GUIDE TO THE GEOLOGY OF REEFS OF THE CAPRICORN AND BUNKER GROUPS, GREAT BARRIER REEF PROVINCE

Australasian Sedimentologists Group
Brisbane, August 1977

GUIDE TO THE GEOLOGY OF REEFS OF THE CAPRICORN AND BUNKER GROUPS, GREAT BARRIER REEF PROVINCE

J.S. JELL & P.G. FLOOD

PREFACE

In Queensland the growing interest in Quaternary sediments and sedimentation is not due merely to an increase in academic curiosity, but also to an urgent need for basic information regarding sediments, sedimentary environments, and sedimentary processes, prompted, in part, by recent and continuing debate of controversial conservation and commercial issues, and by coastal erosion and engineering problems. The large sand islands and the mainland beaches, for example, have become a focus of attention of geologists and geomorphologists from both academic institutions, and government departments including the Geological Survey of Queensland, C.S.I.R.O., and the Beach Protection Authority.

For the effective control of the Great Barrier Reef Marine Park, the province of the recently established "Great Barrier Reef Marine Park Authority" information is sought regarding the coral reef environment, the factors effecting and affecting the development and stability of coral reefs, and the sedimentary processes involved.

The recent application of continuous seismic profiling techniques and side scan sonar to both marine and fluvial investigations has already yielded a considerable increase in our knowledge of subaqueous Quaternary geology, particularly in the Moreton Bay area and in parts of the Great Barrier Reef Province.

The theme of the first Queensland meeting of the Australasian Sedimentologists Group is, therefore appropriate and timely, and to mark this occasion the decision was made to publish a collection of papers, in two parts, which would indicate the present trend of researches. The papers presented for the meeting in pre-print form will be published in the Papers of the Department of Geology - University of Queensland - volume 8 number 2 (Handbook of recent geological studies of Moreton Bay, Brisbane River, and Stradbroke Island) and number 3 (Guide to the geology of reefs of the Carpricorn and Bunker Groups, Great Barrier Reef Province). The Organising Committee is grateful to Professors J.B. Waterhouse and G.E.G. Sargent for their encouragement in this endeavour and for the facilities of the Department of Geology and Mineralogy, University of Queensland. The committee also gratefully acknowledges the co-operation of the Under-secretary for Mines, Queensland, who granted permission for the publication of the papers by Jones *et al.* on "Late Quaternary Sedimentation in Moreton Bay" and Laycock on "North Stradbroke Island".

G.R. Orme
Chairman

R.W. Day
Deputy Chairman

Brisbane, August 1977.

This is an unedited version of the "Guide to the geology of reefs of the Capricorn and Bunker-Groups, Great Barrier Reef Province", which has been prepared for the Heron Island field excursion (26th - 29th August, 1977). In its final form, the guide will be published in the Papers of the Department of Geology- University of Queensland, volume 8, number 3.

G.R.O. and R.W.D.

GEOLOGICAL STUDIES OF THE REEFS OF THE CAPRICORN AND BUNKER GROUPS WITH SPECIAL REFERENCE TO HERON REEF, SOUTHERN REGION, GREAT BARRIER REEF PROVINCE

by J.S. Jell and P.G. Flood

(with 28 Text-figures and 19 Plates)

ABSTRACT Published geological studies of the Capricorn and Bunker Groups of reefs together with preliminary results of our research indicate that the reefal masses which comprise the southern end of the Great Barrier Reef Province had commenced growth by the early Pleistocene (drilling results) on a basement ridge. Since then the reefs have been exposed during the Pleistocene glaciations to subaerial weathering associated with the dissolving action of meteoric water. Subsequent sea level rise allowed coral growth to recolonize the pre-existing reefal bodies which in places may have exhibited a karst topography. The present stage of development of individual reefs can only be partly related to the relative heights of the sea and to the height and slope of the pre-existing reefal body because a northwesterly trend of reef type development occurs irrespective of the size of the reefs and irrespective of differences or similarities in the depth to the pre-Holocene disconformity. A possible explanation is that the rate of reef productivity might increase in the northwesterly direction. Further research is clearly warranted.

Detailed analyses of the skeletal component composition of reef-top sediments from several reef types (eg. closed ring, lagoonal platform and platform) show that variations in composition result mainly from differences in the percentage contribution made by four dominant skeletal types: coral, coralline algae, Halimeda, and foraminiferans. As the reef progressively changes according to a recognisable sequence of reef type development, the component composition of the bulk of the sediments also changes. This trend reflects the changing nature of the biota of the reef top. Recognition of this gradual evolution of reef types allows one to relate conclusions concerning the component and textural composition not only to individual depositional environments on each reef, but also to a scheme of reef development, thereby providing insight into the possible behaviour of the composition of sediment in time as well as in space.

INTRODUCTION

The reefs of the Capricorn and Bunker Groups are distributed astride the Tropic of Capricorn east of Rockhampton and Gladstone; together with Lady Elliot Reef they comprise the southern end of the Great Barrier Reef Province. They are situated on the western Marginal Shelf bathymetric zone of the Southern Region of the Province (Maxwell 1968, 1969, 1976); they rise from approximately the 58 m isobath (Orme et al. 1974; Davies et al. 1977a), and they lie approximately 10 km west of the incised continental shelf edge (100 m isobath) in a zone of pure carbonate sediment (Maiklem 1970). The reefs are aligned in two directions: one trends northwesterly parallel to the shelf edge for 125 km from Lady Elliot Reef to North Reef; the other trends southwesterly perpendicular to the shelf edge with one line extending from Sykes Reef to Polmaise Reef a distance across the shelf of 50 km. Another shorter line extends from Broomfield Reef to the western end of North West Reef (see Text-fig. 1).

Lady Elliot Reef (24°07'S Lat.) which has a manned lighthouse and an airstrip is the most southerly reef of the Reef Province. To the north the next four reefs, Lady Musgrave, Fairfax, Hoskyn, and Boult Reefs, comprise the Bunker Group. The other 16 reefs, Llewellyn, Fitzroy, Lamont, One Tree, Sykes, Heron, Wistari, Erskine, Mast Head, Polmaise, Wreck, Wilson, Broomfield, Northwest, Tryon, and North Reefs are referred to as the Capricorn Group (British Admirality, Australian Pilot 1962). A tourist resort and a marine scientific research station operated jointly by the University of Queensland and the Great Barrier Reef Committee are located on Heron Island. A field research station administered by the University of Sydney is sited on One Tree Island and a manned lighthouse operates at North Reef.

All of these reefs have similar hydrological, bathymetric, geological, and tectonic settings and have common morphological features but all are different in size and shape, in the development of the various morphological zones, in the size configuration and depth of the lagoon (if developed), in the form and nature of their cays. Geological studies over the last six years by the Geology Department of the University of Queensland have been orientated towards understanding the processes involved in producing such variations.

This contribution, prepared as a guide for the 1977 Reef Excursion of the Australasian Sedimentologists Group (Geological Society of Australia Incorporated) includes:

1. a summary of previous geological studies in the area together with air photographic coverage of the reefs and islands,
2. results of the studies undertaken since 1972 by the Geology Department of the University of Queensland, and
3. a preliminary interpretation of the evolutionary nature of reef growth which in turn may offer an explanation for the variation in reef-type development within this part of the reef Province.

PREVIOUS GEOLOGICAL STUDIES

The only morphological/geological studies of these southern reefs before the mid 1950's were the examination of most of the islands by Steers during two expeditions to the Great Barrier Reef in 1928 and 1936 (Steers 1929, 1937, 1938) and the drilling of a bore by the Great Barrier Reef Committee on Heron Island (Richards 1938) to a depth of 223 m in 1937 with the subsequent descriptions of the recovered material (Richards 1938; Richards and Hill 1942; Iredale 1942; Cushman 1942). Fairbridge (1950) made general comments about the reefs and cays, and Edgell (1928) noted changes to the shape of Mast Head Island.

Geophysical surveys of the continental shelf in this southern area of the Reef Province were undertaken by petroleum exploration companies and the Bureau of Mineral Resources in the late 1950's and the 1960's (Wilson 1967; Hill 1970 for summary of unpublished geophysical reports; Ericson 1976). Three wells were drilled on this part of the shelf. The Wreck Island Bore was drilled to a depth of 547 m by Mines Administration Pty. Ltd. on behalf of Humber Barrier Reef Oil Pty. Ltd. (Traves 1960; Derrington 1960). Australian Gulf Oil Pty. Ltd. prospected the Capricorn Basin to the east of the Capricorn-Bunker reefs and drilled the two holes, Capricorn No. 1A in the west to 1710 m and Aquarius No. 1 towards its eastern margin to 2650 m (Wilson 1969). Sedimentary petrological and palaeontological studies of the cores from these and the Wreck Island and Heron Island bores have been made by Maxwell (1962), Travers (1960), Palmieri (1971), Hekel (1972), Lloyd (1967, 1968, 1970, 1973), and Davies (1974b).

Interpretation of the geological structure of the shelf on which the reefs are situated was aided by the knowledge obtained from the geophysical data and from the regional geological mapping of the adjacent mainland and nearshore islands by the Geological Survey of Queensland and the Bureau of Mineral Resources (Ellis 1968; Kirkegaard, Shaw, and Murray 1970; Ellis and Whitaker 1976).

In 1959 Maxwell and his collaborators began systematic morphological and sedimentological studies of the Great Barrier Reef Province. This commenced with the investigation of the Capricorn-Bunker reefs including reef top sediments (Maxwell, Day, and Fleming 1961; Maxwell, Jell, and McKellar 1963, 1964) and inter-reef sediments (Maxwell and Maiklem 1964; Maiklem 1968, 1970). Reference to work in this southern part of the Reef is incorporated in his summaries of various aspects of the Reef Province (Maxwell, 1968, 1969a, 1969b, 1970, 1971, 1972, 1973a, 1973b, 1976a, 1076b; Maxwell and Swinchatt 1970).

Weber and Woodhead (1969) investigated the ^{13}C and ^{18}O stable isotope distribution in the sediments of Heron Reef and adjacent inter-reef areas. The distribution of ^{13}C in the carbonate sediments is highly dependent upon the nature of the environment and can provide information concerning wind direction and sediment transport from one environment to another across the reef.

Veeh and Veevers (1970) identified two terraces on the continental slope adjacent to the Capricorn Group (Text-fig. 1), a lower one at -175 m from which a shallow water coral gave a radio-carbon date of 13600 $\pm$ 220 years B.P. and a uranium series date of 17000 $\pm$ 1000 years B.P., and a second terrace at -150 m from which a sample of beach rock yielded radio-carbon dates of 13860 $\pm$ 200 yrs B.P. and uranium series dates of 17000 $\pm$ 100 years B.P.

The results of these geological investigations up until 1970 are summarized by Maxwell in his various papers (op. cit.) and by Hill (1970, 1974) and Jones (1977).

In 1970, the Bureau of Mineral Resources undertook a morphological/sedimentological study of the continental shelf between latitudes 20°S and 33°S; this included six sample lines 18.5 km apart across the Capricorn-Bunker reefs and adjacent shelf edge (Marshall 1972). Hekel (1973) and Palmieri (1976) have examined the nanoplankton, microascidites, quartz and organic content, and the foraminiferal content respectively, of the sediment samples collected during this survey.

Since 1970, Davies and co-workers have undertaken a variety of projects in the Capricorn-Bunker region. These include: morphological aspects of reef growth and sedimentology on One Tree Reef and other reefs (Davies 1975; Davies, Radke, and Robinson 1976; Davies 1977; Davies and Kinsey 1973, 1977; Davies, Marshall, Faulstone, Thom, Harvey, Short, and Martin 1977; Davies, Thom, Short, Marshall Harvey, and Martin 1977); physical and chemical aspects of the beach rock and intertidal waters on Heron Island (Davies and Kinsey 1973; Davies 1974a); identification of subsurface solution unconformities in the Heron Island bore material (Davies 1974b); and more recently (in 1977), together with the Geological Survey of Queensland, shallow geophysical investigations within the Capricorn Group.

Since Maxwell's initial work in this southern part of the Great Barrier Reef, staff of the Geology Department of the University of Queensland, have researched various geological aspects of the region. These have been primarily physiographic and sedimentological studies based on:

1. Air photo interpretation of both coloured and black and white vertical, oblique, and ERTS photographs of the reefs of this area
2. Aerial reconnaisence of all the reefs
3. Detailed physiographic traverses of selected reefs
4. Sediment sampling of reef top sediments: Heron (Aug. 1975 Jan. 1976

following cyclone 'David', Jan. 1977), Lady Elliot (Oct. 1972, May 1977), Lady Musgrave (Oct. 1972), Firzroy (Aug. 1975, Jul. 1976), North (Jul. 1976, Mar. 1977), Wreck (Aug. 1972), Tryon (Aug. 1972, Jul. 1976, Mar. 1977), North West (Aug. 1972), Mast Head (Aug. 1972, Jul. 1976, Mar. 1977), Erskine (Jul. 1976, Mar. 1977), Wilson (Aug. 1972, Jul. 1976, Mar. 1977), Wistari (Jul. 1974)

5. Successive measurements of the beach profiles of various cays and sediment tracer experiments (A.R.G.C. project of PGF).

Results of this work have been incorporated in published papers of symposia, excursion guide books, and presented at conferences (Flood 1974; Orme, Flood and Ewart 1974; Flood 1976a, b; Jell and Flood 1976; Flood, Allen and Orme 1976, 1977; Flood 1977a, 1977b, 1977c, 1977d; Flood and Jell 1977; Flood and Orme 1977; Orme and Flood 1977).

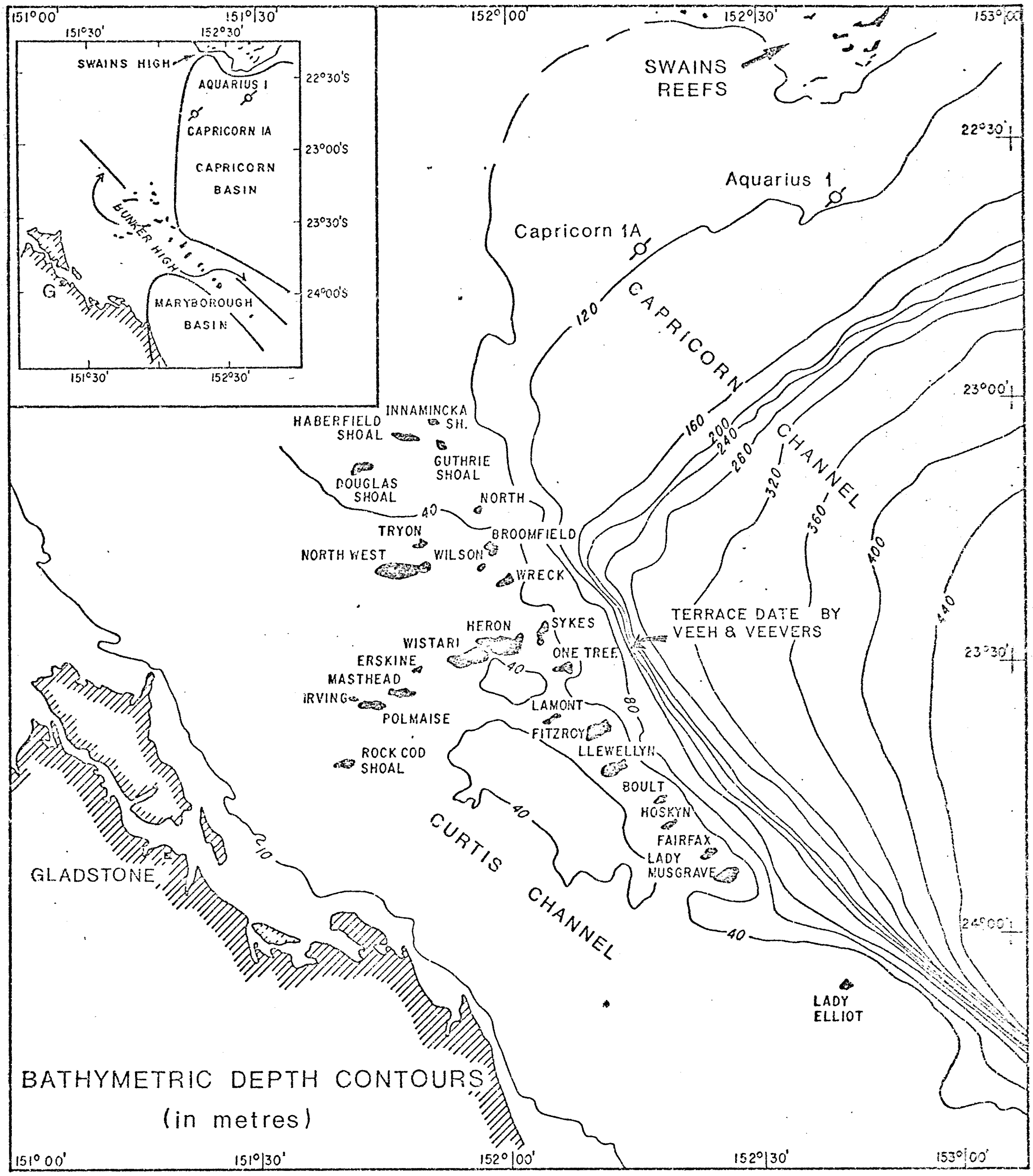
In August 1976 shallow geophysical surveys were conducted over the inter-reef areas and across the platforms between reefs. Preliminary results are presented herein.

REGIONAL SETTING

Reef location

Reef development is localised on the Bunker High (Maxwell 1968) which is bordered on the west by the northern portion of the Maryborough Basin (Ellis 1966) and on the east by the Capricorn Basin (Maxwell 1968). The Curtis and Capricorn Channels are respectively approximately coincident with the positions of these basins (see Text-fig. 1).

Seismic data (Ellis 1966; Wilson 1967; Ericson 1976) and stratigraphic information (Richards and Hill 1942; Maxwell 1962; Hekel 1972; Lloyd 1973; Davies 1974; Palmieri 1971, 1974) obtained from the subsurface in the Heron Island Bore and the three petroleum exploratory wells (HBR Wreck Island 1, AGO Capricorn 1A, and AGO Aquarius 1) illustrate the nature of the Tertiary and Quaternary sedimentary sequence within the Capricorn Basin and on the Bunker Ridge (see Text-fig. 2). A marine transgression occurred in the late Oligocene.



Text-fig. 1 Location of reefs of the Capricorn and Bunker Groups, including Lady Elliot Reef, at the southern end of the Great Barrier Reef Province. Insert showing the tectonic setting.

Following a brief regression represented by a quartz sand sequence another more extensive transgression commenced in the latest Oligocene or earliest Miocene (fide Hekel 1972) and this transgression has persisted to the present except for minor oscillations of the order of 100 m which were related to sea level fluctuations associated with the Pleistocene glaciations. These fluctuations and tectonic subsidence have produced successive intervals of high and low sedimentation rates and Palmieri (1974) has shown that reef growth on the Bunker Ridge commenced approximately one million years ago.

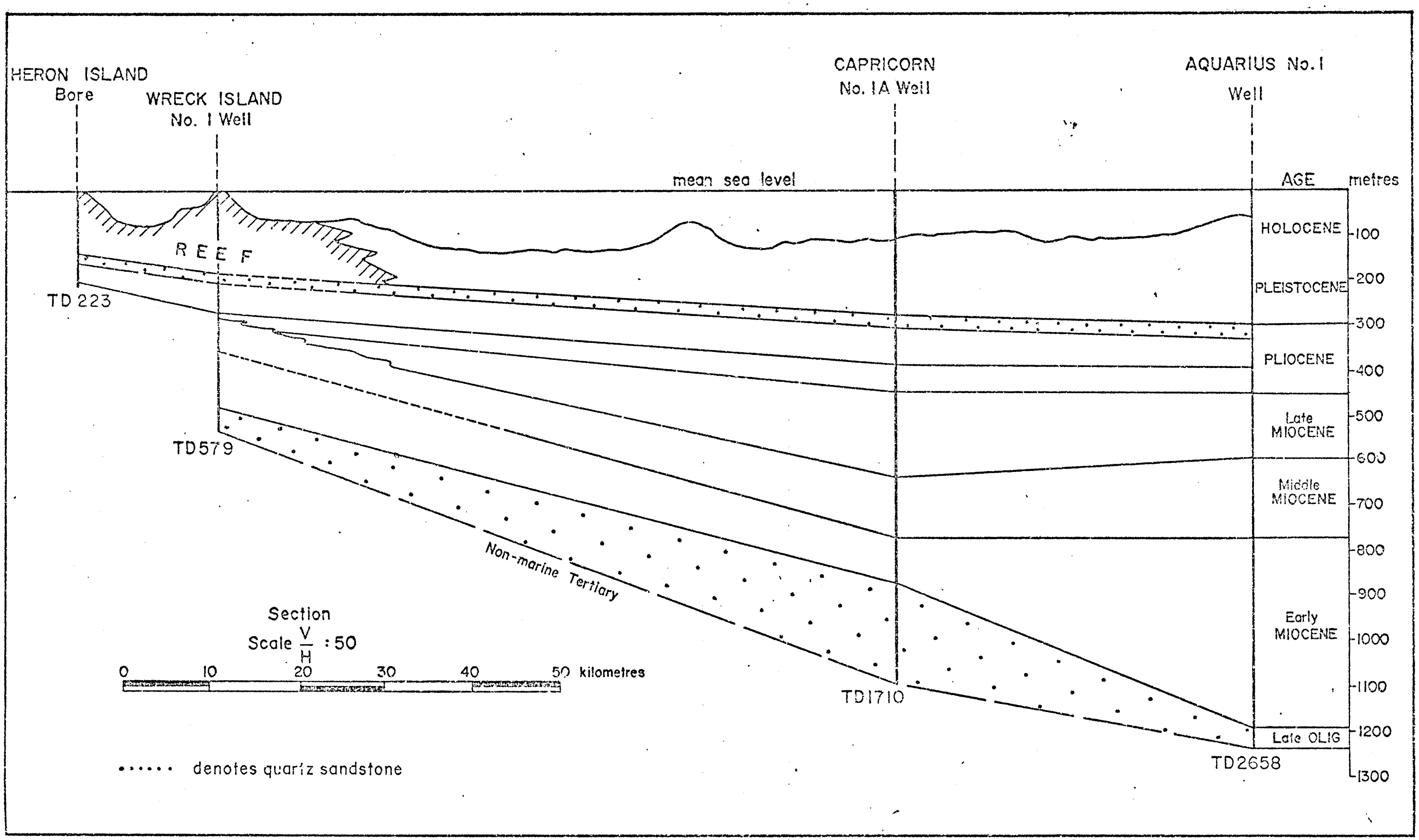
Prevailing physical conditions

Maxwell (1968 and elsewhere) summarized the hydrology, climate, and weather of the Great Barrier Reef. Maiklem (1968), Woodhead (1968), and Brandon (1973) provide general details for the Capricorn Group. Specific details can be obtained from the Commonwealth Bureau of Meteorology which has recorded data since 1963 from weather stations on Heron Island, North Reef, and Lady Elliot Island.

The Southeast Trade Wind blows at an average speed of 20 to 40 km/hour (Beaufort Scale 4 to 5) for approximately 70 per cent of the year. The summer months experience calms or north-northwesterly winds and occasional cyclones.

Ocean swells of 1 to 3 m amplitude predominate from the east-south-east. Waves breaking on the reef rim can exceed 2 m and they refract around the reef producing lateral transport of sedimentary particles from windward to leeward. Sediment is deposited and may accumulate where wave sets converge e.g. the sand cay area. The water level on the intertidal parts of the reef portion is sufficiently shallow even at high tide to allow wind shear to agitate sand-sized particles and to keep silt-sized particles in suspension.

