. J. & P. 187; Fosberg et al. 32)

N. beach, top of beach, Paulay and Spencer 650 (US); Rare, on shore, NW beach 604 (US)

A prostrate creeper with yellow flowers and burr-like fruit, found on sandy beaches.

Flacourtiaceae

Xylosma suaveolens var. **haroldii** Sluemer (St. J. & P. 187; Fosberg et al. 32)

N. beach trail fossil lagoon-plateau, Paulay and Spencer 644 (US, BISH, BM), top plateau mid fossil lagoon, 620 (US, BISH, BM)

Variety endemic to Henderson; abundant in forest on Plateau, No. 644 staminate.

Lythraceae

Pemphis acidula Forst. (St. J. & P.; Fosberg et al. 32)

NW beach Paulay and Spencer 596 (US, BISH, BM, MO).

This species is usually a large shrub, but at the NW Beach in 1934 we found a fair-sized tree, which was seen again in 1987. In Paulay and Spencer, this volume, Vegetation, the species is referred to as a shrub.

Myrtaceae

Eugenia rariflora Benth. (St. J. & P.; Fosberg et al. 32)

Top plateau inland of NW beach, Paulay and Spencer 605 (US, BISH, BM).

Generally common or abundant on coastal flats, cliffs and plateau. We are tentatively maintaining this as a distinct species, though Merrill (1950) included it in the Malaysian Jossinia reinwardtiana. We have the impression that Merrill's lumping together most of the Pacific plants of this affinity (genus Jossinia Comm.)in J. reinwardtiana Bl. was perhaps a course of desperation, rather than a considered judgement. After struggling with the variability of the group, one can understand and sympathize. I have not seen the type of Myrtus reinwardtiana, and fail to get a clear concept of it from Blume's later and fuller description. The scanty material available from Malaysia does not permit a better concept. For the present, I am applying the name E. rariflora to the eastern Polynesian plant, usually a shrub, with leaves broad obovate to suborbicular very obtuse to rounded at apex, green above pale beneath, venation faint, subglabrous when mature, margins tending to be revolute; pedicels shorter than leaves, usually unbranched, fruit with conspicuous persistent sepals, tending to be erect. This does not include some plants with thinner, narrower leaves, which I leave unnamed for the present.

Myrsinaceae

Myrsine hosakae St. John (St. J. & P. 188-190; Fosberg et al. 32)

Top plateau 100-300 m inland from NW beach, Paulay and Spencer 606 (US), very rare, top plateau, fossil lagoon, inland from NW beach, 616 (US), top plateau 619 (US, BISH, BM), fossil lagoon-plateau, 25-30 m, 643 (US), N. beach trail Lagoon -plateau, 25-30 m, 636 (US), N. beach, top of plateau, Paulay and Spencer 659 (US).

This species, endemic in Henderson Island, was overlooked in our account of Eastern Polynesian species of Myrsine (Fosberg and Sachet 1975, 1971). St. John placed it next to M. ovalis Nad. of Tahiti. Suggesting relationship among species of Myrsine is, at best, uncertain. I would consider it closer to N. niauensis Fosberg & Sachet, to which M. ovalis var. wilderi Fosberg & Sachet is close. It resembles M. niauensis in the abundant very minute punctations on the upper leaf surface (which St. John failed to notice), but differs in being equally punctate on the under surface, in the lack of strong inter-marginal veins, and in the ellipsoid rather subglobose fruit. No. 616 is sterile, very coarse, and does not show the punctations very well. It may be something else. No. 606 is small-leafed, and with terminal buds on dwarf branchlets with crowded small cataphylls or scars on same, and zones of crowded scars at intevals on branchlets. These are described by St. John as "terminal scaly buds". They are not easy to interpret and should be studied carefully by the next collector of this species.

Sapotaceae

Nesoluma st-johnianum Lam & Meeuse (St. J. & P. 190; Fosberg et al 32)

N. beach, trail fossil lagoon - plateau,Paulay and Spencer 641 (US, BISH, BM, MO, CHR); top plateau, very abundant , fossil lagoon, NW beach site, 615 (US, BISH); top plateau, NW beach, Paulay and Spencer 603) (US, BISH).

An endemic tree in plateau forest. The genus is widespread but rare in the Pacific. No. 641 is in bud only, 603 somewhat more mature but still not in full flower; 615 with one mature fruit.