The tidal range within the area varies from 2.3 to 1.8 m (springs) and 1.1 to 0.8 m (neaps), increasing in the northwesterly direction. Tidal currents which set westerly on the flood tide and easterly on the ebb tide rarely exceed 2 km/hour and as the water level falls drainage is crudely radial until the reef rim becomes exposed then it flows to leeward. The lagoons experience



Text-fig. 2 Tertiary marine sequence on the Bunker Ridge and adjacent Capricorn Basin (after Palmieri 1974). Location of exploratory wells and bore are shown in Text-fig. 1.

slack water for several hours during each tidal cycle.

The diurnal and annual temperature ranges for the Heron Reef Flat have been determined by Endean et al. (1956). Mean summer (January) water temperatures range between 26° and 27°C, whereas the mean mid-winter (July) temperature drop to between 20° and 21°C.

REEF MORPHOLOGY AND REEF TYPES

Reef Morphology

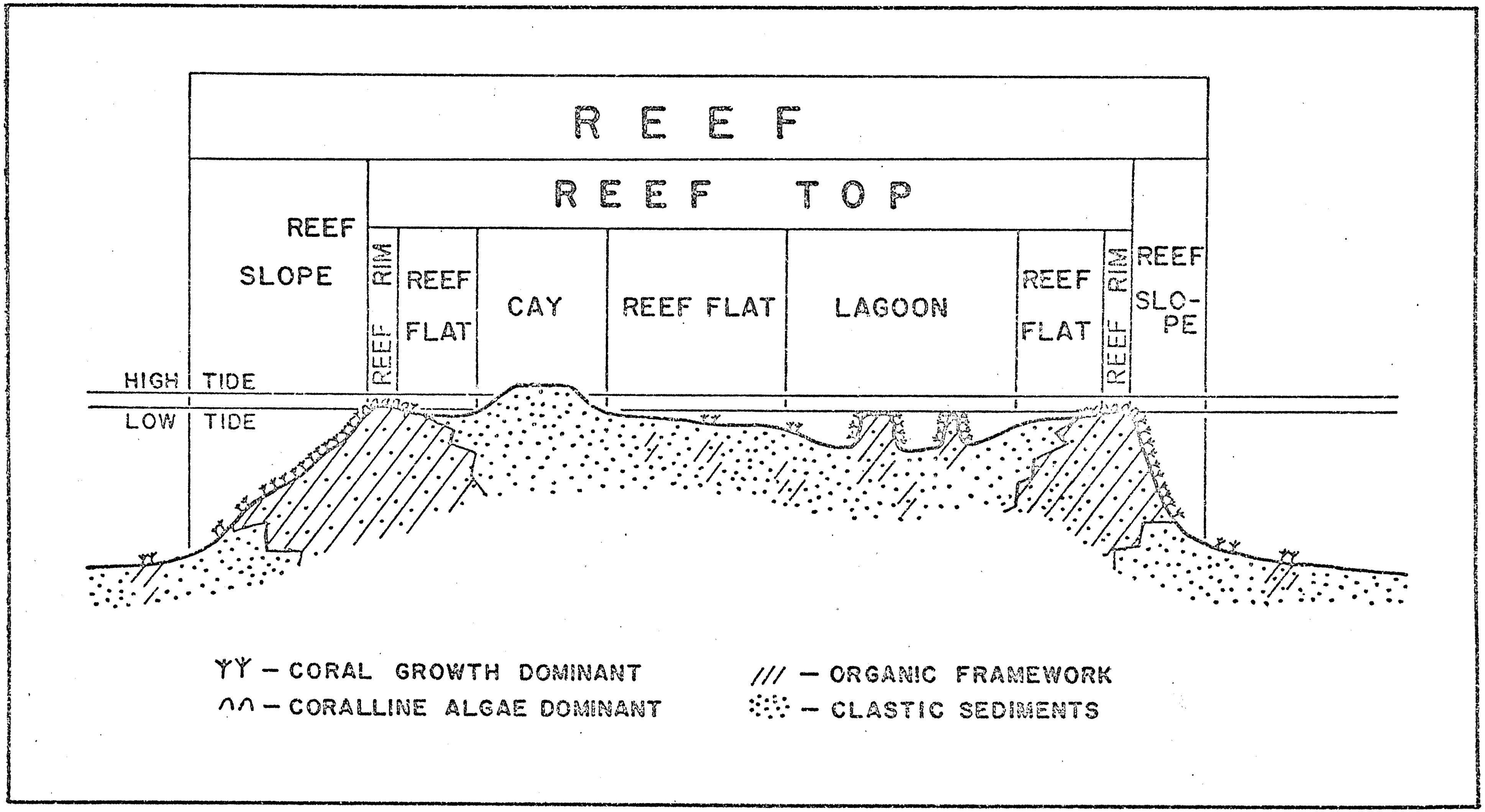
Maxwell et al. (1961, 1964), Maiklem (1968), Maxwell (1968), Orme et al. (1974), Jell and Flood (1976), Davies et al. (1976, 1977a, 1977b), Flood and Orme (1977), Flood et al. (1977) have illustrated the inter-relationship displayed by the morphological, ecological and sedimentological zones which parallel the line of intersection of the reefal mass and the water surface at low tide. The following zones (see Text-fig. 3) are encountered traversing the reef from windward (i.e. southeast) to leeward (northwest).

Windward reef slope

The reef slope is a steeply inclined (10° to 40°) surface extending from the outer edge of the zone of coralline algal encrustations which usually coincides with the edge of the reef rim, downwards to the relatively flat continental shelf area of the off-reef plain. Spur-and-groove structures occur on the upper part above a terrace at -10 to -14 m (w.r.t. low water datum). The upper surface of the spurs which is exposed during low water tides is the site of luxuriant low-profile growths of Acropora spp. whereas the growing edges and the terrace support the branching (staghorn) varities. Corals decrease markedly below -10 m and the reef is a coral veneered cemented limestone mass.

Reef top

The reef top includes that part of the reef surface enclosed within the outer edge of the coralline algal zone (or reef rim) and is divisible into three distinct depositional environments (supratidal, intertidal and subtidal). Several morphological sub-zones may be recognised:-



Text-fig. 3 Generalised cross-sectional view of a lagoonal platform reef (after Maiklem 1968).

1. Reef rim surrounds each reef top and is built slightly higher than the adjacent reef flat by coralline algal encrustations. Coral shingle may form extensive covers over the algal pavements.

2. Reef flat extends inward from the reef rim as a series of radial lineations, consisting of living corals (mainly Acropora spp.), arranged normal to the refracted wave fronts. Moving inwards living coral (which constitutes the ecological coral zone) progressively covers less of the reef flat area, giving way to areas (sometimes subtidal) of bioclastic carbonate sand cover. Branching and massive corals are common, together with echinoids (predominantly Diademae), Halimeda, molluscs, foraminiferans (Calcarina and Baculogypsina), and holothurians.

3. Cays or islands are those parts of the reef permanently above high water level. The islands of the Capricorn-Bunker Group display an extremely interesting variety of sizes, shapes, vegetation, etc. (see Domm 1971; Fosberg *et al.* 1961, Flood 1977). Three varieties may be recognised (Steers 1937; Fairbridge 1950; Maxwell 1968):

   a. Shingle cays (Fairfax east, Hoskyn east, One Tree),

   b. Sand cays (Fairfax west, Hoskyn west, Heron, Mast Head, North West, Wreck, North, Tryon), and

   c. Mixed Shingle/Sand cays (Lady Musgrave, Wilson, Erskine, Lady Elliot).

All cays except for the shingle types are located towards the leeward margin of the reef top.

They vary in size (see Plates 1-5) covering from one to twelve percent of the reef top surface area (20 percent in the case of Lady Elliot). Arranged in increasing order of their area (approximate only):

North (45,000 m^2), Erskine (65,000), One Tree (75,000), Wilson (120,000) Wreck (140,000), Hoskyn (east 40,000, west 125,000), Tryon (210,000), Lady Musgrave (275,000) Lady Elliot (280,000), Heron (290,000), Fairfax (west 125,000, east 375,000), Mast Head (500,000), and North West (1,500,000).

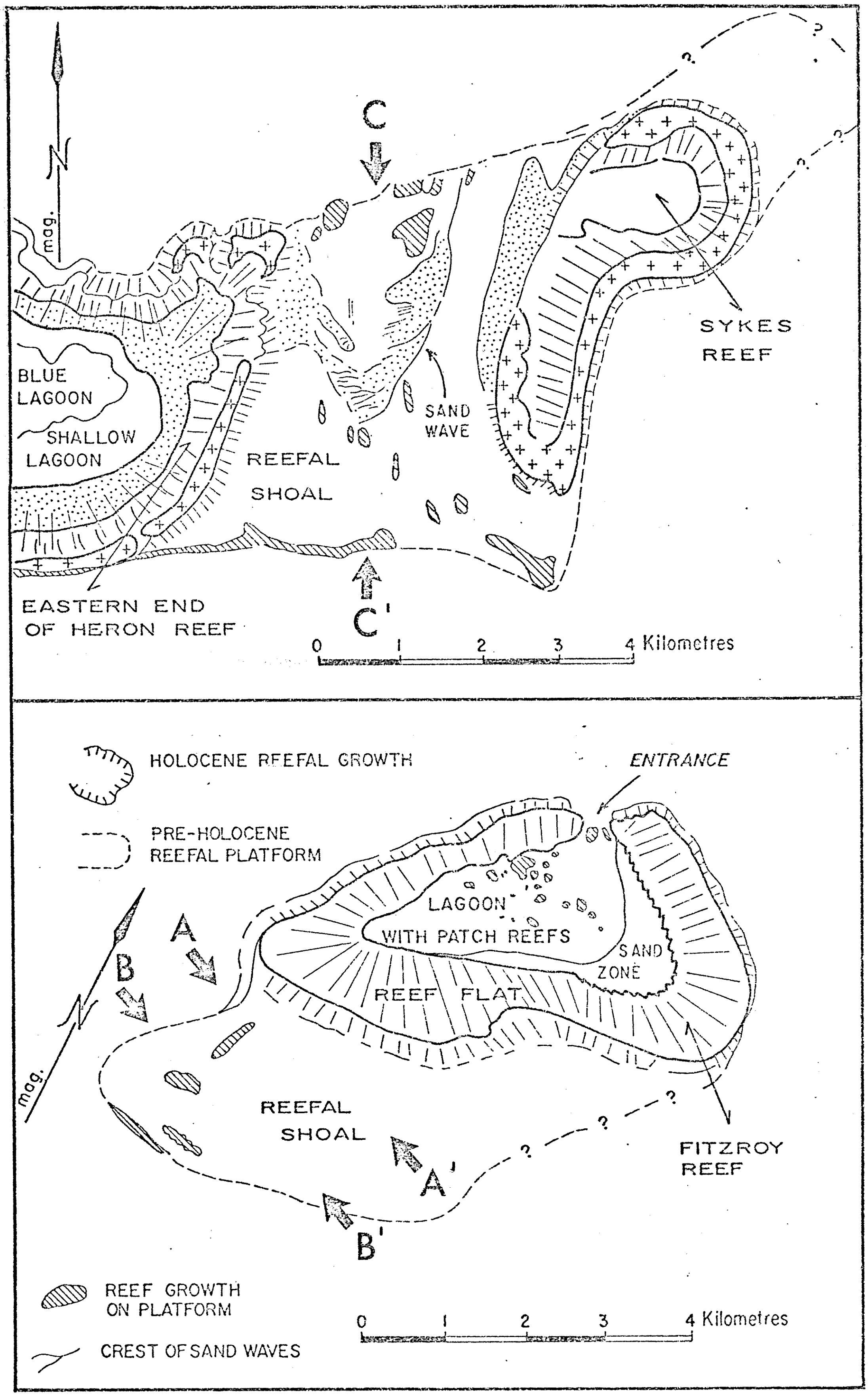
There does not appear to be any correlation between island size, reef size, or stage of reef development.

Beachrock is exposed on all the islands and cay rock (supratidally lithified sediment) occurs on Tryon, Fairfax east, Lady Musgrave, and Lady Elliot Islands (see Maxwell 1962; Davies and Kinsey 1973 for discussions of the probably origin of beachrock). Some reefs do not possess a cay but have intertidal sand bodies on their leeward reef flat (e.g. Boult, Fitzroy, Wistari, and Broomfield).

4. Lagoons may occupy the central portion of the reef tops and their depth below low water datum is usually less than 10 m. The lagoonal floor is relatively flat. Patch reefs stud the floor and rise to the same level as the surrounding reef flat. The junction between the lagoon and the reef flat may or may not be clearly defined. Usually present is a subtidal accumulation of bioclastic sand which slopes from the level of the base of the windward reef flat corals towards the lagoonal floor. The presence of lagoonal patch reefs within this sand zone illustrates its prograding nature. In situ addition of Halimeda, coralline algae and molluscan debris contributes to the bioclastic sediment which has been carried in from the reef flat and the reef rim. The lagoons vary in size, occupying from approximately 30 percent of the reef top surface area in the case of the Lady Musgrave, Llewellyn, and Fitzroy Reefs to about 20 percent for Heron and Wistari Reefs to practically zero in the case of Broomfield Reef.

Leeward reef slope

From the outer edge of the leeward reef flat to about half a kilometre offshore from the reef is a gently inclined slope. Massive corals (e.g. Porites spp. forming large heads up to several metres in diameter) are common in water depths to about 10 m. Skeletal carbonate sand which has been washed from the reef top produces sandy areas in the lee of the reef (see Davies and Kinsey 1977). During cyclonic conditions many of the coral heads are cast up onto the leeward reef flat producing a zone of coral boulders.



Text-fig. 4 Plan view of the reefal shoals present between Heron and Sykes Reefs, and underlying the southwestern corner of Fitzroy Reef. On the Heron-Sykes platform skeletal carbonate sediment which is carried by ebbing tidal currents from Heron Reef is deposited to form a train of sand waves having approximately 200 m wavelengths and 3 m amplitides with secondary bedforms superimposed.

Reef types

Maxwell (1968, 1970) recognised that reefs could be classified on the basis of morphological differences recognisable in plan view (eg. symmetrical or linear, the presence or absence of a central lagoon, etc). Six or Maxwell's reef types are represented among the 20 reefs of the Capricorn-Bunker Group. These are:-

1. Wall reefs - Lamont and Sykes
2. Platform reefs - North, Tryon, Wilson, Wreck, Erskine, and Lady Elliot
3. Elongate platform reefs - North West, Mast Head, and Polmaise
4. Lagoonal platform reefs - Heron, Wistari, One Tree, and Broomfield
5. Closed ring (platform) reefs - Fitzroy, Llewellyn, Boult, and Lady Musgrave
6. Ingrown closed ring reefs - Fairfax and Hoskyn

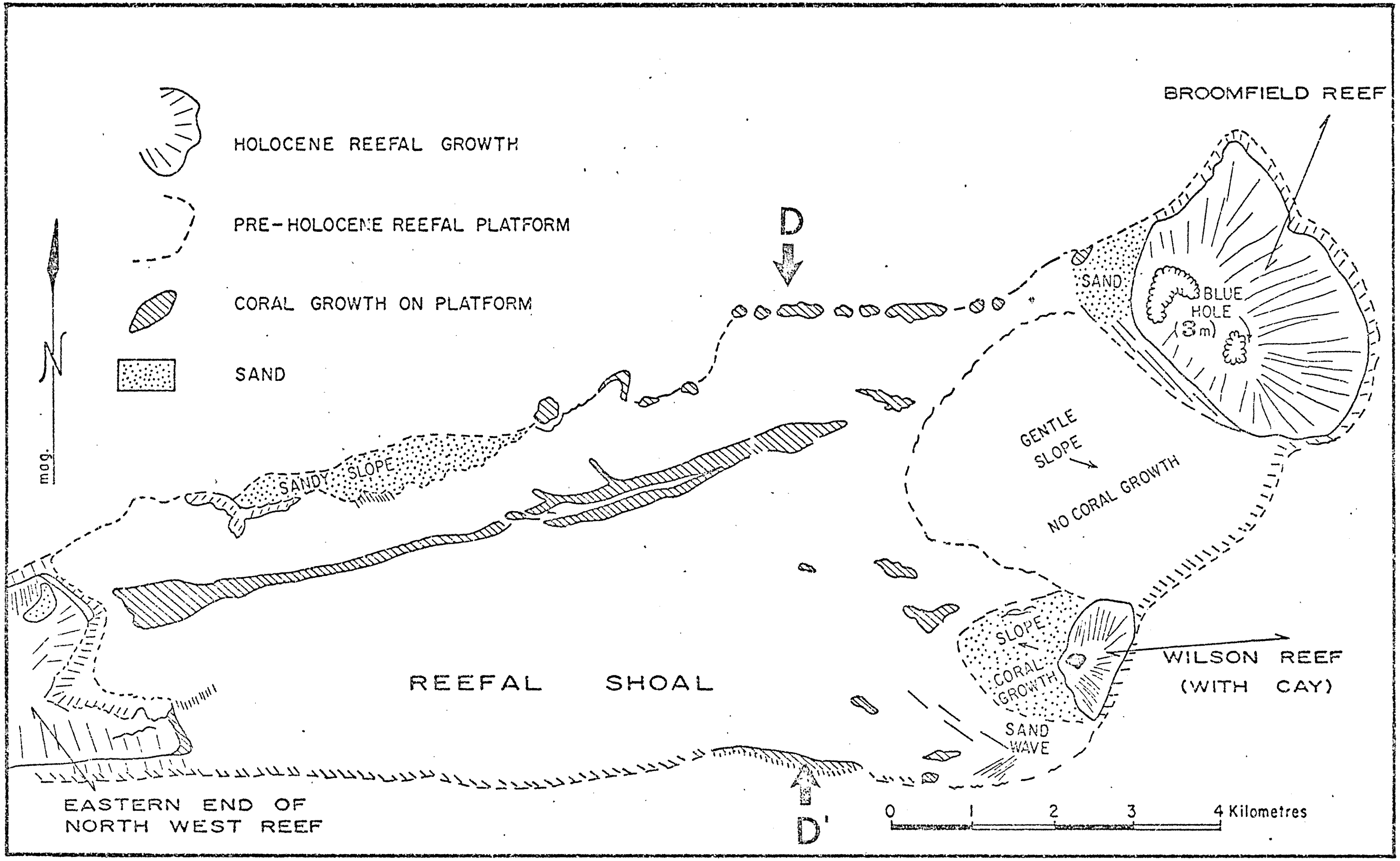
These reefs are shown in Plates 6 to 10. They vary in size from a maximum dimension of one to 11 km with corresponding surface areas of one to approximately 40 km^2. Arranged in increasing order of surface area they are:- Wilson (1 km^2), Erskine (1.25), Lady Elliot (1.5), Tryon (2), Lamont (2.5), North (2.5), Hoskyn (3), Fairfax (4), Wreck (4), Boult (6), Mast Head (7), Polmaise (7), Sykes (7), Broomfield (9), Lady Musgrave (10), Fitzroy (12), Llewellyn (12), One Tree (14), Wistari (25), Heron (27), and North West (38).

On the northwesterly trend (excluding Lady Elliot Reef) the reef type changes from closed ring or ingrown closed ring to lagoonal platform to elongate platform or platform. This trend which occurs irrespective of the size of individual reefs is accomplished by:-

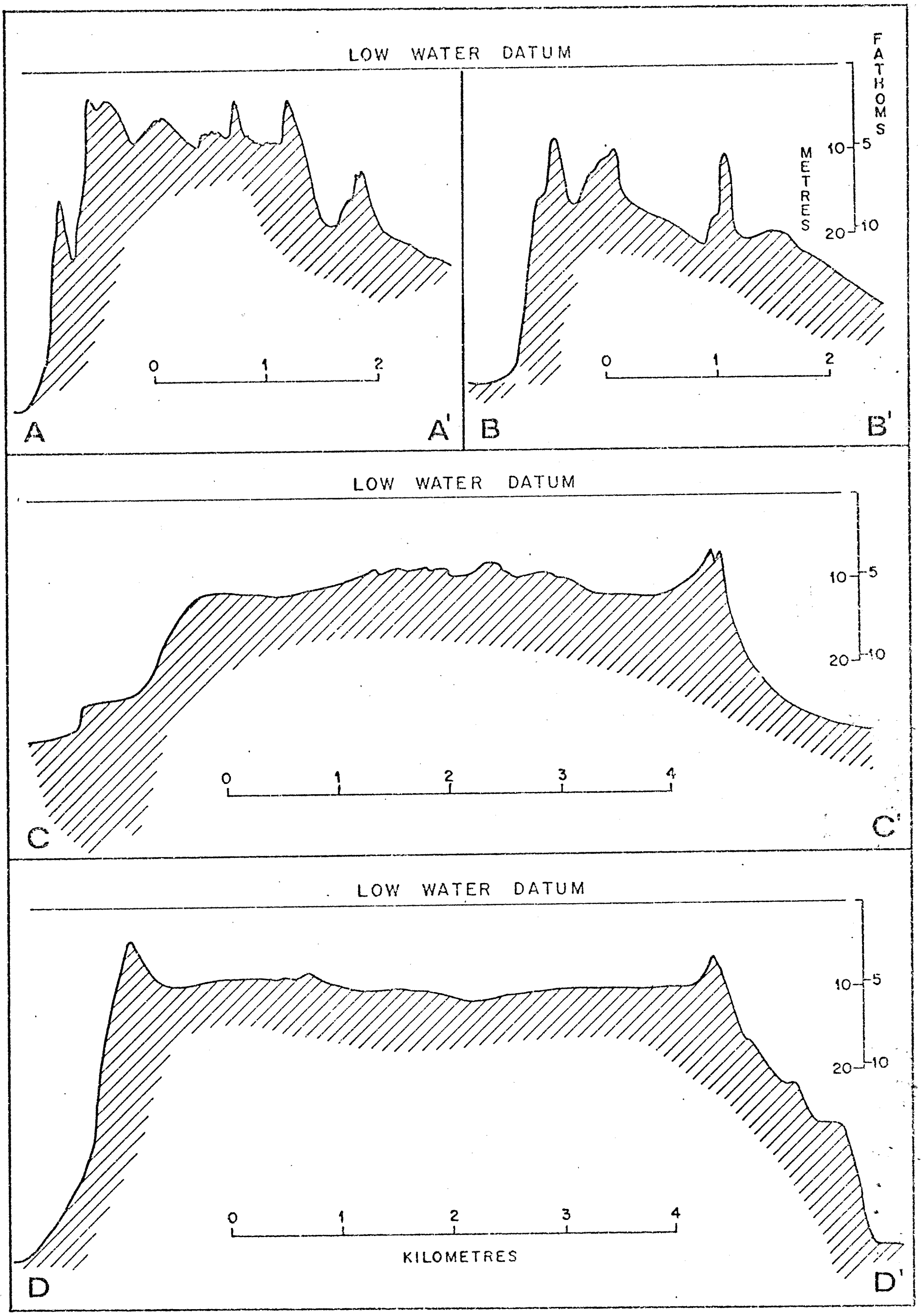
1. a shallowing of the lagoonal floor,
2. progressive infilling of the lagoon by a prograding wedge of skeletal carbonate sediment, and
3. obliteration of the radial pattern of coral growth by a thin cover of sediment and/or by algae veneering the tops of the reef flat corals.

Reefal shoals

Reefal shoals (Text-figs 4-6, Plate 11) rise to within approximately 10



Text-fig. 6 Plan view of the reefal shoal between North West, Broomfield, and Wilson reefs.