Loganiaceae

Geniostoma hendersonense St. John (St. J. & P. 190-192; Fosberg et al. 32)
"Species of Buddleia" Beechey ?

N. beach top plateau, Paulay and Spencer 658 (US, BISH, BM); top plateau off NW beach, common Paulay and Spencer 594 (US).

Excellent fruiting specimen # 658, capsule valves 5-9 mm long, black when dry, strongly transversely rugose. Number 594 flowering.

Apocynaceae

Alyxia sp.
Alyxia stellata sensu auct. non Forst. (St. J. & P. 192; Fosberg et el. 32)

Very common, Top plateau, NW beach site, Paulay and Spencer 621 (US)

The Henderson Island plant hitherto referred to Alyxia stellata is an endemic species, well-characterized by 4 leaves in a whorl, large inflorescences and fruit. I have had it in manuscript for some time. The present fruiting specimen helps to complete the description.

Convolvulaceae

Ipomoea macrantha R. & S. (Fosberg et al. 32)
Ipomoea glaberrima Boj. (St. J. & P. 192)

N. beach cliff path near top, Paulay and Spencer 627 (US, BISH); rare at top of cliff face, NW beach, 609 (US).

Boraginaceae

Cordia subcordata Lam. (St. J. & P. 193; Fosberg et al. 32).

N. beach, top plateau, Paulay and Spencer 657 (US, BISH)

Heliotropium anomalum var. **argenteum** Jtn.
Heliotropium anomalum var. candidum St. John (St. J. & P. 192-193; Fosberg et al 32)

N. beach, beach strand, Paulay and Spencer 635 (US),near top of cliff face, NW beach site, 612 (US, BISH)

The variety candidum said to be in Henderson Island, indeed differs sharply from the eastern Polynesian var. anomalum, in its indument, which, at least in our specimens, I would call, at least the Paulay specimens, densely sericeous, rather than pilosulus, as described by St. John. In this respect this plant resembles the Hawaiian var. argenteum, in fact, comparison of no. 635 with a good series of Hawaiian specimens show that it falls well within the range of that variety. The variation in this species needs further study, and especially careful field observation. In some varieties the flowers are strongly dimorphic, even with different fragrances.

Tournefortia argentea L. f. (Fosberg et al. 33)
Messerschmidia argentea (L. f.) I.M. Jtn. (St. J. & P. 193)

N. beach strand, Paulay and Spencer 625 (US).

Verbenaceae

Premna cf. **serratifolia** L.
Premna integrifolia L. (St. J. & P., 193)
Premna obtusifolia R. Br. (Fosberg et al. 33)

N. beach trail, fossil lagoon plateau Paulay and Spencer 645 (US); North beach, top plateau, 656 (US), N. beach, lagoon-plateau, 622 (US).

Apparently common on plateau.

These specimens are sterile and have entire medium-small oblong obtuse firm leaves # 622 has reticulate, almost obovate leaves, old inflorescence, several loose pyriform fruits with reflexed calyx. This species is bewilderingly variable over its Indo-Pacific-wide range.

Rubiaceae

Canthium barbatum f. **calcicola** Fosb. (St. J. * P. 193; Fosberg et al. 33)

Common in forest on Plateau off NW beach, Paulay and Spencer 593 (US, BISH, BM)

Canthium odoratum (Forst. f.) Seem. (St. J. & P. 193; Fosberg et al. 33)

Abundant on top plateau off NW beach, Paulay and Spencer 595 (US, BISH, POM, MO, BM, CHR)

Abundant on rough coral on plateau.

Ixora fragrans (H. & A.) Forst f. (St. J. & P. 187; Fosberg et al. 32)
Cephaelis fragrans H. & A.

N. beach trail, fossil lagoon-plateau, Paulay and Spencer 648 (US); top plateau off NW beach 588 (US).

This is a member of Ixora sect. Phylleilema, characterized by its cymes strongly reduced and enclosed between two leaf-like, usually cordate bracts. No. 648 is sterile , no.588 is fruiting.

Morinda umbellata var. **forsteri** (Seem.) Fosberg (St. J. & P. 194; Fosberg et al. 33)
Morinda forsteri Seem.