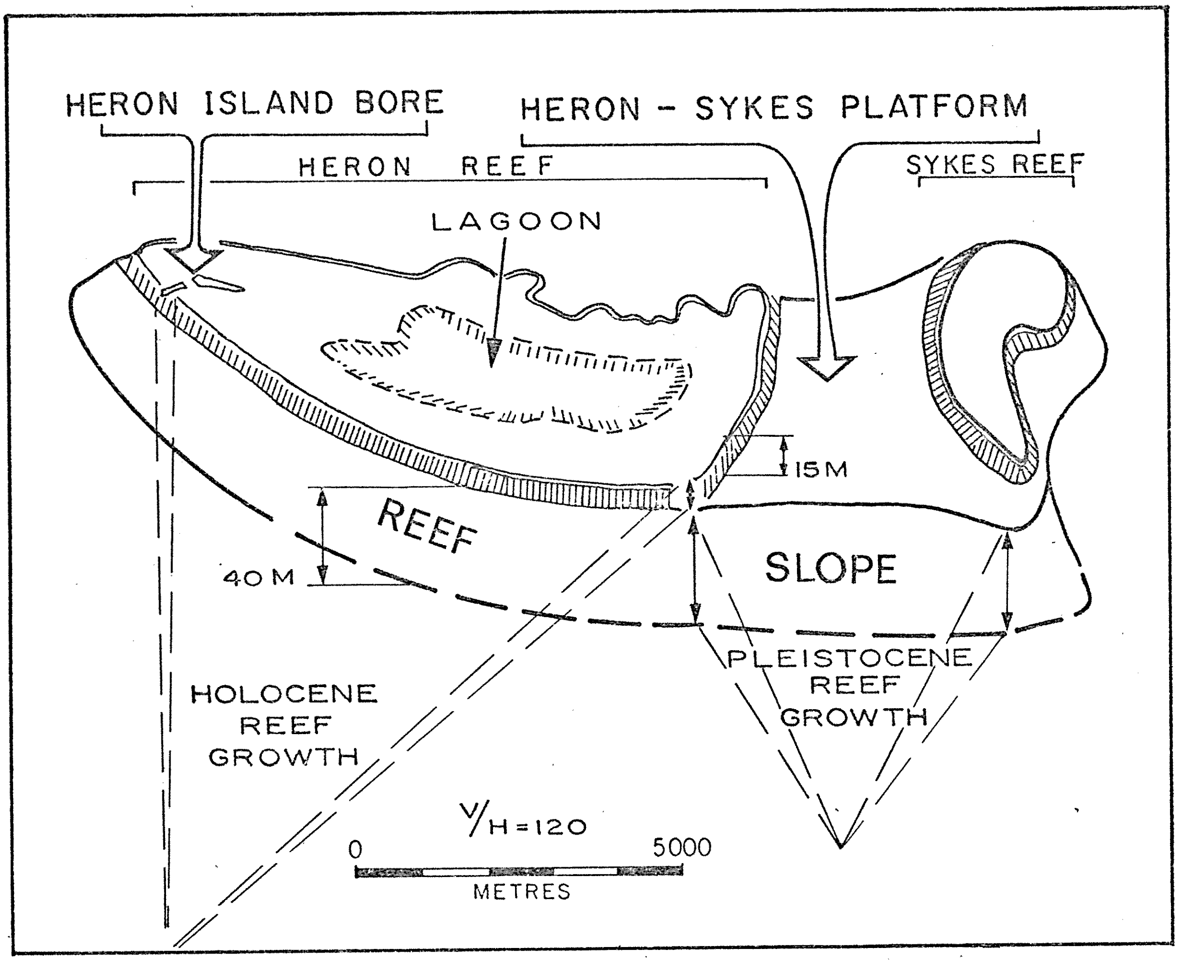
Text-fig. 5 Echosounder profiles across the reefal shoals. Locations of these cross-sections are shown on Text-figs. 4 and 6.

to 20 m of the water surface at low spring tides. They occur as individual mounds (Rock cod, Irving, Douglas, Haberfield, Guthrie, and Innamincka), as submarine platforms between reefs (North West, Wilson and Broomfield; Heron and Sykes; Wistari and ERskine), or as submarine platforms underlying other reefs (e.g. North, Firzroy). The Australian Pilot (British Admirality 1962, pp. 58-62) gives details of other patches, banks, and shoals. Their morphology and composition have been examined using scuba and they appear to be pre-existing reef on which coral growth was not been able to keep pace with the rising sea level during the Holocene transgression.

The platform between Heron and Sykes reefs extends under the former at approximately 15 m below low water datum (Flood 1976a). At this level Maxwell (1962), Davies (1974), and Purdy (1974) recognised a decrease in the proportion of aragonite in material from the Heron Island Bore (Richards and Hill 1942). Such a change was interpreted by Davies and by Purdy as indicating subaerial weathering of a pre-existing reef which would have been exposed by the lowering of sea level during the last glacial maximum (ca. 15000 years B.P.). Therefore Holocene coral growth on Heron Reef as well as on other reefs of the Group (see Davies et al. 1976, 1977a, b) appears to be a veneer over a pre-existing surfaces which have been karstified (see Text-fig. 7).

Preliminary results of geophysical investigations (high resolution boomer and side-scan-sonar) conducted by Prof. G.E.G. Sargent and the authors in August, 1976 indicate the following:-

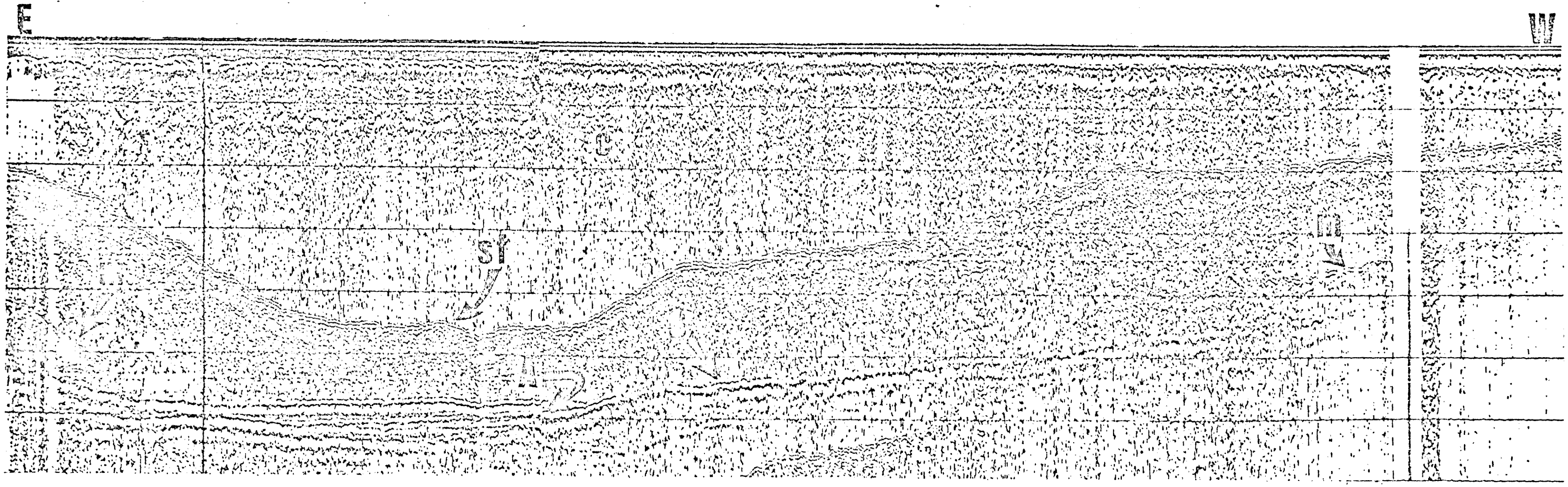
1. recent sedimentation within the shelf area of the Capricorn Group forms a veneer over a pre-existing surface (see Text-fig. 10).
2. wedges of Recent carbonate sediment are located adjacent to the reefal shoals (see Text-figs 10,11).
3. a major disconformity representing a regression followed by a transgression and subsequent reef growth is located at a shallow depth below the water/sediment interface on the shelf in the vicinity of



Text-fig. 7 Diagramatic representation of the relationship of the Holocene reef growth, pre-Holocene reefal platform, and the continental shelf.

Text-fig. 8 Continuous seismic reflection profiles (high resolution boomer) extending from the vicinity of Heron Reef westward to the lee of Wistari Reef, across the Heron-Wistari inter-reef channel (upper profile) and extending northward from the lee of Wistari Reef (lower profile).

Sf, sea floor; m, multiple; c, response change +ive to -ive; A and B, prominent sub-bottom reflectors; brs, back-reef sediments; rs?, questionable sub-horizontal reef sediments. Each timing line on the vertical scale is 10 milliseconds apart (2 way travel time) or approximately 7.5 m. Horizontal length of each profile is approximately 1 km.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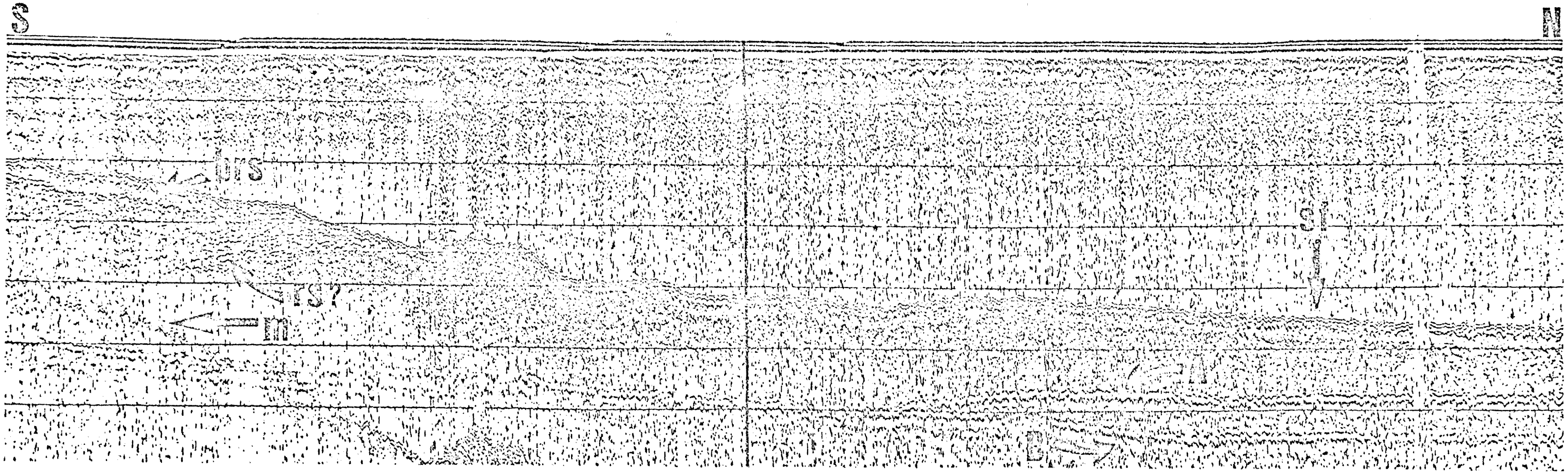
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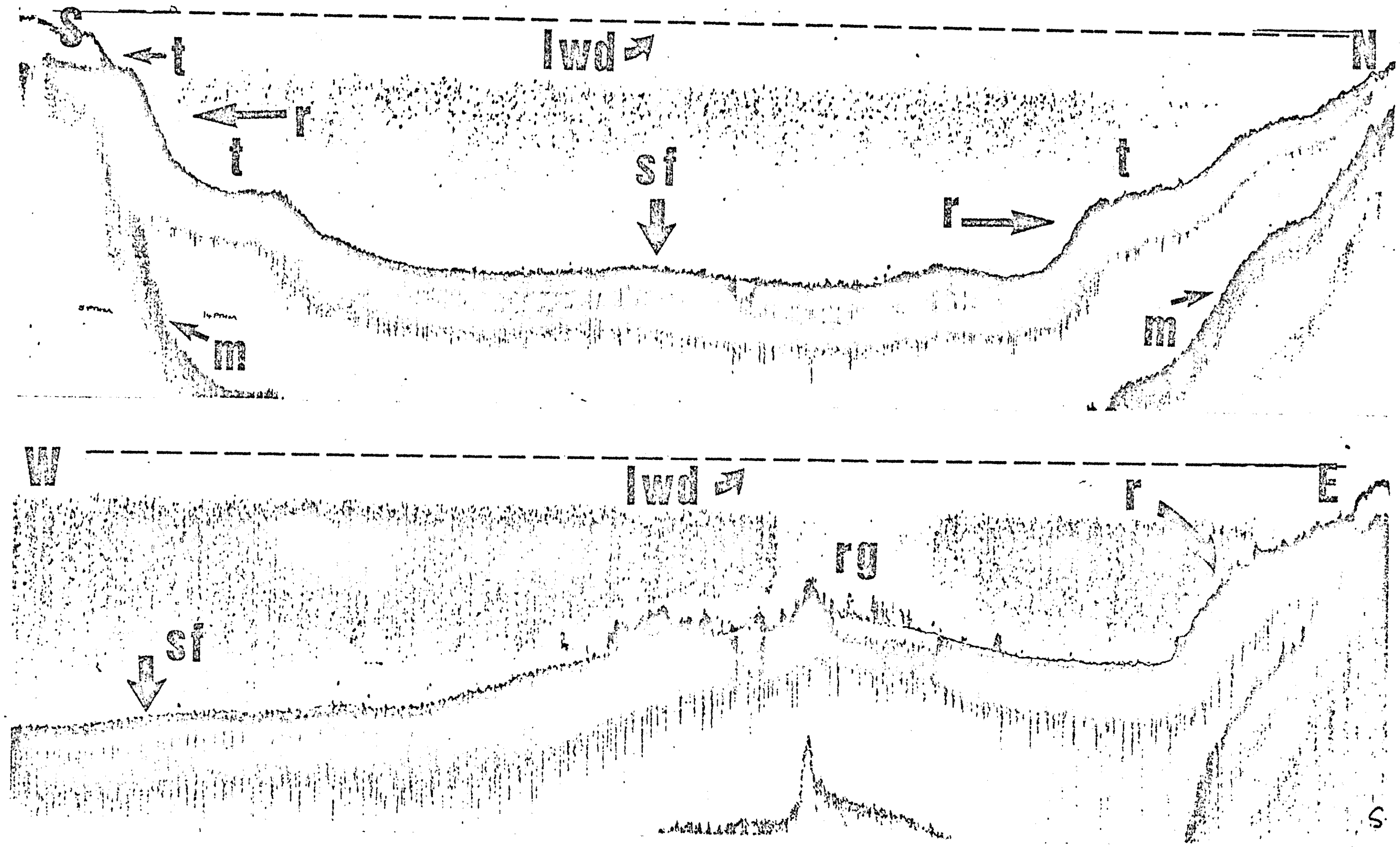
Text-fig. 9 Echosounder profiles of the inter-reef channel between Heron and Wistari Reefs. Upper profile S to N from Wistari to Heron Reef from mid-way along NE reef slope. Lower profile W to E meeting Heron Reef just north of profile 4 (Text-fig. 16). Profiles are across similar area as upper profile of Text-fig. 8. t, terrace; r, reef; sf, sea floor; rg reefal growth; m, multiple; lwd, low water datum. Vertical scale 1 cm = 10 m; horizontal distance 800 m (approx.).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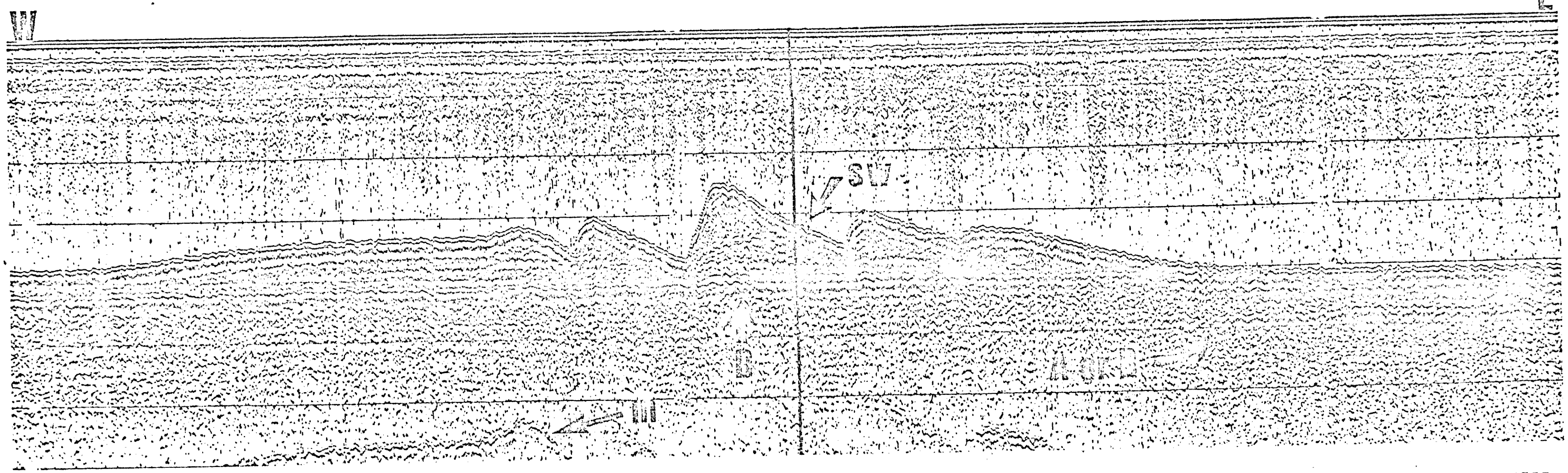
Text-fig. 10 Continuous seismic reflection profiles (high resolution boomer). Upper profile extending west to east approximately 1.5 km north of Polmaise reef across asymmetrical sand waves consisting of skeletal carbonate sand derived from the reef top of Polmaise Reef.

Lower profile across the lee slope of the North West - Broomfield - Wilson platform along a line from Wilson to Tryon Reefs.

sf, sea floor; sw, sand wave; m, multiple; rs, reefal shoal on platform; s, lee slope sediment wedge; D, prominent reflector which approximately coincides with the sea floor except where overlain by Holocene carbonate sediments; A or B, prominent sub-bottom reflector which occurs at progressively deeper depths moving across the shelf.

Scales as for Text-fig. 8.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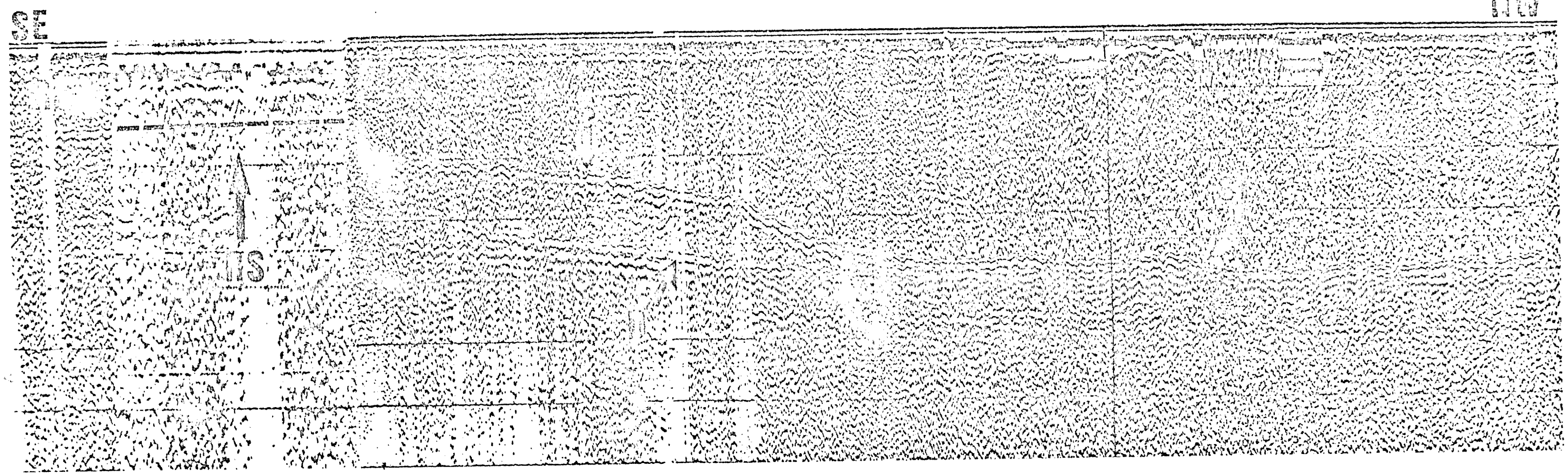
SE
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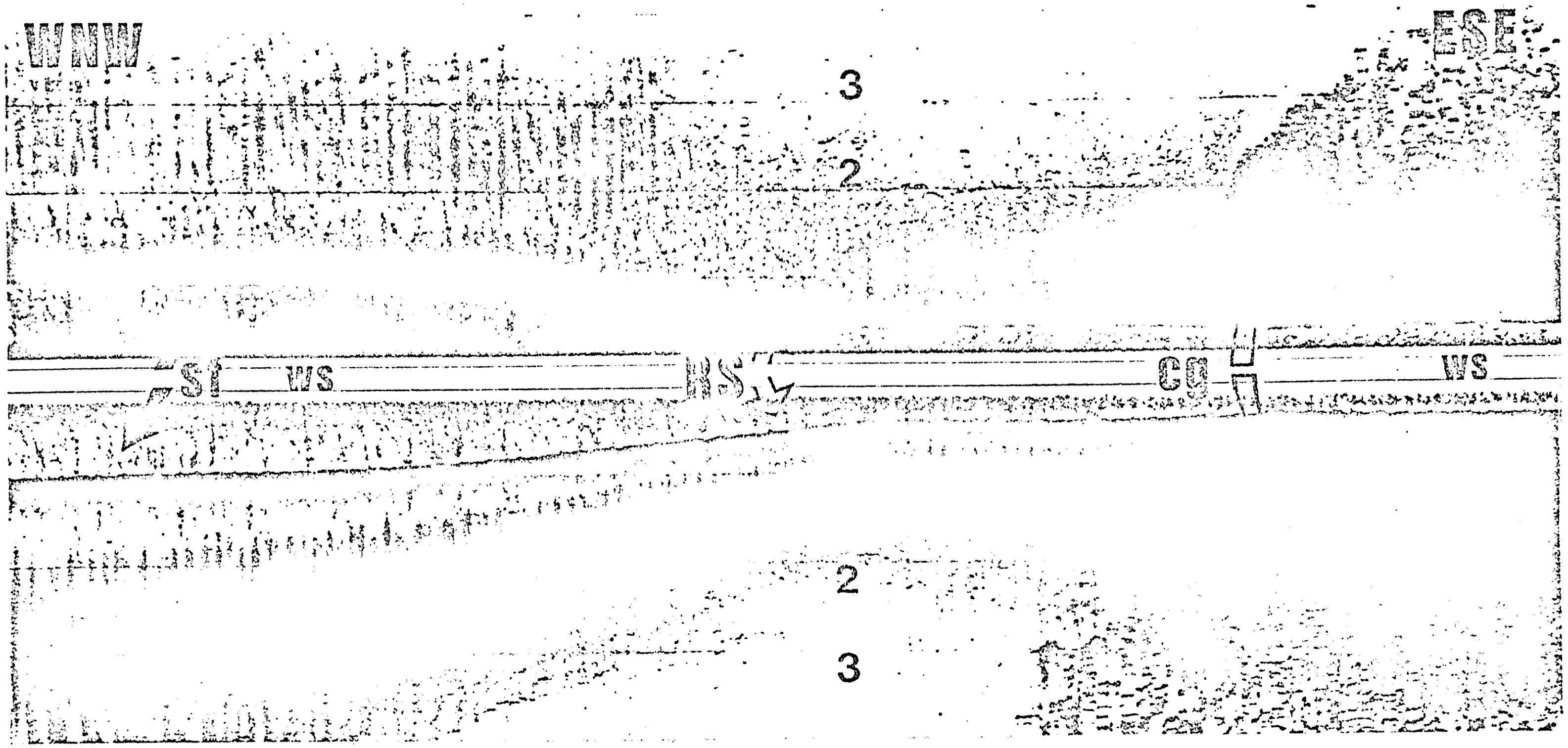
Text-fig. 11 Side-scan-sonar record of the seabed in the lee of the North West - Broomfield - Wilson platform on a traverse line bearing 110° from Tryon Island. Position approximate to the lower profile in Text-fig. 10. Prominent sand wave field occurs to leeward of the platform. sf, sea floor; ws, approximately water/air interface; RS, reefal shoal or platform; cg, coral growth on the platform; Timing lines (1,2,3) are spaced to show slant range intervals of 25 m. Horizontal length of record 0.3 km (approx.).