N beach trail, fossil lagoon-plateau, Paulay and Spencer 646 (US); top plateau off NW beach, 589 (US).

Occasional climber in forest on western plateau, 1987 specimens sterile.

Timonius polygamus (Forst. f.) Robins. (St. J. & P. 193; Fosberg, occ. Pap. Bis. Mus. 13: 263, 1937.; Fosb. et al. 33)
Timonius forsteri DC

N. beach, cliff top, Paulay and Spencer 652 (US, BISH, BM), beach trail, fossil lagoon-plateau, 649 (US),1-300 m, NW beach site, 610 (US, BISH); top plateau off NW beach, 587 (US)

This shrub is notoriously variable in habit, leaf size and shape, and size of cyme. It is abundant in forest on the plateau and cliffs. No. 652 is staminate, with large open cymes. no. 649 is similar with smaller cymes, no. 717 similar but leaves smaller, 3.5 X 2 cm.

Goodeniaceae

Scaevola sericea var. **tuamotuensis** (St. John.) Fosb. (Fosberg et al. 33)
Scaevola taccada var. tuamotuensis St. John (St. J. & P. 194)

N. beach strand, Paulay and Spencer 628 (US, BISH, BM, CHR), N. beach 624 (US, BISH).

Typical var. tuamotuensis, prostrate and with glabrous narrowly spatulate leaves. This variety extends westward at least to the Cook Islands.

Asteraceae

Bidens hendersonensis Sherff (St. J. & P. 194, Fosberg et al. 33)

Common in central lagoon, top plateau, NW beach site, Paulay and Spencer 614 (US, BISH, BM); rare on top plateau off NW beach 590 (US, BISH).

Leaves simple, broadly elliptic, on slender petioles; inflorescence loosely corymbose, achenes less than 1 cm long, flat, thin, biaristate, pappus spine-like, with strong retrorse spinelike barbs, margins ciliate with antrosely subspreading barbs.

Senecio stokesii F. Br. (St. J. & P. 194; Fosberg et al. 33)

N. beach, trail, fossil lagoon-plateau, Paulay and Spencer 642 (US, BISH);N. beach trail, fossil plateau, 640 (US)

Apparently fairly common on plateau, becoming rather weedy in disturbed places, as along a cut path. A medium sized glabrous suffruitescent herb; originally described as endemic in Rapa. Many earlier collections available.

Additional specimens examined, Tait 36, 39 (BISH); St. John and Fosberg 15141, 15080, 15108, 15109, 15178, 15077m, all (BISH).

Henderson Island specimens of this species vary in height up to 2 m, stems simple to much-branched, especially toward apex, glabrous, leaf blade 2-12 cm x .08-7 cm, thin, elliptic to ovate or broadly ovate, apices from rounded to obtuse or, usually, acute to slightly acuminate. The original description is reasonably complete, but based only on the type, Stokes 108 (BISH) from Rapa. It also occurs on Raivavae, *St. John* *16036* (BISH).

The following 7 plants were seen but not collected in 1987, all quite common: *Pandanus tectorius* Park., *Cocos nucifera* L., *Thuarea involuta* (Forst. f.) R. & S., *Thespesia populnea* (L.) Sol. ex Correa, *Glochidion pitcairnense* (F. Br.) St. J., *Pisonia grandis* R. Br., and *Guettarda speciosa* L.

Previously recorded from Henderson but not found on this trip were the following 15 species: *Asplenium lobulatum* Mett., *Asplenium obtusatum* Forst. f., *Fimbristylis cymosa* R. Br., *Santalum hendersonense* F. Br., *Achyranthes aspera* var. *pubescens* (Moq.) Townsend, *Portulaca lutea* Sol. ex Forst. f., *Capparis sandwichiana* DC., *Pittosporum arborescens* Rich. ex Gray, *Sesbania coccinea* (L. f.) Poir. *Suriana maritima* L., *Aleurites moluccana* (L.) Willd.,*Meryta brachypoda* Harms, *Jasminum didymum* Forst. f. (?), *Lycium carolinense* var. *sandwicense* (A. Gray) Hitchc., and *Fitchia nutans* Hook. f. (?).

Plants of Pitcairn Island

Polypodiaceae

Davallia solida (Forst. f.) Sw.

Roadside, *Paulay, Spencer and Schuster* *685* (US).