WNW
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WS
HS
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2
3

Heron and Wistari Reefs (see Text-fig. 10). The level of this disconformity approximately correlates with a lithological change in the Heron Island Bore (Richards and Hill 1942) from white reef rock to lithified calcareous mud at 120 feet (i.e. 36.6 m).

4. The surface of the outer portion of the continental shelf in the vicinity of the reefs appears to be a carbonate (limestone) plain possessing variable relief with modern reef growth restricted to topographic highs.

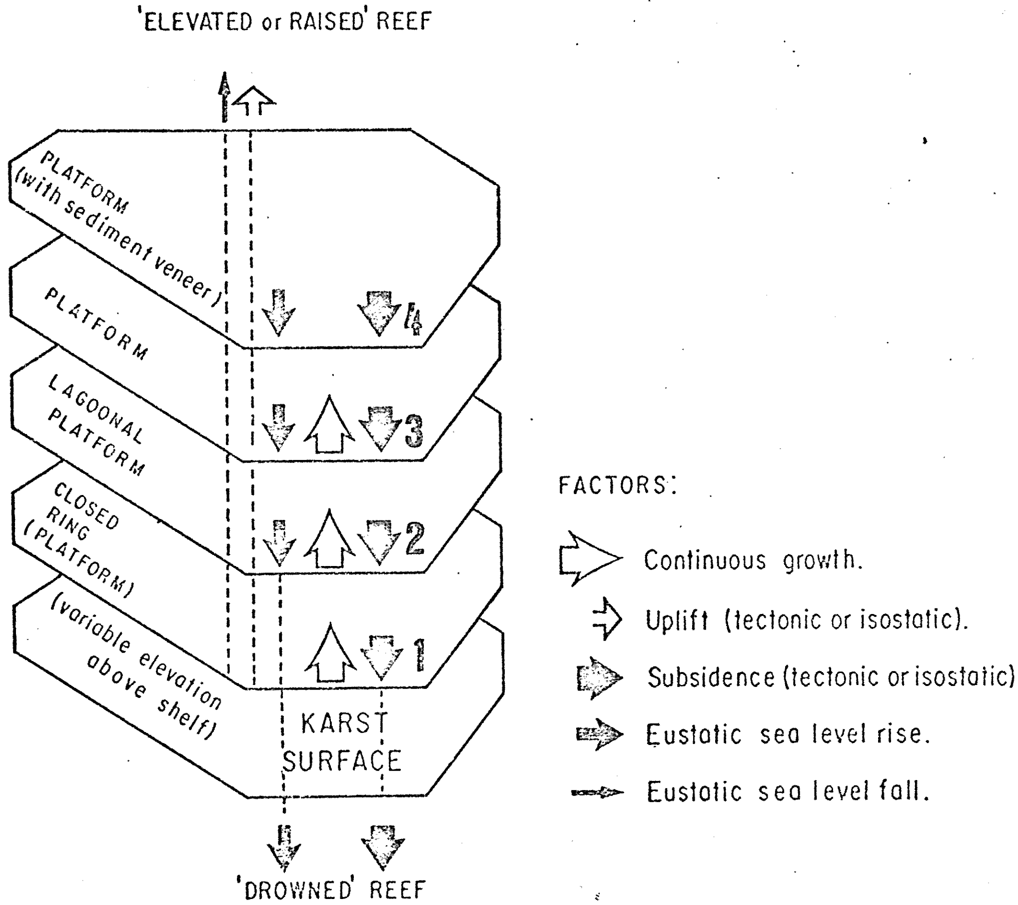
Similar findings have been reported from the northern region (Orme _et al._ 1977a, b; Orme and Flood 1977) where a major disconformity coincides with a prominent subsurface seismic reflector.

Sequential development of reef types

Recent research (Davies 1975, 1977; Davies and Kinsey 1977; Davies _et al._ 1976, 1977a, b; Flood 1976a, b, 1977a) has shown that morphological differences between individual reef (and reef types) might be explained not only by organic growth (Fairbridge 1950, 1967; Maxwell 1968) but also by one or a combination of the following process:

1. Holocene reef morphology is initially controlled by the shape of the pre-existing reef (see section on reefal shoals) which was exposed to subaerial weathering by the lowering of the sea during the Pleistocene glaciations. The dissolving action of meteoric water differentially lowers the central area of the large carbonate platform and subsequent reef growth during the Holocene transgression colonizes the topographic highs on the platforms (antecedent karst theory of Purdy 1974).

2. The stage of development of an individual reef is also related to the relative height of carbonate platform (i.e. the pre-existing reef) with respect to sea level at the commencement of the Holocene transgression. Reef growth on the higher platforms will reach modern sea level before the growth on the lower platforms (_cf._ Davies 1975).



Text-fig. 12. Scheme illustrating the development of successive reef types as a function of tectonic, isostatic, eustatic, and biological growth variables (after Flood 1977a).

3. When reef growth reaches the level of mean low water springs only then does it interact with the prevailing hydraulic regime as envisaged by Fairbridge (1950) and Maxwell (1968). Subsequent modification is related to

   a. lateral growth (primarily to leeward, see Scoffin et al. 1977; Davies 1977; Davies and Kinsey 1977),

   b. sediment infilling of the lagoons (where developed), and

   c. replacement of the framebuilding organic groups such as coral and coralline algae by the epithitic and benthic organic groups such as soft algae, foraminifera, Halimeda, molluscs, etc.

This produces the following sequence of reef types:

closed ring → ingrown closed ring → lagoonal platform → platform

Flood (1977a) presented a scheme which incorporates tectonic, isostatic, eustatic, and biological growth as variables in explaining the succession of reef types (see Text-fig. 12). This scheme follows the following sequence:

The topographic expression of the surface of the pre-Holocene carbonate platform will determine the initial reef type which developed during the Holocene transgression. As sea level reaches slightly above the platform a planar surface will give rise to a platform reef; a surface with a shallow centrally located depression will produce a lagoonal platform reef; a broad surface with a very deep centrally located depression will produce a closed ring reef. Organic growth may not keep pace with the rising sea level, therefore, any height difference which exists between the carbonate platforms will result in coral growth on the highest platform reaching the sea level first. Only then will the reef development follow the sequence 1 → 2 → 3 → 4. If the rate of vertical coral growth and associated reef development equals the rate of subsidence or eustatic sea level rise, the reef type will persist. If the rate of vertical coral growth and associated reef development is less than the rate of subsidence or eustatic sea level rise then reef type which is at mean low water neap tide level will follow the succession 4 → 3 → 2 → 1. If the rate of vertical coral growth and associated reef development is greater than the rate of eustatic sea level rise or tectonic subsidence then any reef which is at mean low water neap tide level will follow the succession 1 → 2 → 3 → 4 starting at whichever reef type is in existance at that time. Once the coral growth has reached the level of mean low water neap tides, and if stable sea level is maintained then the reef type will develop through the succession 1→ 2→ 3→ 4 starting at whichever reef type existed once it had reached this level. Rapid subsidence or eustatic sea level rise will cause the reef to be drowned. (This may have happened in the case of the reefal shoals). If the reef is already at the level of mean low water neaps, either eustatic sea level fall or tectonic/isostatic uplift will produce an 'elevated or raised" reef. With stable sea level or a slight drop, development beyond Type 4 will result in the reef top being veneered by skeletal sand and gravel.

This scheme does not, however, fully explain the northwesterly trend of reef type development evident within the reefs of the Capricorn-Bunker Group. This trend was previously explained by Flood (1976a) as suggestive of hydro-isostatic tilting (differential subsidence) along and across the continental shelf in a southeasterly direction. Recent research (Davies et al. 1977) has shown that differential subsidence has not occurred because depths to seismic discontinuities corresponding to the junction of Holocene reef growth and the pre-Holocene carbonate platforms do not display a consistent pattern either across or along the shelf. There is no indication (if their preliminary results are representative) of the disconformity being at a greater depth in the south-eastern reefs than for the others (e.g. 7.9 - 12.8 m and 8.2 - 12.5 m for Wreck and Fairfax reefs respectively; they are reefs of similar surface area).

An alternative suggestion that might explain the difference in reef types between reefs of similar size is that the rate of carbonate productivity, organic growth rates sediment productivity etc. increases in the northwesterly direction. (If this be the real situation then the southern-most reef of the area, namely Lady Elliot which is a platform reef with a well developed shingle cay (see Flood 1977b), should show an extremely shallow depth to the pre-Holocene disconformity). Unfortunately, to date One Tree Reef is the only place where detailed calcification and budget studies have been undertaken (Davies 1977; Davies and Kinsey 1977) and details pertaining to the physical oceanography of the area (Brandon 1973; Palmieri 1976) are too generalised to be able to make any definitive statement either supporting or reputing this suggestion. Further research is clearly warranted.

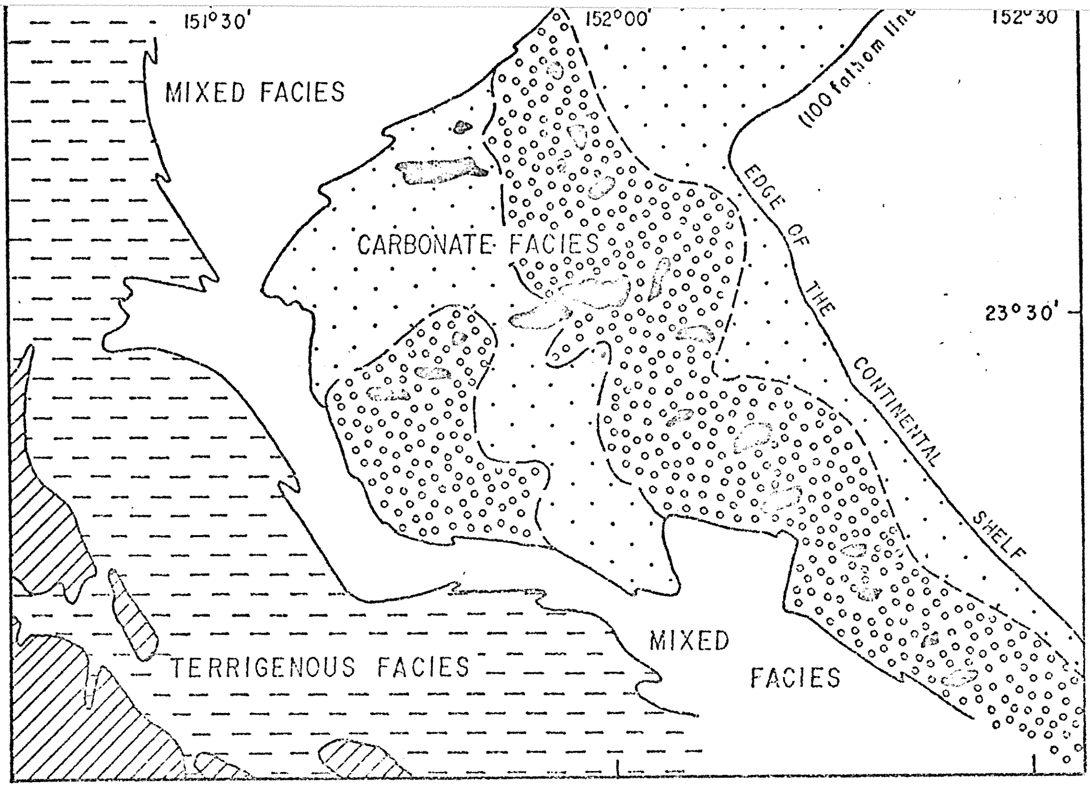
SEDIMENTS

Sediments of the continental shelf

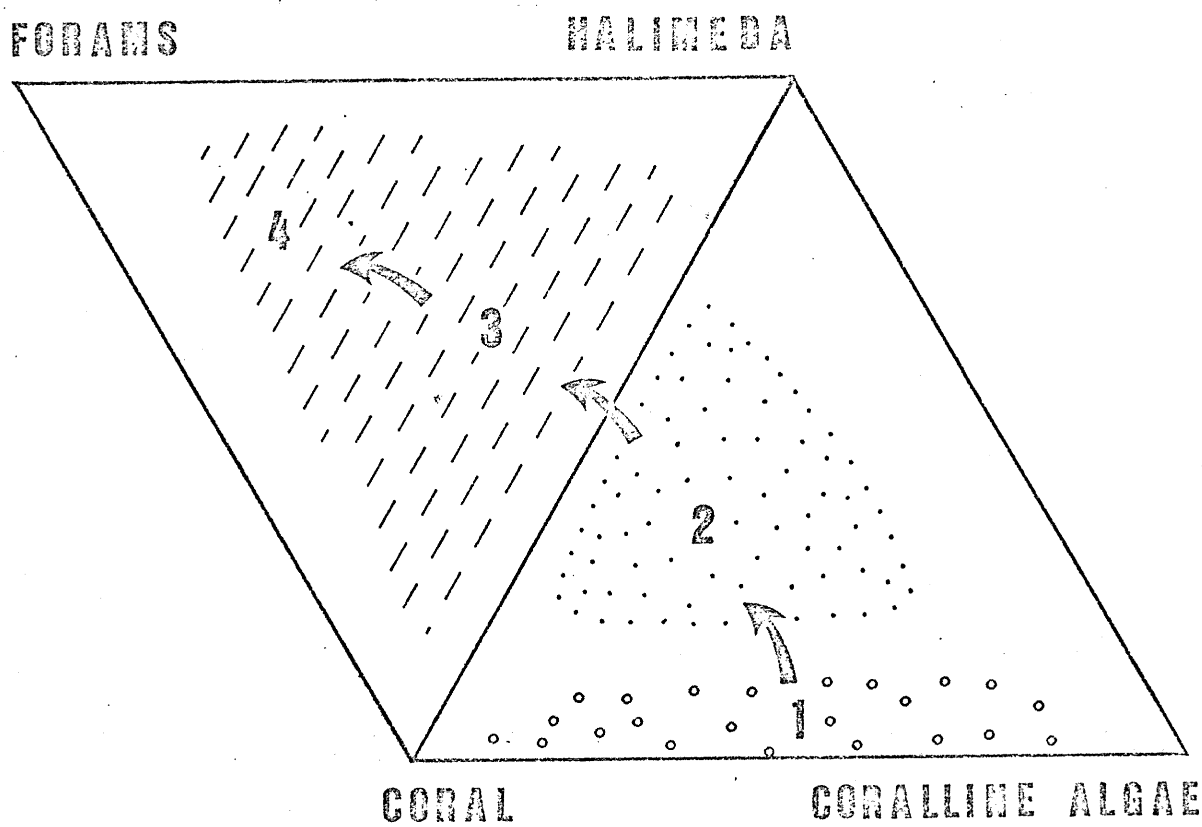
Maxwell and Maiklem (1964), Maxwell (1968, 1973), Maxwell and Swinchatt (1970), Maiklem (1970), and Palmieri (1976) have illustrated that the continental shelf sediments display the influence of a mainland source, a reefal source, and *in situ* contributions of benthic foraminiferans and molluscs. A convenient way to distinguish the contribution of the skeletal carbonate material (reefal + *in situ*) from the terrigenous (mainland) source is the carbonate: non-carbonate ratio (i.e. the percent acid-soluble content). The following facies may be recognised (see Text-fig. 13).

1. Terrigenous facies characterised by less than 60% acid-soluble content,
2. Carbonate facies characterised by greater than 80% acid-soluble content, and
3. Mixed (or transitional) facies characterised by 60 to 80% acid-soluble content.

The terrigenous facies is restricted to the inner shelf adjacent to the mainland. Detrital quartz sand is the major constituent and appears to have been derived from the present coastal dune material, as well as from ancient dune systems of the shelf and older fluviatile deposits. The carbonate facies occurs on the outer shelf in the vicinity of the reefs. It consists of reef-derived bioclastic carbonate sand and gravel as well as *in situ* skeletal material of benthic foraminiferans, bryozoans, molluscs, *Halimeda*, etc. A low mud subfacies is restricted to the immediate proximity of the reefs and consists of moderately sorted carbonate sand and shingle (i.e. coral sticks of gravel size or coarser).



Text-fig. 13 Distribution of the sedimentary facies on the continental shelf in the vicinity of the Capricorn-Bunker Groups. The low mud subfacies is represented by the open circles and the variable mud subfacies by the dots. (Modified after Maxwell and Maiklem 1964; Maxwell 1968, 1973; Maxwell and Swinchatt 1970; Palmieri 1976).



Text-fig. 14 Plot of the general fields occupied by the sediments of the various reef types 1 to 4 (see Text-fig. 12). The percentage contribution made by the three main components is normalised to 100 percent and then plotted on the ternary diagrams. A trend is indicated which displays the changing role of framebuilders and benthic organisms.

A variable mud subfacies consists of poorly sorted carbonate sand and it represents the area free of coarse-grained reef derived skeletal debris. The mixed facies represents the transitional zone between the above mentioned facies.

Maiklem (1970) has provided an extremely informative account of the inter-relationship of the source, hydraulic agents, and organic skeletal groups which mould the composition, texture, and distribution patterns of the various sediment types.

Reef sediments

Reef sediments (sensu stricto) include the sediments of the reef top and the sediments on the reef slopes. Very little is known about the latter sediments save for some general comments and the underwater photographs of Maxwell (1968 Figs 75, 76, 78, 79 and 81) and Maiklem (1968 Fig. 15). Our observations have shown that the sediments on the windward slope are poorly sorted and consist of a predominance of coarse coral detritus including broken Acropora sticks, complete coral heads, and massive blocks of reef rock derived from the collapse of overhanging spurs. The sediments to leeward are better sorted, and consist of fine sand sized coral detritus and benthic foraminiferans washed off the reef top. The foraminiferan Marginopora sp. and the coral Fungia sp. are ubiquituous throughout the reef slope sediments.

Maxwell et al. (1964), Maxwell (1973) and Orme et al. (1974) have shown that four organic groups (corals, coralline algae, foraminiferans, Halimeda account for approximately 90 percent of the constituent particle composition of the reef top sediments within the southern region of the Great Barrier Reef Province. The distribution patterns of the skeletal detritus constituting the sediments are controlled by:

1. the distribution of the living organisms,
2. the susceptibility of the skeletons to mechanical breakdown,
3. the production of specific size ranges upon breakdown, and
4. the movement of skeletal detritus from growth areas to depositional areas under the action of

a. breaking waves,

b. translatory waves, and

c. tidal currents

These factors influence the particle size and degree of sorting exhibited by the sediments (see Orme (1977), and Flood and Orme (1977) for a discussion of reefal sedimentation). Coralline algae which are relatively resistant to abrasion and mechanical breakdown contribute to the very coarse sands and gravels on the reef rim. Corals (especially Acropora spp.) are rapidly broken down into distinct size modes (shingle sticks, very coarse sand, fine to very fine sand) under the influence of the "Sorby Principle" (see Folk and Robles 1964). The winnowing action of the breaking waves and translatory waves leaves the boulder and gravel-sized particles as a lag deposit (shingle banks) on the reef rim and outer reef flat, and transports the coarse sand as bedload into the sanded zone. Very find sand and silt are carried in suspension either to the lagoon where it settles out during periods of slack water, or off the reef to settle onto the continental shelf. Consequently there is a size gradient from gravel and coarse sand to fine sand, from the windward reef rim to the centrally located lagoon. The factors responsible for the particle size differentiation also promote a segregation of calcitic detritus (coralline algae and foraminifera) and aragonitic detritus (corals and Halimeda). The former which constitute the coarser sediments remains near to the source whereas the latter finer material is transported towards the lagoon (see Orme et al. 1974; Davies et al. 1976; Flood et al. 1977).

Reef top sediments and reef types - compositional relationships

To date detailed component analyses have only been published for Lady Musgrave Reef (Orme et al. 1974) and Heron Reef (Maxwell et al. 1964). Recent research by one of the authors (PGF) indicates a marked difference in the skeletal component composition of the reef top sediments at various stages of morphological development:

Type 1. The closed ring reefs (data from Lady Musgrave and Fitzroy reefs) display a predominance of skeletal debris of framebuilding organisms such as coral and coralline algae.

Type 2. The lagoonal platform reefs (data from Heron and Wistari reefs) show increased importance of benthic or sessile organisms such as foraminifera, mollusca and Halimeda (especially). The latter two groups display a preferential living association with the thin mobile sediment bodies.

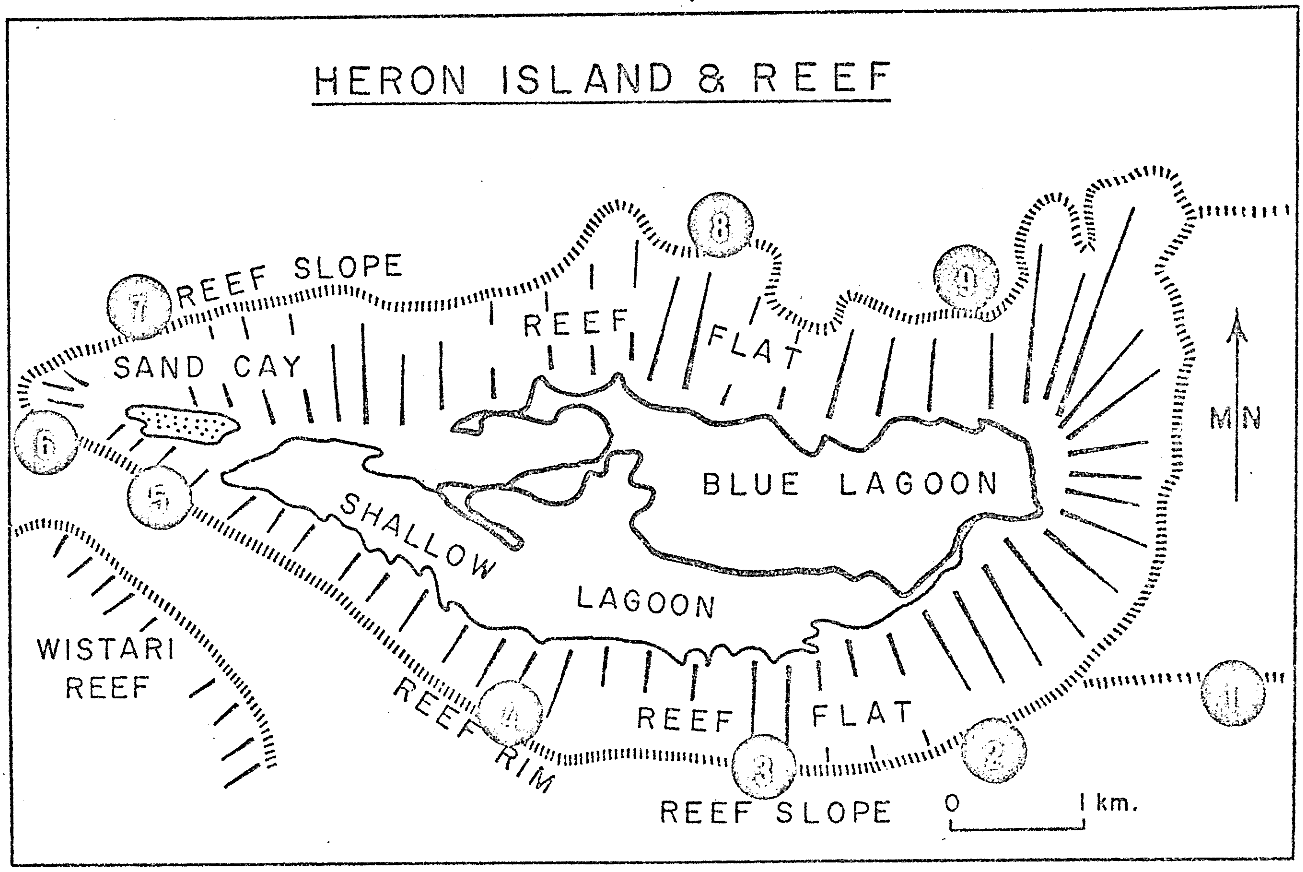
Type 3. The platform reefs (data from Tryon, Wreck and North reefs) exhibit a marked increase in the relative significance of the skeletal remains of epithytic organisms such as the foraminiferans Calcarina and Baculogypsina spp. These organisms grow attached to the soft algae which colonize the dead upper surface of the reef flat corals or the coralline algal pavements typical of these platform reefs.

This trend in the component composition of the sediments is accomplished by the readjustment of the contribution of only four skeletal types: coral, coralline algae, Halimeda, and foraminiferans. One way of illustrating this trend is to normalise to 100 percent the constituent particle composition of the three main skeletal contributors. The relative proportions of the contribution made by each of the groups is then plotted on a ternary diagram (see Text-fig. 14). A trend is evident which displays the changing nature of the reef top sediments associated with the different reef types.

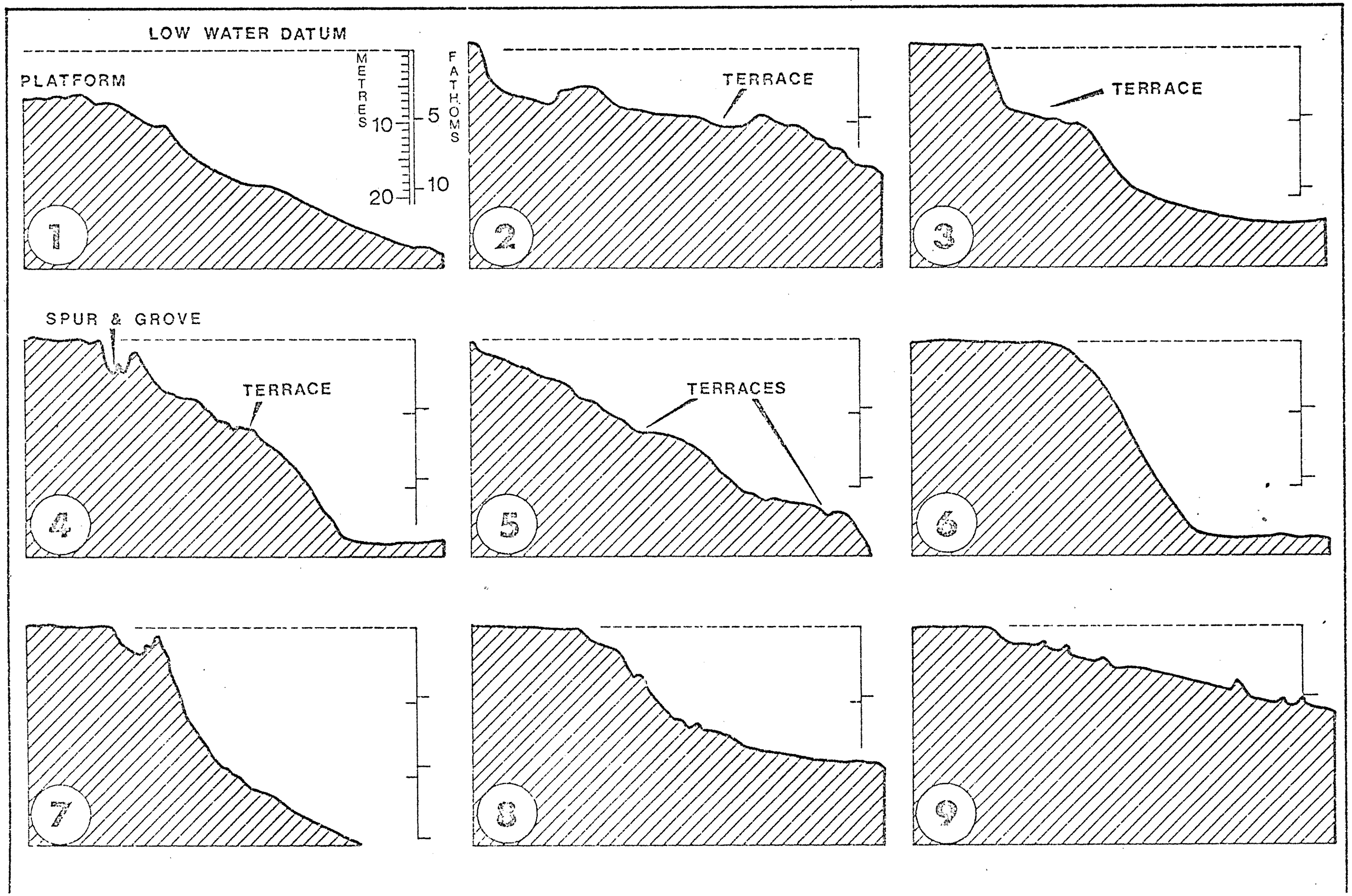
Recognition of an evolutionary trend of reef type development, combined with the knowledge that the biota and component composition of the sediments are characteristic of the various reef types and that the grain size composition of the sediments is indicative of the hydrodynamic processess acting within the different depositional environments (see Flood and Orme 1977) should enable researchers to unravel some aspects of the complex history of reef development both in time and space.

HERON ISLAND

The Heron Island Research Station has been the focus for most of the biological and geological research conducted in the southern part of the Great



Text-fig. 15 Physiographic zonation of Heron Reef.



Text-fig. 16. Echosounder profiles of the reef slope of Heron Reef. All depths are reduced to Low Water Datum and the length of each profile is about 200 m.

Barrier Reef. Aspects of the biological zonation of the reef have been described by Cribb, 1966, 1973) and the physiographic zonation has been described by Maxwell et al. (1961, 1964) and Jell and Flood (1976). There is a close interrelationship between the biological, phsiographic and sedimentological zonations. Six physiographic subdivisions can be identified and several of these can be further divided into subzones. Their spatial arrangement are shown on Text-figs 15, 17 and Plate 12.

Reef Slope

The Reef Slope extends seaward from the reef rim and falls steeply towards the off-reef floor. Its upper 15 m consists of a profusion of living coral forming a strong ruggered framework. On the windward (south-eastern, southern and southwestern) side of the reef, spur-and-groove structure is well developed towards the top of this zone (Plate 13). The spurs carry luxuriant developments of coral and coralline algae whereas the sandy rubble floors of the grooves support little coral or algal growth apart from occasional plants of Halimeda because of the scouring action of waves and tidal run off through these gullies. The grooves often open out onto a terrace where a fan of rubble and coarse sand accumulates under normal conditions. Sediment is distributed either back to the reef top or down the reef slope during storms or cyclones. The reef slope on the windward side is dominated by large spreading and branching species of the coral Acropora and large heads of massive corals, and coralline algae encrust the coral marginal to the reef rim.

On the leeward side spur-and-groove structures are not developed, the slope is less steep, large stands of branching Acropora are less common, and a thick sediment wedge develops at the base of the slope (Plate 14).

Detailed echo-sounder profiles of the reef slope of Heron Reef (Text-fig. 16) clearly show the gradient varies considerably from 1 in 20 (profile 2) to 1 in 4 (profile 6). Changes of slope occur consistently at -22 to -24 m, -9 to -13 m and -4 to -6 m.

The -9 to -13 m terrace has a sparse cover of living coral. It corresponds to the level of the submarine platform which occurs between Heron and Sykes Reefs. The -4 to -6 m terrace approximate the level at the base of the spur-and-groove structures and in general it also approximates the level of the lagoonal floor.

Reef Rim

The Reef Rim is continuous except for a few places on the western and northeastern margin. It is the highest part of the intertidal portion of the reef, being a few centimetres above the upper level of coral growth. The rim usually slopes gently seaward or is irregularly terraced. It is only breached significantly in a few places and these control the ebb tide currents thereby modifying the sediment distribution on the reef top.

Coral shingle, in places forms extensive mounds up to 240 m long and 15 m wide and 1 m high (Plate 15). Reef blocks (previously called niggerheads or negroheads) are also common on the lee side. To seaward is a sediment free smooth platform with corals restricted to the potholes and basin-like pools. Acropora, Favites, Montipora, and other encrusting forms are common and the pavement may be encrusted by coralline algae which in places forms low meandering terraces, or covered by a low, sand-binding, algal mats which entraps considerable quantities of sediment including the foraminiferans Calcarina and Marginopora. In places extensive patches of the soft coral Palythoa may occur.

Reef Flat

The Reef Flat is that portion of the reef top which is exposed during low tide and extending inward from the inner side of the reef rim. Algal encrustration is characteristic of the outer region; living coral cover decreases inwards and sand predominates on the inner part of the reef flat. Around the eastern and southern margins, the large banks of shingle project as tongues from the reef rim across the flat. They have formed on the windward parts of the reef, in east-southeasterly directions. The sediment of the reef flat at the western end is a veneer over a porous limestone substrate which is cemented by coralline algae.

Four subzones are readily defined on the western end of the reef (Text-fig. 17) but their differentiation is less obvious to the east. They are:

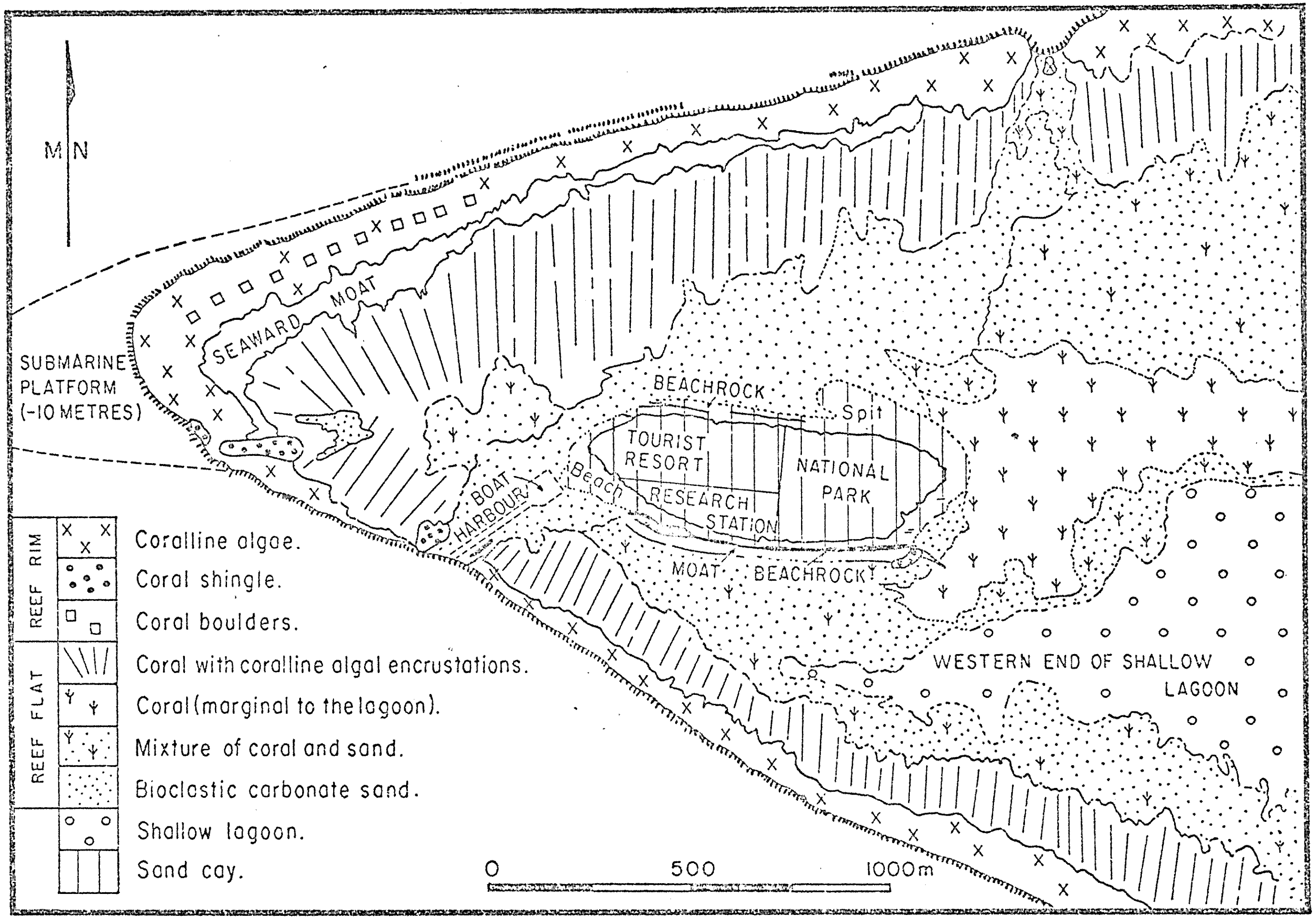
1. Outer coral-algal subzone - living coral with extensive algal encrustation and sheets of coral shingle are typical of this outermost zone of the reef flat. Sand patches are restricted to coral pools or narrow channels which average 2.5 m in width and 0.5 m in depth and are aligned perpendicular to the reef rim, giving this zone a radial pattern. The zone varies in width from 15 to 105 m on the southern side to a width of 275 m in the north. The shingle bank on the western end of the reef flat has grown considerably in the past 15 years and is now 200 m long and 1 m above low tide level. Usually the coral grows 3 to 5 cm above the extreme low-water levels of the reef flat. With the breaches in the harbour wall, the water levels of the reef flat have fallen approximately 10 cm and the upper part of the corals have been killed (Plate 16).

Branching _Acropora_ species such as _A. hebes_, _A. pulchra_, _A. aspera_, and _A. cuneata_ are common in this zone. Massive coral genera _Favites_, _Favia_, _Goniastrea_ are common while _Platygyra_, _Seriatopora_, _Pocillipora_, _Lobophyllia_, _Tubipora_, _Montipora_, and _Fungia_ occur spasmodically through this zone. Echinoids, starfish, molluscs, foraminerans are abundant.

2. Coral-sand subzone - merges with the zones on either side of it. It contains fewer stands of living coral, and dead coral is commonly encrusted by algae. On the southern flat this zone extends for 90-180 m on the northern flat.

Many of the corals common in the zone of living coral are also found in this zone, but many of the species are rarer while others such as _Porites andrewsi_ and _P. lutea_ become commoner. The dead coral clumps support a rich growth of macroscopic algae (Cribb 1966, 1973). These algae also support rich faunas of larger foraminifera including _Calcarina hispida_, _C. calcar_, _Baculogypsina sphaerulata_, and _Elphidium craticulatum_ (Jell _et al_. 1965). Molluscan communities flourish in this environment and holothurians are common.

3. Sand subzone - typified by broad expanses of sand with sparse clumps of living coral interspersed with patches of dead coral supporting thick algal



Text-fig. 17. Physiographic zonation on the western end of Heron Reef. (Drawn from vertical airphotograph).

growth. Micro-atolls of Porites andrewsi and P. lutea are common in the deeper waters of this zone (e.g. at the eastern end of the cay). Beche-de-mer are prolific inhabitants of this sandy flat and are responsible for the reworking of the bulk of the surface sediment.

4. Coral subzone marginal to the lagoon - is developed to the east of the Island on the northwestern flanks of the lagoon. It is characterized by thick growth of Acropora, Goniopora, Tubipora and less common heads of massive corals. Non-encrusting algae including Halimeda are common.

Shallow Lagoon

This is a broad, sandy shelving area in which very few frame-building organisms live. It is situated between the deeper Blue Lagoon and the southern reef flat and represents the prograding sand zone. The marked differences in depth and fauna between it and the reef flat and the Blue Lagoon clearly define it as a major phsiographic unit. Well-sorted sand of medium grade composed of equal proportions of coralline algae, Halimeda, coral, and slightly less molluscan detritus is typical of this zone. There is a noticeable absence of large coral growth. At low tide water depths range from 0.3 to 1 m. The fauna of the shallow lagoon is sparse and consists of small colonies of corals including Acropora and Goniastraea, and a wide variety of small molluscs; Halimeda is also common as are foraminifera. Bioturbation of the sediments is widespread.

Blue Lagoon

The central part of the reef consists of a deeper belt, 4.4 km long and 1.2 km wide. At low tide it has an average depth of 3.5 m, and its margin is clearly marked by an abrupt increase in depth. The floor of the lagoon is covered with very fine sediment. Numerous small patch reefs 6 to 25 m in diameter grow in the lagoon, especially in the northern and eastern parts where they cover approximately half of the surface area. In the Blue Lagoon, the patch reefs are composed mainly of species of Acropora and other corals common to the reef flat with some coralline algal encrustations. The fine sediment on the floor of the lagoon contains a rich in-fauna and bioturbation is extreme.

Sand Cay

The Sand Cay situated at the leeward end of the reef rises abruptly from the southern beach to a height of 4.5 m and then slopes gently northwards. The southern margin is constantly subjected to the strong, prevailing southeast winds which carry the finer sand upward to form a low marginal ridge. A sandy beach, 15-30 m wide at low tide, surrounds the island; this in turn is partly surrounded by a belt of beach rock, 9-21 m wide on the southern shore, 3-6 m wide in the north and west.

The cay is bordered on the southern shore by a shallow moat which is 15-30 m wide and consists of a sandy floored depression approximately 1 m below the general level of the reef flat. The moat represents the plunge line of the main body of breaking waves and has resulted initially from wave scour. Its stronger development on the southern flat is caused by the smaller width of the flat and the fact that it is on the windward side. Strong current action has augmented the effect of wave scour. The moat is bordered on its landward side by beach rock and is the channel through which lagoonal water flows as the tide recedes. These currents enter the moat from the east and south-east. The moat is relatively barren of fauna except for molluscs and occasional coral heads developed on solid substrates; Porites lutea is common and rolls about the channel living on that part of the coral which is uppermost in the manner described by Glynn (1974). On the northeastern side of the cay a large sand flat usually shows well developed ripple marks.

Beach rock occurs along the southern, northern, and eastern beaches. Along the southern intertidal zone the beach is approximately 20 m wide, while much narrower strips occur along the northern and eastern beaches. It can be divided into three shore-parallel zones based on differing algal assemblages (Cribb 1966). Maxwell (1962) provides a detailed description of the beach rock: it is composed mainly of algal skeletal debris with lesser percentages of molluscan, foraminiferal, coral and byrozoan material. Fine interstitial material is completely lacking and the rock has a high porosity. Narrow fringes of aragonite can be distinguished around some of the grains. He attributed the formation of the beach rock to organic factors, principally the binding action of the algae. Davies and Kinsey (1973) undertook a detailed petrological and chemical study of the beach rock in an attempt to determine its origin. They rejected Maxwell's hypothesis on the basis that no evidence existed for the presence of algal mats within the beach rock and they found that aragonite cementation was a function of depth which they equated to time and concluded that the aragonite cement "must therefore be a function of either inorganic precipitation or precipitation due to micro-organisms" (p.64). They conclude that precipitation from pore solutions is the main cementing process.

General account of the sediments

The bulk of the sediment on Heron Reef is composed of the skeletal detritus of coralline algae, coral, Halimeda, molluscs and foraminiferans (see Maxwell et al. 1964; Weber and Woodhead 1968; Maxwell 1973b). Because of different composition (calcite or aragonite), different skeletal structure, different resistance to destructive agencies (see Chave 1962), and individual organic groups preference for specific growth areas, there is an initial differentiation of the detritus rather than a random heterogeneous distribution pattern. The calcitic organisms (coralline algae and foraminiferans) appear to be more resistant and tend to produce coarser, more durable, and less mobile material whereas by contrast the skeletal material of the aragonitic organisms (corals, Halimeda, and molluscs) provide the finer more mobile sedimentary material. Thus the initial tendency of separation which is effected at the source is developed further during transportation by wave action (breaking and translatory) and tidal currents. Complete separation is prevented because of the restricted area over which the processes operate. The resultant sedimentary pattern is one of regions of coarse predominantly calcitic material (e.g. reef rim), other regions of fine aragonitic material (e.g. lagoon), and areas of intermediate character. Variations in the pattern depend on the relative influence of physiography, source, and mechanical agencies, all of which are interrelated.

Grain size

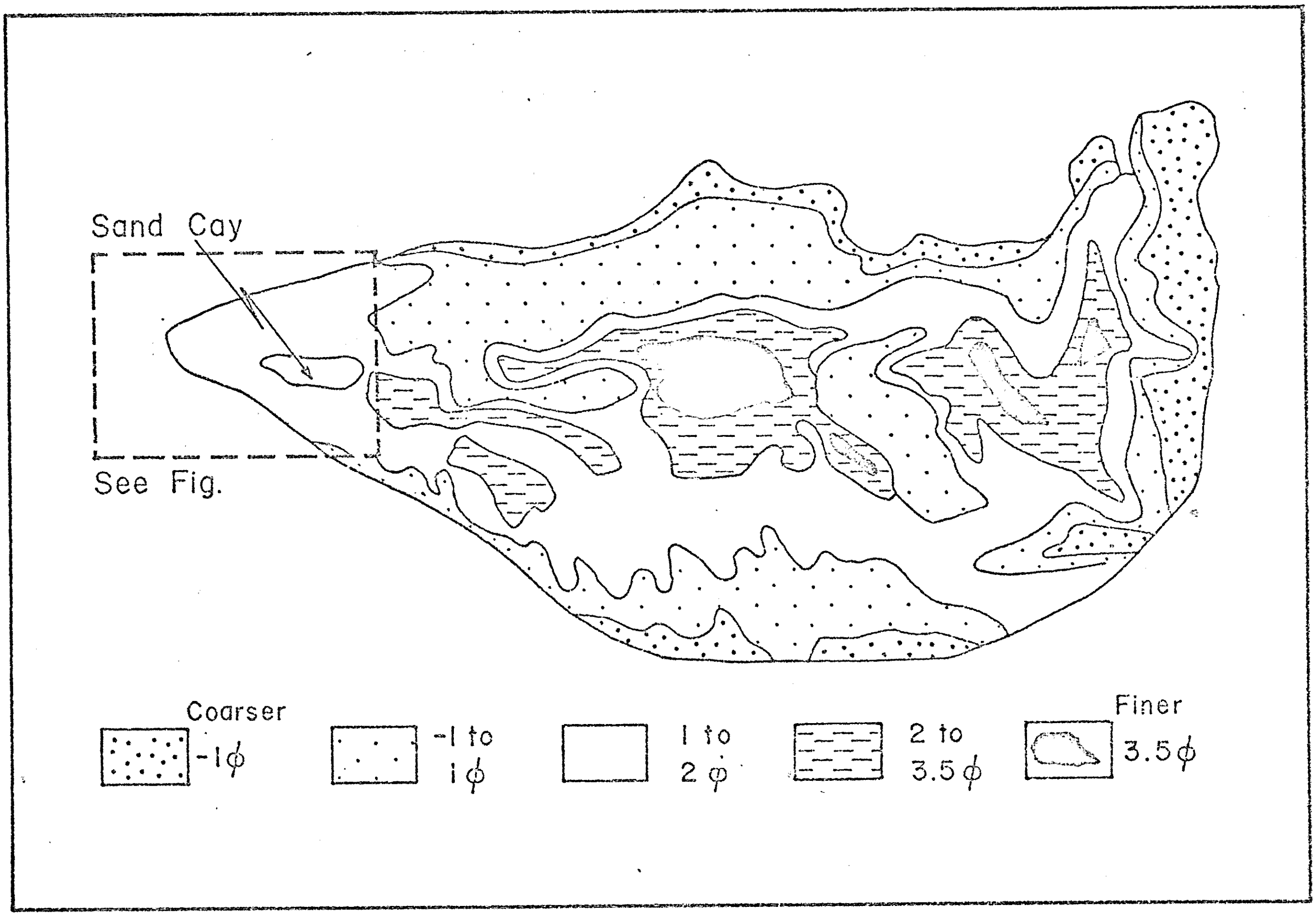
Maxwell et al. (1964) analysed a comprehensive collection of sediments representative of the range of depositional environments present on the reef top. They found that the modal size (i.e. the most commonly occurring particle size) displays a concentric-horizontal gradation across the reef top (see Text-fig. 18). The general trend is from very coarse sand and gravel on the windward and leeward reef rim and outer reef flats to very fine sand and silt at the reef centre corresponding to the lagoon (see Plate 17).