Nephrolepis hirsutula (Forst. f.) Presl

Very common, *Paulay, Spencer and Schuster* *684* (US).

Polypodium scolopendria Burm. f.

Paulay, Spencer and Schuster *693* (US).

Thelypteris cf. parasitica (L.) Tard.

Paulay, Spencer and Schuster *694* (US).

Poaceae

Cynodon dactylon (L.) Pers.
Seashore, *Paulay, Spencer and Schuster* *683* (US).

Paspalum conjugatum Berg

Occasional, *Paulay, Spencer and Schuster* *676* (US).

Setaria verticillata (L.) Beauv.

Paulay, Spencer and Schuster *674* (US).

Sorghum halepense (L.) Pers.

Disturbed, fallow ground, rampant, *Paulay, Spencer and Schuster* *667* (US), *673*

(US).

Commelinaceae

Commelina diffusa Burm f.

Adamstown, common, Paulay, Spencer and Schuster 691 (US).

Amaranthaceae

Alternanthera brasiliensis (L.) O. Ktze.

Roadside, Adamstown, Paulay, Spencer and Schuster 679 (US).

Nyctaginaceae

Mirabilis jalapa L.

Roadside, Adamstown, Paulay, Spencer and Schuster 669 (US).

Fabaceae

Bauhinia cf. purpurea L.

Roadside, Adamstown, Paulay, Spencer and Schuster 692 (US).

Cassia (Senna) **septemtrionalis** Viviani

S.l. Ross 31b (AK).

Dolichos lablab L.

Paulay, Spencer and Schuster 664

Erythrina variegata var. **orientalis** (L.) Merr.

Not common, Paulay, Spencer and Schuster 686 (US).

Inga ynga (Vell.) J.W. Moore

Probably planted, Ross 69 (AK).

Leucaena leucocephala (Lam.) de Wit

Paulay, Spencer and Schuster 665 (US).

Oxalidaceae

Oxalis corniculata L.

Paulay, Spencer and Schuster 696

Malvaceae

Abutilon pitcairense Fosberg

a second collection of this has come to light, thanks to Rhys Gardner.
Pitcairn Island, Ross 31-19 Pitcairn name "Foutoo" (AK 74663)

Hibiscus ornamental hybrid aff. **H. rosa-sinensis** L.

Paulay, Spencer and Schuster 675 (US).

Flaucortiaceae

Homalium taypau St. John
Main ridge, common, Paulay, Spencer and Schuster 678 (US).

Xylosma suaveolens Forst.) Forst. f.

Main ridge, very rare, Paulay, Spencer and Schuster 677 (US).

Myrtaceae

Eugenia uniflora L.

Roadside, Paulay, Spencer and Schuster 687 (US).

yzygium jambos (L.) Alston

Abundant, Paulay, Spencer and Schuster 680 (US).

Begoniaceae

Begonia sp. (probably a cultivated hybrid).

Paulay, Spencer and Schuster 655 (US).

Myrsinaceae

Myrsine aff. **niauensis** Fosb. & Sachet
Bumelia sp.

S.l. Ross, sterile, US).

Apocynaceae

Allamanda hendersonii Bull

Paulay, Spencer and Schuster 682

Convolvulaceae

Ipomoea indica (L.) Merr.

Common, Paulay, Spencer and Schuster 666 (US).

Verbenaceae

Lantana camara L.

Rampant, Paulay, Spencer and Schuster 697 (US).

Verbena bonariensis L.

Radio station (Adamstown) not seen elsewhere, Paulay, Specer and Schuster 681 (US).

Plantaginaceae

Plantago major L.

Down Niger, Paulay, Spencer and Schuster 689 (US), Adamstown, 690 (US).

Caprifoliaceae

Lonicera japonica Thunb.

Big fence, Paulay, Spencer and Schuster 672 (US).

Asteraceae

Bidens pilosa L.

Roadside, Paulay, Spencer and Schuster 668 (US).

Conyza bonariensis (L.) Cronq.

Spreading over whole island, Paulay, Spencer and Schuster 661 (US).

But heads are far smaller than usual.

Sonchus oleracus L.
Big fence, Paulay, Spencer and Schuster 671 (US).

Vernonia cinerea (L.) Less.