Our analyses of grainsize data obtained by sieving at quarter phi intervals shows several log-normal distributions with truncation points at approximately 1 and 3 phi (sometimes 2 phi) on the cummulative curves (probability ordinate). The presence of such populations within bioclastic carbonate sediments have been interpreted by Flood and Orme (1977) in a similar manner as Visher (1969) did for terrigenous clastic sediments. They appear to correspond to the differing modes of transportation (traction, saltation, and suspension). Under normally prevailing conditions the bed load/suspension break occurs at approximately 3 phi, and at a considerably coarser value during cyclonic conditions.

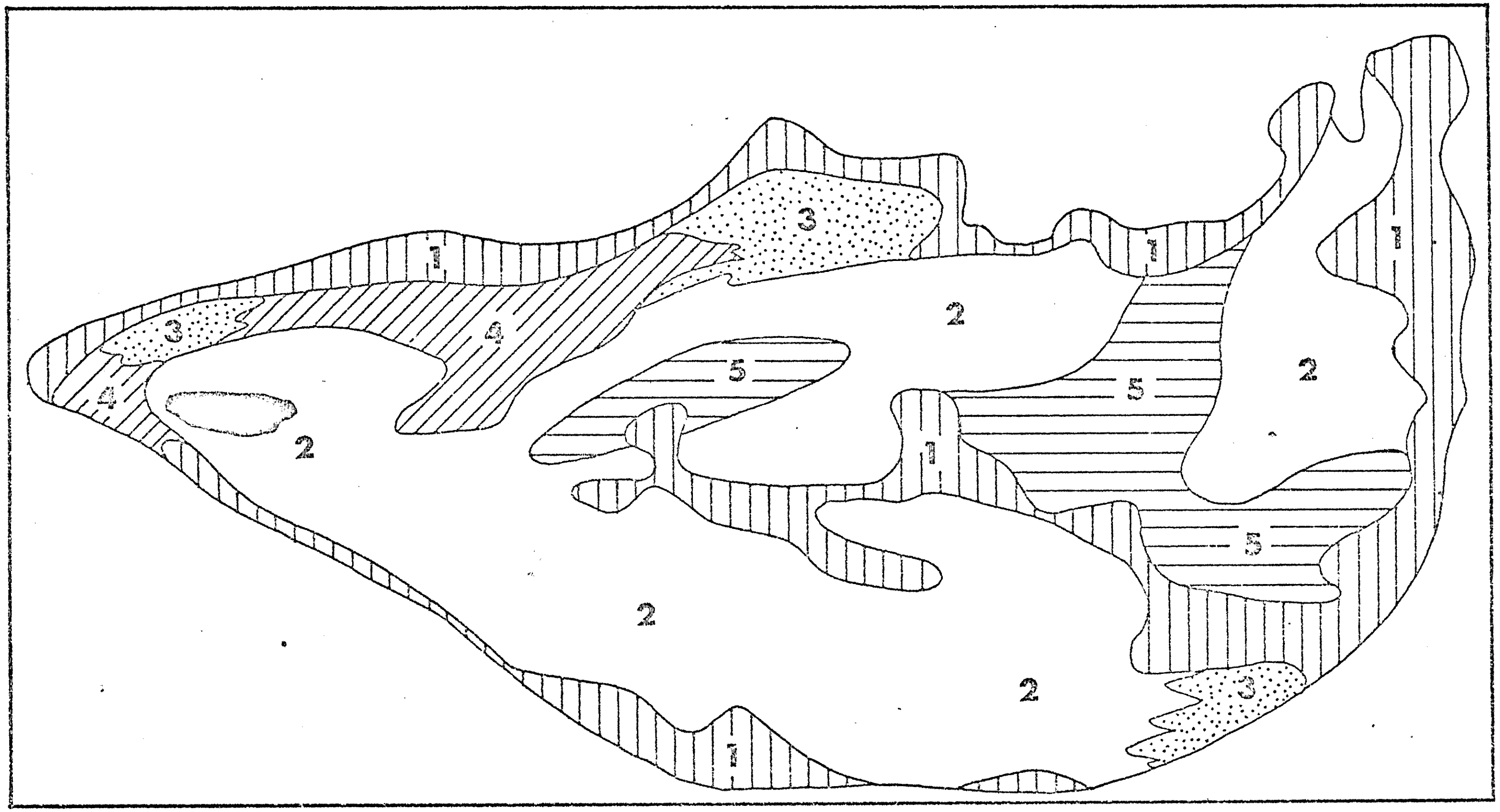
Component composition

The distribution patterns of components throughout the reef top sediments has been shown by Maxwell et al. (1964) and Maxwell (1973) to be controlled primarily by the location of the living organisms, and secondarily by the subsequent transportation of skeletal material. Maxwell (1973) proposed five main facies types (see Text-fig. 19 for their distribution patterns):

1. The Lithothamnion-dominated facies (coralline algae > 40%, molluscs > 10%, foraminiferan > 5%, Halimeda - coral < 20%) is restricted to the reef rim and the axial zone of the lagoon.
2. The Halimeda facies (Halimeda > 30%, coral 20-30%, coralline algae < 20%, molluscs < 10%, foraminiferans < 5%) dominates the windward reef flat, shallow lagoon, and the northern half of the lagoon.



Text-fig. 18. Distribution pattern of the grain size (modal diameters) of skeletal particles on the reef top environment of Heron Reef (after Maxwell *et* al. 1964). See Text-figs 26 and 27 for details of the patterns on the western end of the reef.



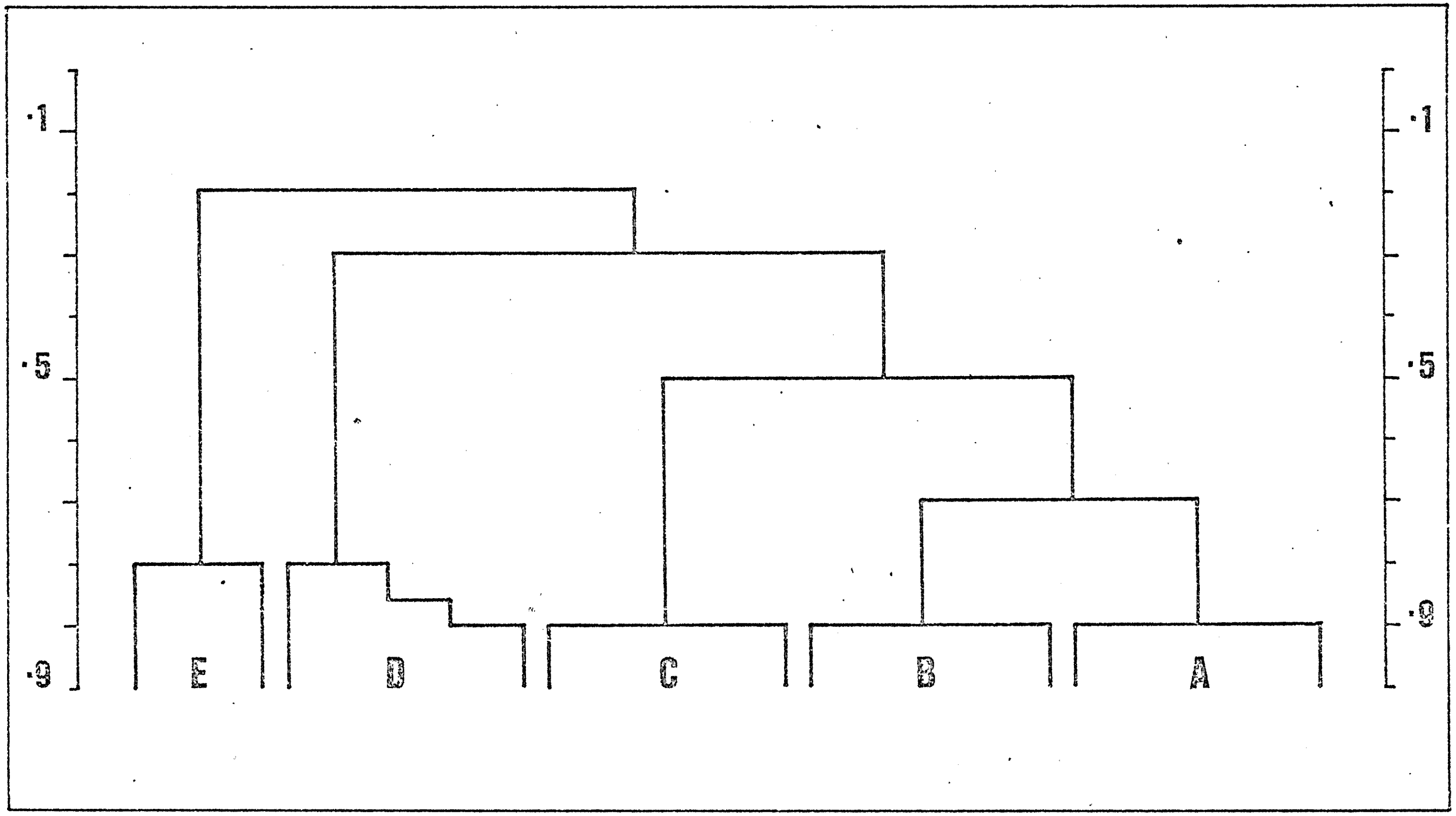
Text-fig. 19 Idealised distribution pattern of the skeletal-component sedimentary facies on Heron Reef (after Maxwell 1973).

3. The Foraminifera facies (foraminiferans > 10%, coralline algae 25%, molluscs > 10%, coral < 25%, *Halimeda* < 25%) generally occurs on the inner part of the reef rim.
4. The Mollusca facies (molluscs 10-20%, coral > 30%, *Halimeda* < 30%, coralline algae < 10%, foraminiferans < 5%) is restricted to the north-western part of the reef flat where there is a substantial cover of dead coral.
5. The coral facies (coral > 30%, *Halimeda* 20-30%, coralline algae 20-30%, molluscs < 5%, foraminiferans < 5%) occurs in parts of the lagoon and on the beach of the cay.

The idealised nature of the distribution patterns of Maxwell's facies becomes evident when comparing the amount of overlap between areas having coralline algae > 40% (facies 1), *Halimeda* > 30% (facies 2), and/or coral > 30% (facies 5). The data in Appendix 1 of Maxwell *et al.* (1964) was reanalysed using multivariate numerical techniques which enable the covariation of all the variables to be examined simultaneously thereby providing an objective analysis which could be viewed for the presence of distinct grouping.

The cluster, discriminant, and factor analysis programmes of Davis (1973), Nie *et al.* (1975), and Klovan and Imbrie (1971) respectively were employed sequentially to determine the number and nature of statistically recognisable sediment types. Plotting the type of each sediment on the original sample locality map enables one to see whether or not the types do in actual fact represent facies (i.e. mappable units).

Q-mode cluster analysis (weighed pair-group method, correlation coefficient, unstandardized data, 6 variables and 173 samples) showed five significantly different (Hotelling T^2 test, 95 percent level) cluster groupings labelled A to E (Text-fig. 20). Intra-group values of the correlation coefficients are: groups A, B, and C all greater than 0.9; D and E greater than 0.8. Intergroup correlation coefficient values are: A and B 0.7, (A,B) and C 0.5; (A,B,C) and D 0.3; (A,B,C,D) and E 0.2.



Text-fig. 20. Q-mode cluster dendogram of skeletal-component composition of the reef top sediments (data of Maxwell et al. 1964). Five groups are recognisable, A to E. Value of the correlation coefficient is indicated.

The mean and standard deviation (value in brackets) of the five main constituent particles within each group are:

	Corals	Coralline algae	<u>Halimeda</u>	Foraminiferans	Molluscs
Group A	25(4)	22(5)	35(4)	4(3)	10(4)
B	32(5)	24(5)	26(4)	4(3)	10(5)
C	20(4)	33(5)	26(5)	4(3)	16(4)
D	30(7)	37(8)	14(6)	5(4)	11(4)
E	41(10)	19(4)	16(6)	9(10)	13(5)

Max. value 52

The sediment samples within each of the groups are as follows:

Group A: 4, 14, 21, 23, 73, 100, 113, 172, 173, 177, 189, 204, 205, 207, 212, 232, 236, 247, 249, 254, 256, 263, 280, 283, 291, 299, 306, 310, 313, 359, 362, 384, 389, 391, 400, 401, 402

Group B: 31, 49, 75, 106, 108, 112, 174, 178, 180, 181, 182, 187, 188, 190, 194, 199, 206, 215, 239, 261, 265, 266, 267, 274, 277, 278, 281, 295, 302, 311, 358, 374, 386

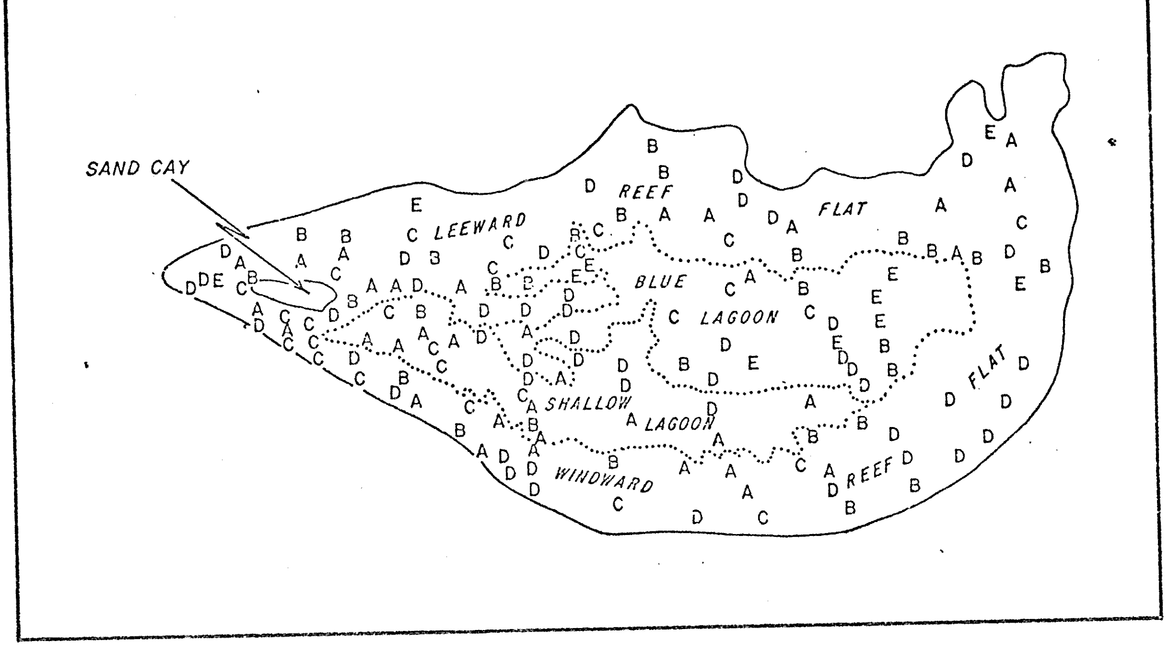
Group C: 19, 25, 32, 37, 39, 47, 54, 58, 71, 97, 146, 201, 208, 228, 240, 252, 268, 289, 293, 300, 304, 353, 366, 372, 374, 381, 287, 390, 392, 403

Group D: 12, 40, 45, 72, 79, 102, 103, 116, 117, 118, 119, 153, 156, 171, 192, 198, 202, 203, 209, 210, 211, 213, 217, 220, 221, 222, 223, 230, 235, 237, 243, 244, 245, 246, 259, 260, 262, 269, 271, 272, 273, 275, 279, 287, 294, 296, 297, 308, 309, 314, 355, 373, 382, 397, 398

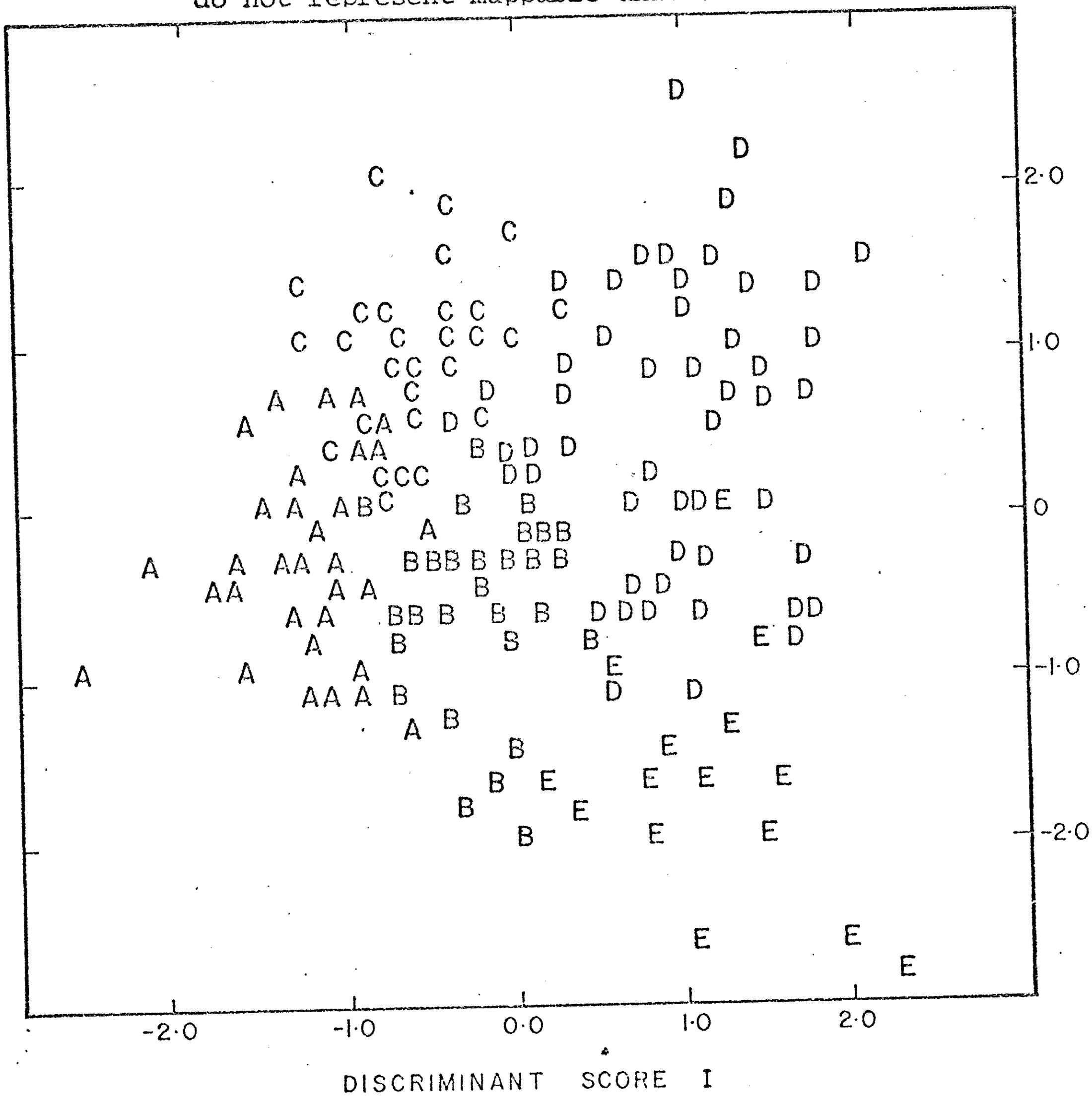
Group E: 17, 110, 152, 179, 183, 184, 185, 226, 234, 241, 242, 270, 286, 352, 378

These objective groupings (see Plate 18) do not represent mappable units (see Text-fig. 21).

Discriminant analysis (Rao's V, stepwise, Priors = equal) shows that three functions are needed to adequately classify the five cluster groupings (Bell 1977). The unstardardized discriminant function coefficients of the



Text-fig. 21 Spatial distribution of the skeletal component groups within the various physiographic environments. Obviously the groups do not represent mappable units.



Text-fig. 22 Bivariate plot of Discriminant Function I vs Discriminant Function II. Values of the Discriminant Scores are indicated, and the generally discrete fields of the skeletal - component groups are evident. Sediments may be classified using this plot (see text for discussion of the technique).

component skeletal groups for each of the functions are as follows (see Nie et al. 1975 for the technique):

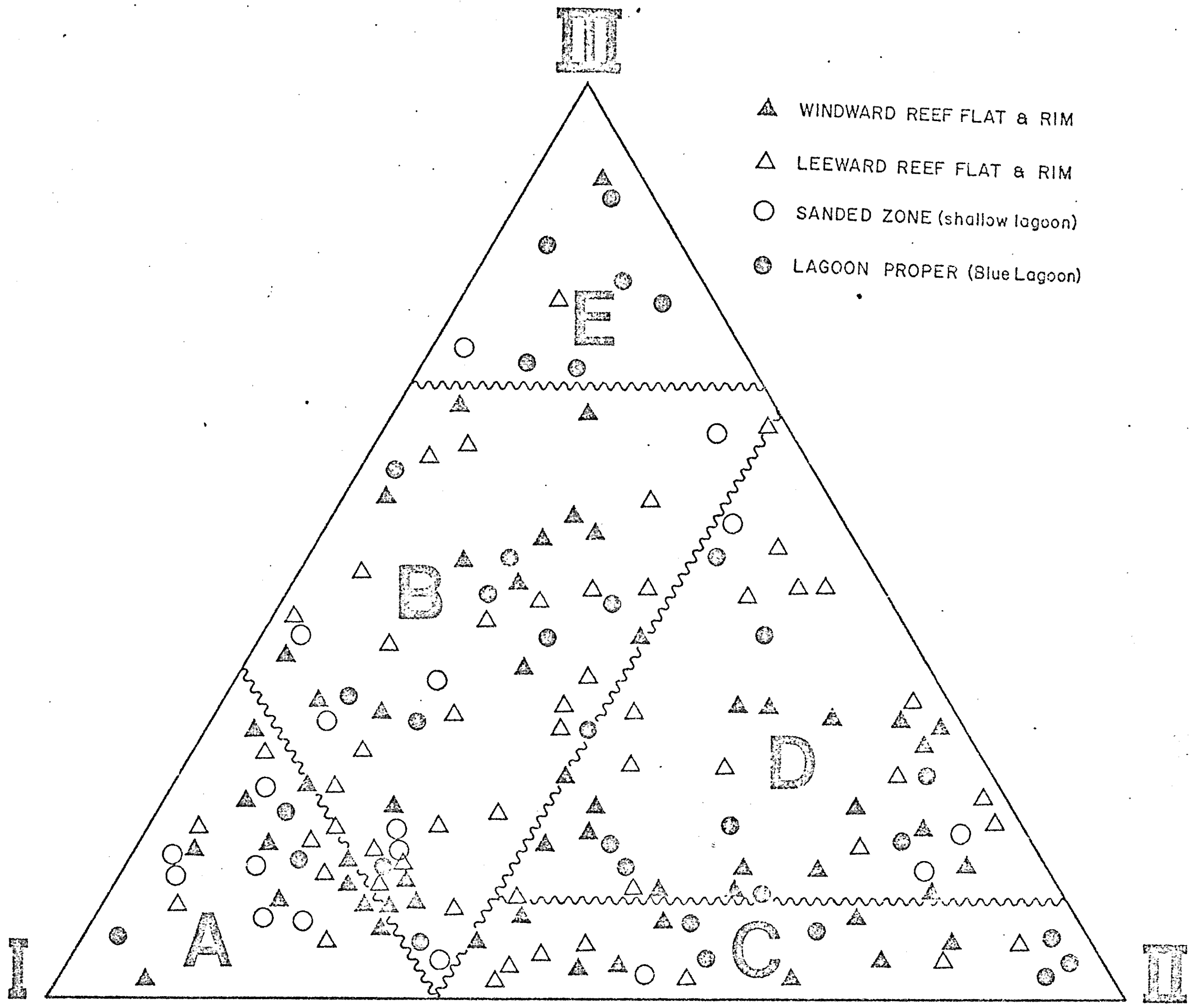
Variable	Functional Coefficients		
	I	II	III
Coralline algae	0.00	0.12	0.05
Halimeda	-0.09	0.04	0.07
Corals	0.03	-0.02	0.06
Molluscs	-0.01	0.03	0.25
Foraminifera	0.03	0.00	0.12
Constant	1.23	-4.19	-8.25

The groups are readily discernable when plotted with respect to the first two functions (see Text-fig. 22).

Thus, to assign an unknown sample to a group simply sum the products of the percentage contribution of each component variable by its respective functional coefficient and add the constant. This gives a value called the score for each function which can then be plotted on the bivariate plot of Function I *vs* Function II which shows the approximate fields of the five groups.

Q-mode factor analysis (cosine theta coefficient, data transformed to percent of the variables range) indicated that three principal factors will explain 98 percent of the variance in the data. Varimax Factors I, II, and III contribute to 38.5, 71.0, and 96.0 percent of the cumulative variance. The scaled varimax factor scores indicate that the percentage content of Halimeda is the main contributor to Factor I (values are coralline algae 0.07, Halimeda 2.14, coral -0.04, molluscs 0.61, forams 0.20), coralline algae is the main contributor to Factor II (values are coralline algae 2.08, Halimeda -0.29, coral 0.23, molluscs 0.71, forams 0.19), and coral is the main contributor to Factor III (values are coralline algae 0.27, Halimeda -0.02, coral -2.22, molluscs -0.66 forams -0.11).

A normalized varimax plot of the sediments is shown in Text-fig. 23.



Text-fig. 23 Plot of the sediments in terms of the three normalised varimax factors. The approximate areas occupied by the skeletal - component groups A to E are indicated. Varimax factor I mainly represents the contribution of Halimeda; factor II - coralline algae; factor III - coral.

It illustrates that Halimeda, coralline algae, and coral are the three most important skeletal components within the sediments, and that sediments from different morphological zones cannot be differentiated on the basis of their skeletal component composition.

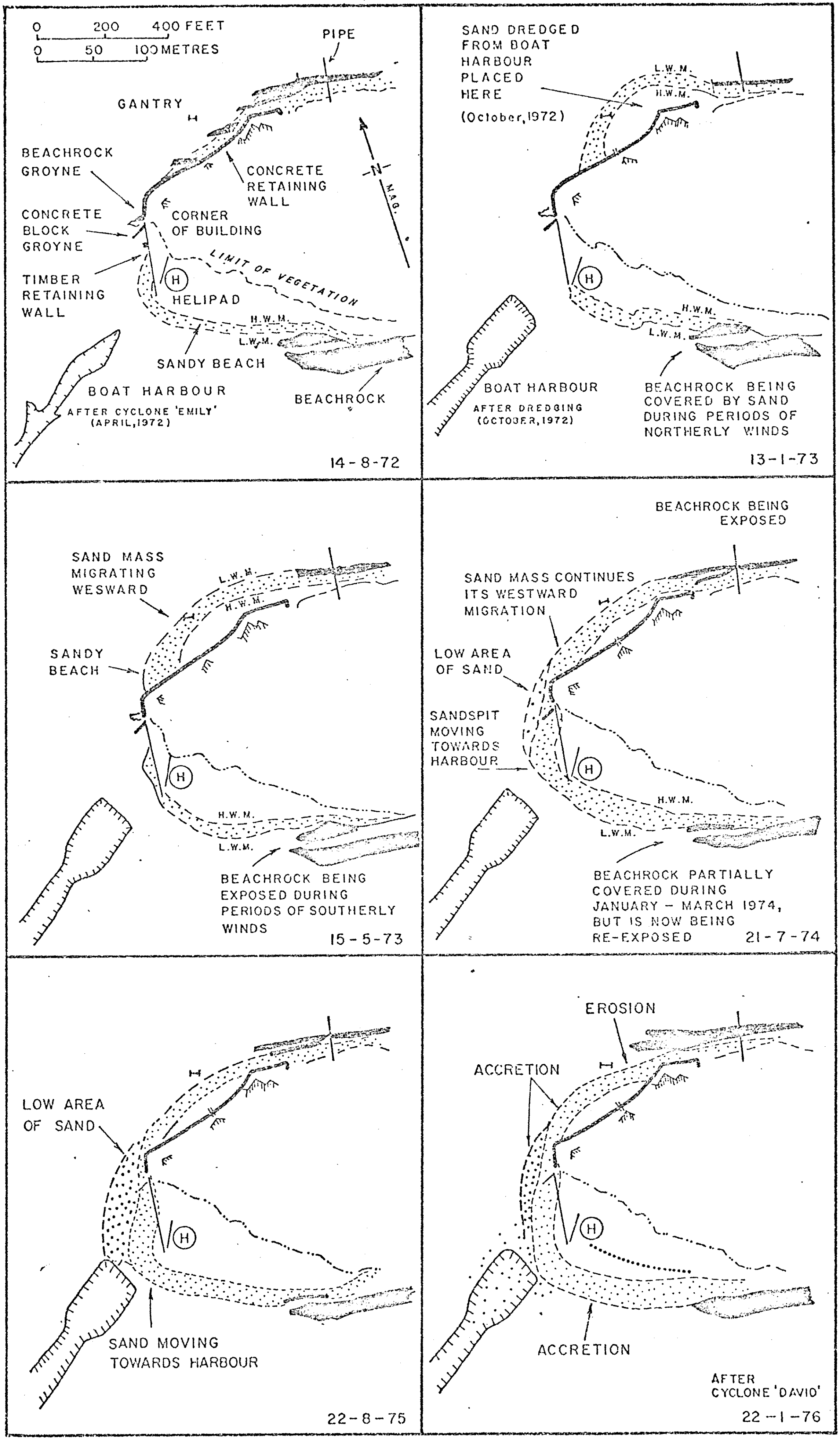
BEACH EROSION AND CHANGES TO THE SEDIMENT DISTRIBUTION PATTERNS - WESTERN END OF HERON REEF

The beach on the western end of Heron Island and the sediments distribution patterns on the adjacent reef flat have undergone major significant changes since the early 1950's. Such changes have been produced by any one or a combination of the following:

1. The initial blasting (ca.1945) of a gap in the reef rim to allow small boats access to the island during low tide periods. This gap was adjacent to the wreck which was placed in its present position about this time. The gap allowed ebbing tidal currents passing around the island to be channelled in the direction of the gap rather than radially out over the reef rim. The increased velocity of the redirected tidal currents which now moved across the area of the sand spit adjacent to the western beach produced erosion on the spit and beach. Comparison of the sketch map of the island made in 1936 (Steers 1938) with the vertical aerial photographs taken by the R.A.A.F in 1959 and the comments contained in articles by Maxwell et al. (1961) and Gillham (1963) indicate that the north-western part of the island experienced severe erosion in the early 1950's.
2. The management of the tourist resort attempted to protect their buildings by constructing a vertical faced retaining wall along the eroding sector of the beach. The alignment of the wall reflects waves approaching the island from the northwest or northeast and enhances the erosive capacity of such waves thereby promoting

erosion in the areas adjacent to the end of the wall. Concern over continuing erosion resulted in the construction of extensions to the retaining wall during 1964-65. This extension only caused further realignment of the beach (see Flood 1974).

3. In 1966 a channel was dredged into the reef rim and reef flat to provide boat harbour facilities for the island. During the dredging the reef was subjected to severe cyclonic activity (cyclone "Dinah", February 1967) which cause infilling of the dredged area and other undocumented readjustments to the beach and sediment distribution patterns. Redredging of the silted harbour occurred in 1967 and the spoil was placed within the beach zone on the south-western corner of the island forming a base for the helipad which was built in 1968.
4. Sediment was prevented from entering the harbour by walls which were constructed around it and above the level of the reef flat, even so, further erosion continued and readjustment of the beach continued and the helipad was endangered. More retaining walls were constructed.
5. The harbour walls were breached during the cyclone season of 1971. Tidal currents and cyclone "Emily" (April 1972) produced marked changes to the beaches by infilling the boat harbour through these breaches with sediment derived from the reef flat and beach.
6. The boat harbour was redredged in 1972 and the spoil (approx. 20000 m^3) placed near the northwestern beach, the area suffering erosion since the early 1950's. This artificially formed beach and spit underwent re-orientation and migration by westward movement of sand along the beach. This sediment was able to re-enter the boat harbour through the gaps in the walls as these had not been fixed after the dredging operation. During the cyclone season of 1976 (cyclone "David", January 1976) the harbour was once again infilled. The mound of spoil from the 1972 dredging had been totally removed by this time (see Text-fig. 24).



Text-fig. 24 Sequential surveys of the western end of Heron Island showing the nature of the sediment movement since the boat harbour was re-dredged in 1972, till cyclone "David", January 1976.

Recently attempts have been made to block the gaps in the harbour walls.

We have attempted to determine the nature of changes to the sediment distribution patterns on the western end of Heron Reef in the following way: firstly by recollecting sediments at 50 m intervals along the lines shown in Maxwell et al. (1961), thus allowing comparisons to be made for the period 1959-1975; secondly by recollecting some of the sites immediately after cyclone "David" (January, 1976) thus allowing comparison of the pre-and post-cyclonic distribution patterns (see Flood and Jell 1977); and thirdly by recollecting again 12 months later (January, 1977) to determine subsequent changes. Sediments (i.e. the 1975, '76, and '77 collections, Text-fig. 25) were sieved using U.S. Standard Sieves (half phi intervals, sieving time 10 mins) and the textural parameters median size, graphic mean size, Trask's sorting, and graphic standard deviation were determined.

Changes to the sediment distribution patterns are shown in Text-figs 26-28.

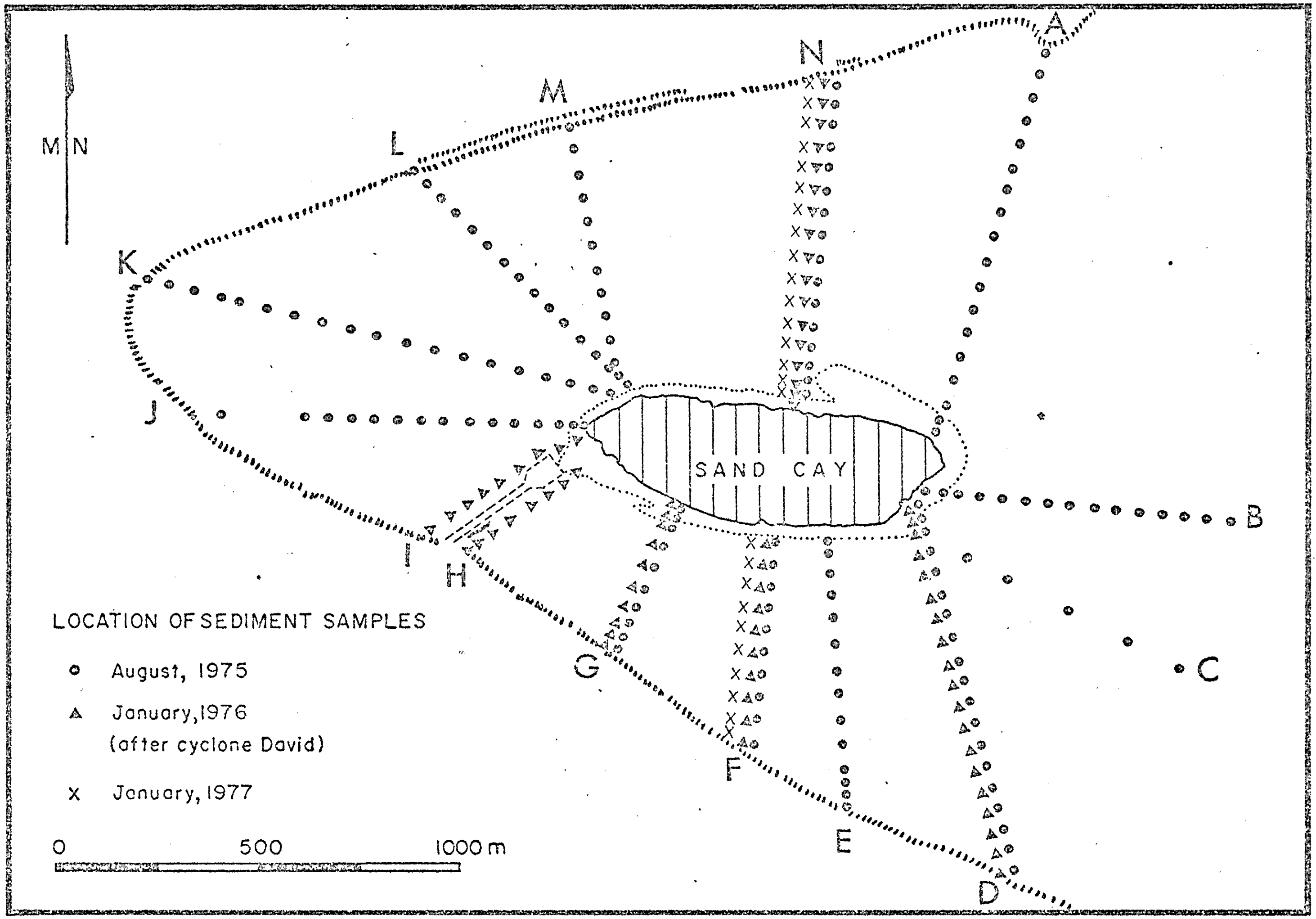
1959-1975

A marked increase in the size of sedimentary particles to the north-west of the island. This coarsening is attributed to the presence of the boat harbour chanelling tidal currents which otherwise would have flowed radially out across the reef into the boat harbour. Increased current velocity removes the finer particle sizes that otherwise would normally be present on the reef flat.

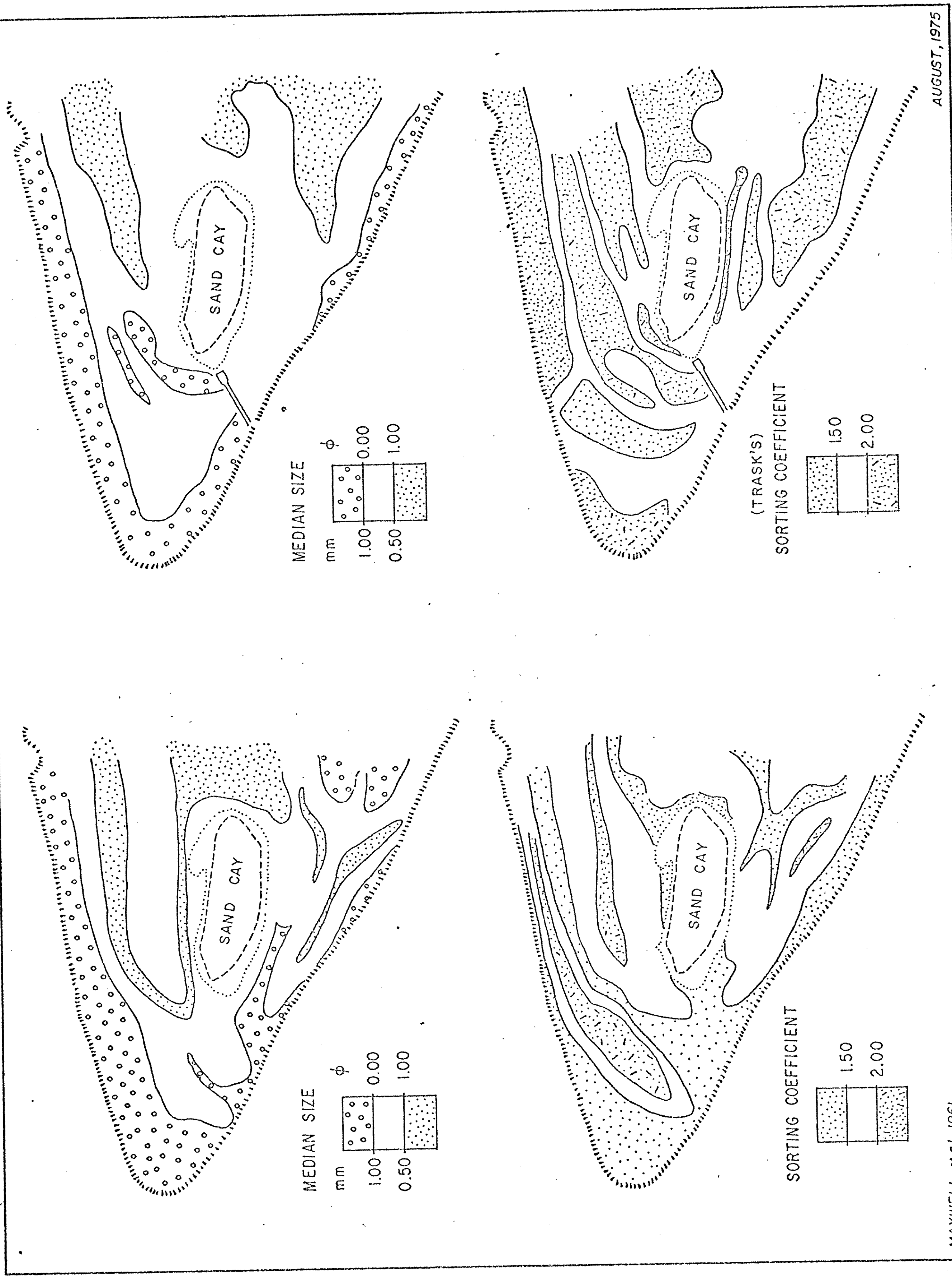
The sorting values of the sediments on the northwestern reef flat also display the influence of the tidal current drainage through the boat harbour. Areas having similar values trend towards the gaps in the wall surrounding the harbour.

Cyclone "David"

On January 19, 1976, tropical cyclone "David" with central pressure of 960 millibars and winds up to 200 km/hr passed within 150 km to the north of



Text-fig. 25 Showing the location of reef top sediment samples collected on the western end of Heron Reef, adjacent to the cay.



Text-fig. 26 Showing the distribution patterns of median size and sorting coefficients for the sediments collected in 1959 (Maxwell <u>et al</u>. 1961) and 1975.

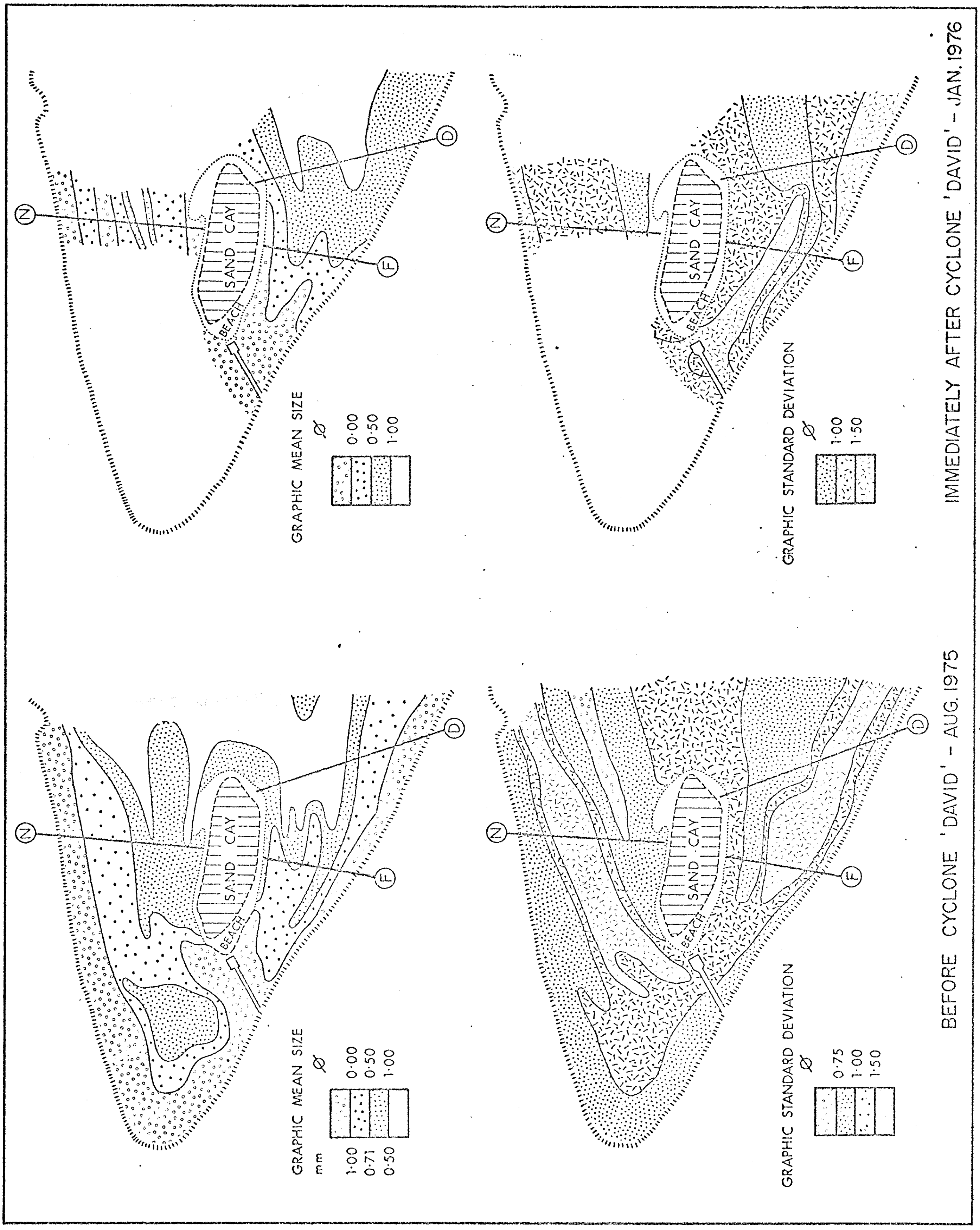
Heron Island. The weather station on Heron Island recorded a minimum pressure of 984 millibars and wind gusts up to 120 km/hr. Two to three metre high waves were breaking on the reef edge and the period of strongest winds and highest waves coincided with the period of highest tides for that year (2.6 m on the early mornings of the 19th and 20th). Associated storm surge exceeded 2 m above the level of mean high water spring tides. The dominant winds were from the southeast (see Plate 19). One of us (JSJ) was resident on Heron Island during the period of cyclone "David" thereby providing first hand observations as to its effect and also allowing resampling immediately after the cyclone (January 20) of several of the sites sampled the previous August.