Adamstown Paulay, Spencer and Schuster 662

Plants of Oeno Atoll

Bryaceae

Brachymenium indicum (Doz. & Molk.) Bosch. & Lac.

W. Islet, Paulay and Spencer 711 (US)

Polypodiaceae

Polypodium scolopendria Burm. f.
Phymatodes scolopendria (Burm. f.) Ching (P. & St. J. 402)

W. Islet, Paulay and Spencer 709 (US, BISH, BM).

Fronds rather small, lobes very narrow, lower ones mostly 2 cm or less wide, upper ones narrower.

Poaceae

Lepturus repens (Forst. f.) R. Br. var.
Lepturus repens (Forst. f.) R. Br. var. repens

W. Islet, Paulay and Spencer 698

No. 698 is a tufted slender plant strongly resembling var. septentrionalis of the Northern Marshall Islands, but with triangular lanceolate glumes, rather bluntly pointed, not at all subulate or aristate. Disposition of the southern Polynesian form must await a critical consideration of the Forster specimens.

Amaranthaceae

Achyranthes velutina H. & A. f. rosea (P. & St. J. p. 402).

W. Islet, Paulay and Spencer 701 (US, BISH, BM)

Flowers bright-rose pink.

Nyctaginaceae

Pisonia grandis R. Br. (P. & St. J. 402).

W. Islet, Paulay and Spencer 703 (US, BISH, BM).

A narrow tomentose line along side of midrib and principal veins.

Boerhavia tetrandra Forst. f.
Boerhavia diffusa var. tetrandra (Forst. f.) Heimerl (P. & St. J. 402).

W. Islet, Paulay and Spencer 708 (US, BISH, BM).

An unusual small-leafed form of this widespread species, but probably this.

Lauraceae

Cassytha filiformis L. (P. & St. J. 402)

W. Islet, Paulay and Spencer 710 (US).

Brassicaceae

Lepidium bidentatum Mont. (P. & St. J. 402).

W. Islet, Paulay and Spencer 700 (US, BISH, BM)

A rather dwarfed small-leafed form.

Pandanaceae

Pandanus tectorius Park.
Pandanus faruliferus St. J. (P. & St. J. 402)

W. Islet, Paulay and Spencer 707 (US)

Terminal fragment of leaf only.

Surianaceae

Suriana maritima L. (P. & St. J. 403).

W. Islet, Paulay and Spencer 699 (US, BISH, BM, CHR)

The leaves on this collection are shorter than often seen in this species, and with a tendency to be rather scattered on the upper stems rather than in terminal rosettes as is often the case.

Boraginaceae

Tournefortia argentea L. f.
Messerschmidia argentea (L. f.) Jtn. (P. & St. J. 403).

W. Islet, Paulay and Spencer 704 (US).

Rubiaceae

Hedyotis romanzoffiensis (C. & S.) Fosb. (P. & St. J. 403).

W. Islet, Paulay and Spencer 706 (US).

Leaves and fruit unusually small, easternmost occurrence of the species.

Goodeniaceae

Sacaevola sericea var. **tuamotuensis** (St. John) Fosb.

Previously unrecorded from Oeno.

W. Islet, Paulay and Spencer 702

Fruits unusually small, 5 X 4 mm, appearing blackish when dry.

Ducie Atoll

A search was made on Ducie Atoll for plant species but only one, Tournefortia argentea L. f., was found, reported previously by Rehder and Randall (ARB, 183: 18, 1975), and earlier by Chapin in 1936 and Quayle (ms journal) of the Whitney Expedition in 1922, who also noted "a few rare clumps of coarse grass Lepturus" and "one vine of a common Tuamotu shrub = Epigaea?" [This may have been Nesogenes euphrasioides A. Gray, or Triumfetta procumbens Forst. f. the only Tuamotu plant even faintly resembling Epigae]. Cuming, who visited in 1827, in a letter to Hooker at Kew wrote of his observation on Ducie, "has a number of trees and a small stunted grass". The grass was probably Lepturus repens and the trees, as well as those casually mentioned by earlier visitors, were doubtless Tournefortia. The fact that despite careful searches neither Rehder and Randall, nor the 1987 Expedition, found any trace of other land-plants suggests that in the interval between 1922 and 1975 storm waves may have swept the island, removing or killing the two herbaceous plants. The Tournefortia would have survived, and now forms a low forest over much of the atoll.

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