Interpretation of the manner in which the distribution patterns altered during the cyclone is based upon the following:

(a) personal observations of a body of finer particle sizes being carried, in suspension, by translatory wave action related to extremely heavy seas coinciding with a strong tidal current moving from the area of the shallow lagoon (to the east of the island) in a northwesterly direction across the windward reef flat and

(b) inspection of the reef flat and reef rim during periods of low water immediately after the cyclone and whilst collecting the sediment samples. Considerable quantities of coarse sand, gravel, and boulder sized skeletal fragments as well as complete coral heads had been carried from the reef slope to the reef top surface as the waves broke. These particles are too large to be moved by tidal currents.

On the windward side the mean size of the sediments shows a marked increase at the reef rim (addition of coarse material), a slight decrease within the coral zone (addition of lagoonal sediment), a consistent increase within the sand zone (removal of finer sizes), and little change in the area of microatolls adjacent to the lagoon. On the leeward, the sand zone generally shows a slight increase in size (addition of coarser, removal of finer sizes), the coral zone shows an increase in the area adjacent to the sand zone (removal of finer sizes)



Text-fig. 27 Showing the distribution patterns of graphic mean size and graphic standard deviation for the sediments before and after cyclone "David" (after Flood and Jell 1977). Using the same data different textural parameters were determined for the August 1975 samples shown on Text-figs. 26 and 27.

but a decrease towards the outer part and then a marked increase at the reef rim (value is not shown on the diagram; addition of boulder sized material).

On the windward side the sediments show a decrease in the degree of sorting at the reef rim (addition of higher energy particle sizes to more normal sizes), an increase in the coral zone (removal of fines), little change within the sand zone, and a decrease in the area of microatolls (addition of higher energy particle sizes to more normal sizes). On the leeward the sand zone shows a decrease in the degree of sorting except for the central region (addition of coarser and finer sizes), the coral zone and reef rim generally display improved sorting (removal of finer sizes).

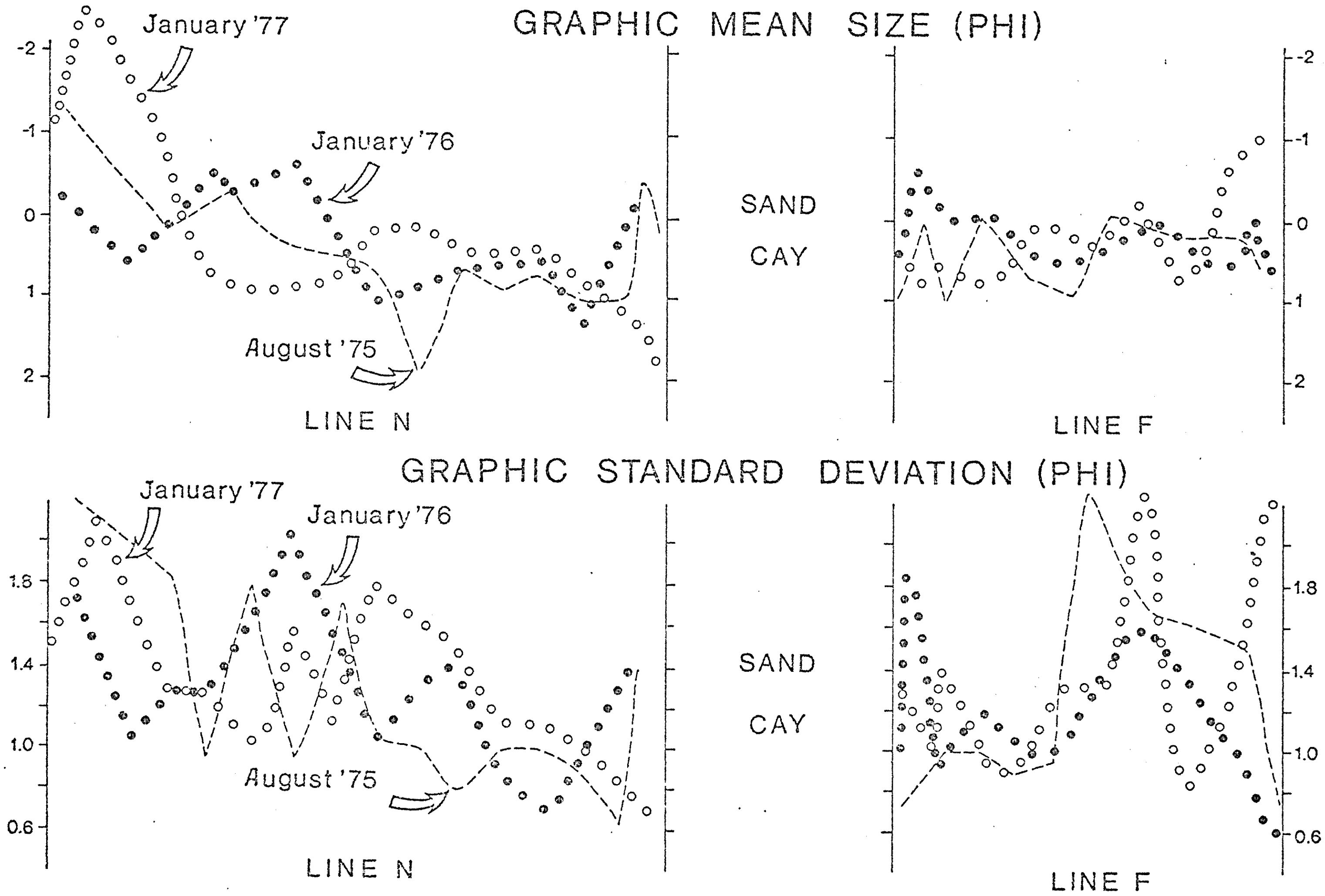
The cumulative curves show that although the general value of mean grain size for the majority of sediments changed very little during the cyclone (values lie between -1 and 1 phi) the nature of the percentage of the material either coarser or finer differed rather markedly. Most sediments (with the exception of those from the sand zone which received fine material from the lagoon) show a real decrease in the percent of particles finer than 3 phi (0.125 mm). By inference then this would approximate the mean maximum size of particles carried in suspension from the reef at the height of the cyclone's activity. Most sediments also show an increase in the percentage content of particles of gravel size (-1 phi) and coarser - this also is a real difference. Thus the cyclone has tended to introduce larger sized particles onto the reef top surface from the reef slope and has removed particles finer than 3 phi. Sediments recovered from the boat harbour also show an absence of particles finer than 3 phi. This suggests that the predominant factor contributing to its siltation is bedload transportation by tidal currents accompanied by wave produced lateral migration of sediment along the beaches to the western end of the island where the beach is prograding into the harbour.

1976-1977

Two of the traverse lines, namely N and F were resampled in January 1977, twelve months after Cyclone David. The pattern of graphic mean size and graphic standard deviation display little or no correspondence, to the precyclone or cyclone patterns (see Text-fig. 28). Maybe a longer period than 12 months is needed before the patterns will approach those of August '75 (if this did represent a static pattern in harmony with the prevailing hydraulic conditions) or it could indicate that the distribution patterns are in a constant state of change, every major event leaving its imprint on the sediment texture and rarely is the sediment at a specific locality identical in time. Nevertheless along these two traverse lines the following changes can be observed:

Line N - sediments on the outer reef flat and reef rim are considerably finer in size and better sorted. Within the area of coral development they are consistently finer and less well sorted. On the sandy area of the reef flat they are finer and less well sorted. This trend is interpreted as 1) the removal of finer material from the outer reef flat and reef rim with deposition of same in the area of the coral growth, and 2) a similar removal of fines from the sandy area with their addition to the beach. The point of demarcation occurs about midway across the reef flat and could be related either to the influence of westward flowing tidal currents or a change in the prevailing energy conditions; action of breaking waves on the outer reef flat and reef rim, and the action of translatory waves and tidal currents on the inner reef flat.

Line F - sediments on the outer reef flat and reef rim are coarser and better sorted; on the inner reef flat including the sandy area they appear to have changed little except for a general progradation of the 1977 curves towards the cay; near to the beach and moat area the sediments are finer and less well sorted. This trend is interpreted in a similar manner as for line N except that there only appears to be one pattern of removal of fines from the outer reef flat and reef rim with their subsequent addition to the sediments of the inner reef flat.



Text-fig. 28 Plots showing the changes in mean size and sorting for August '75, Jan. '76, and Jan. '77.

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APPENDIX

Reef	Flight	Run	Photo
Boult	CAB 2020	45	296
Broomfield	CAB 2021	39	452
Erskine	CAB 2021	40	396
Fairfax	(CAB 2020	44a	220
	(also AA 1971		
Fitzroy	CAB 2022	43	618
Heron	(COG Dept. Brisbane		
	(CAB also available		
Hoskyn	CAB 2020	46	356
Lamont	CAB 2022	42	579
Llewellyn	CAB 2020	44a	260
Lady Elliot	(R.A.A.F.		
	(CAB also available		
Lady Musgrave	(CAB 2020	47	322
	(also AA 1971		
Mast Head	(CAB 2021	40	395
	(also COG 1972		
North	CAB 2025	38	946
North West	(CAB 2025	38	942
	(also COG 1972		
One Tree	CAB 2022	42	577
Polmaise	CAB 2021	40	394
Sykes	CAB 2022	41	666
Tryon	CAB 2025	38	944
Wilson	CAB 2021	39	452
Wistari	CAB 2021	40	398
Wreck	(CAB 2021	39	453
	(also COG 1972		

The 1964 CAB series (B&W) are available from:

Department of National Mapping
P.O. Box 667
CANBERRA CITY A.C.T. 2601

The 1972 COG series (Colour or B&W) are available from:

Australian Aerial Mapping
13 Cribb Street
MILTON, Q. 4064

Copies of the R.A.A.F. series (B&W) which cover both the islands and reefs (on several occasions) may be obtained from:

Photographic Officer
Geology Department
University of Queensland
St. Lucia, Q. 4067

The 1971 AA series (Colour or B&W) are available from:

Adastra Airways Pty. Ltd
P.O. Box 101
MASCOT, N.S.W. 2020

PLATES 1-19

PLATE EXPLANATIONS

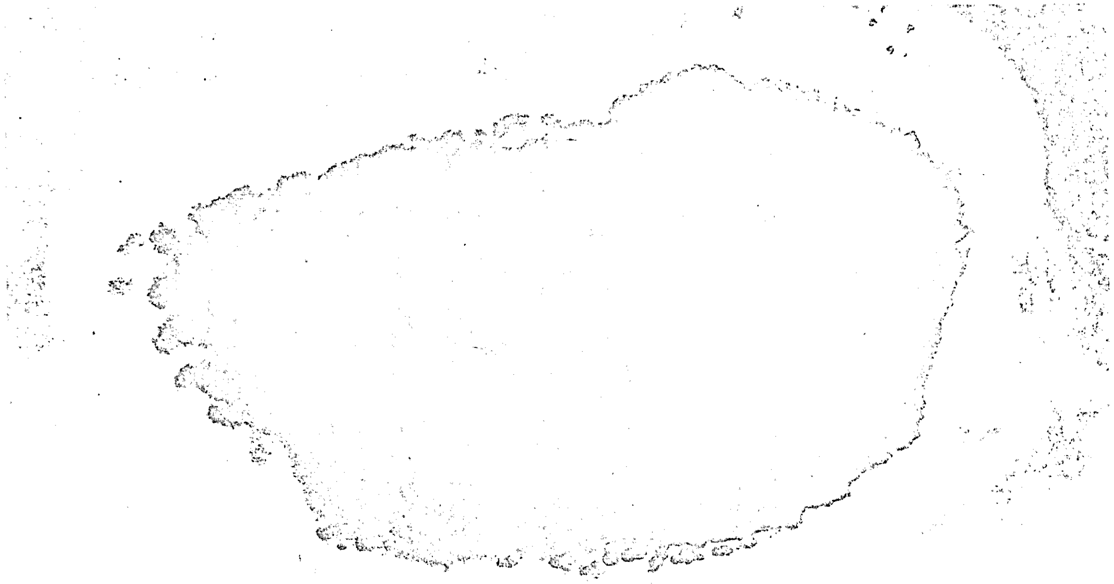
Plate 1 Cays or Islands

Fig. 1 Lady Musgrave Island, a mixed shingle/sand cay. Beachrock borders the southeastern beaches and cay rock (lithified cay shingle) crops out on the southwestern corner. (R.A.A.F. Sept. '73).

Fig. 2 One Tree Island, a shingle cay. The white squares are the buildings of the research station. A brackish pond is centrally located. (R.A.A.F. Sept. '73).

Fig. 3 Mast Head Island, a sand cay. Beachrock is exposed on the northwestern and southeastern beaches. (C.O.G. June '72).

All figs. to same scale 1.3 cm represents 100 m. No specific orientation, right to left the long axis is approximately E to W.



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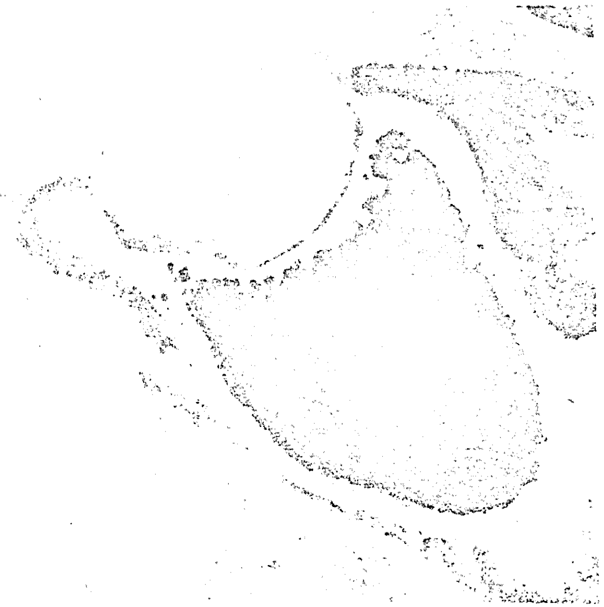

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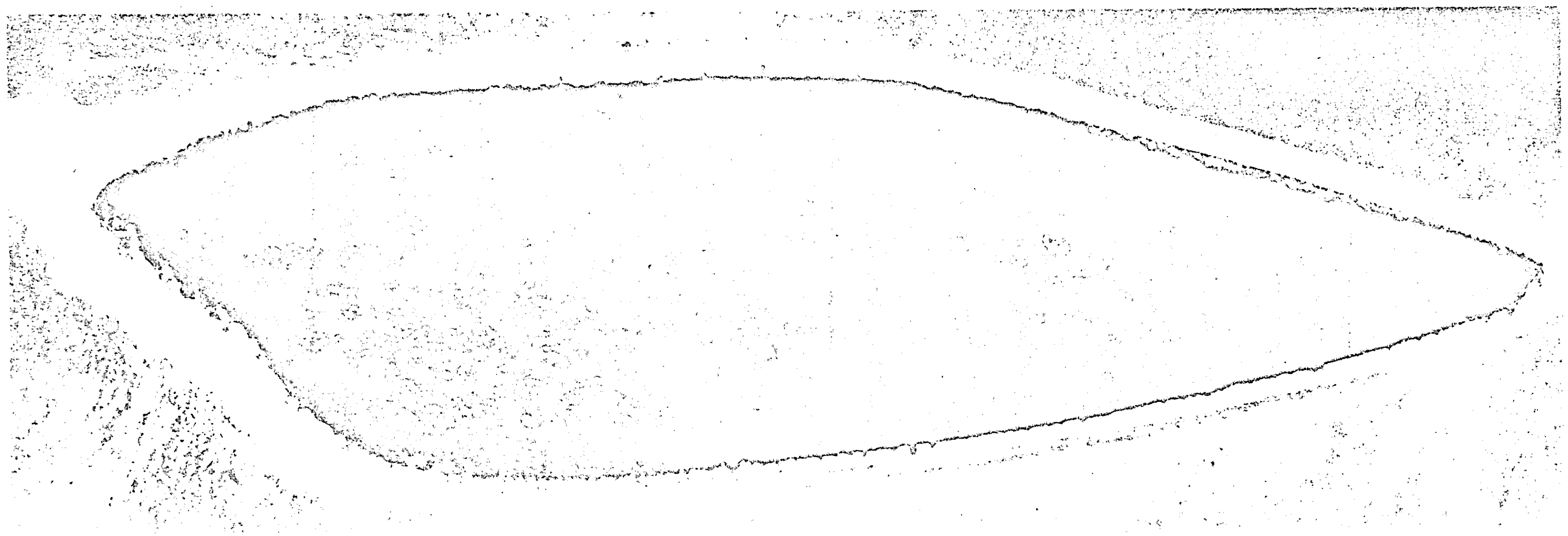

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Plate 2 Cays or Islands

Fig. 1 Hoskyn (west) Island, a sand cay.

Fig. 2 Hoskyn (east) Island, a shingle cay.

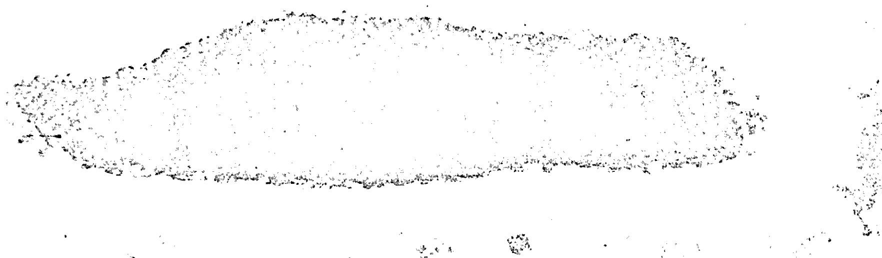
Fig. 3 Sand cay on North Reef. Lighthouse and buildings are obvious.

Fig. 4 Wreck Island, a sand cay. Beachrock exposed along the southeastern beach.

Fig. 5 Tryon Island, a sand cay. Beachrock exposed on southwestern corner and northeastern beach. Cay rock (lithified sand) exposed along the northwestern upper beach.

Fig. 6 Wilson Island, a mixed shingle/sand cay. Extensive development along northeastern and southeastern beaches.

All figs. to same scale 1.3 cm represents 100 m. No specific orientation, right to left long axis is approximately EtoW. All photographs taken by R.A.A.F. Sept. '73.



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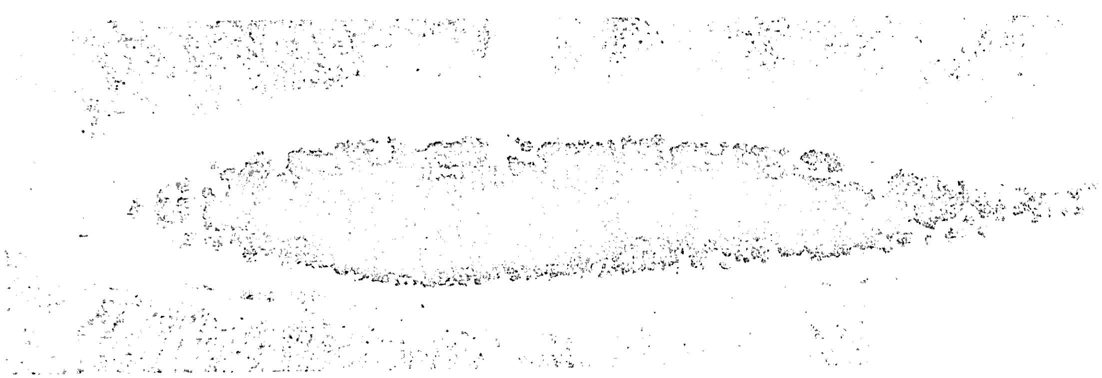

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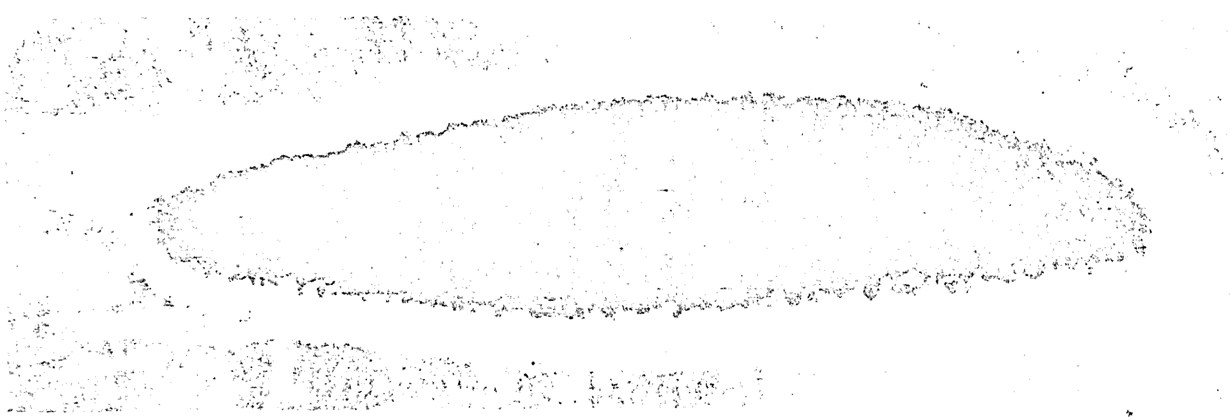

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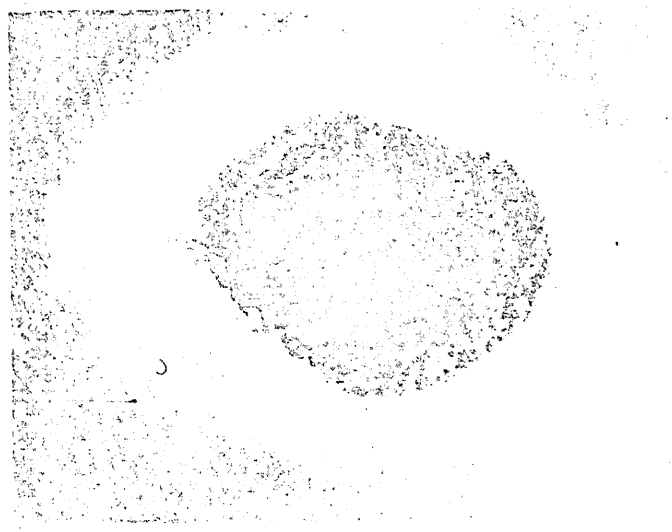

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Plate 3 Cays or Islands

Fig. 1 Fairfax (west) Island, a sand cay. The long sand spit joining the main development of vegetation and the isolated trees is frequently washed away producing two islands (eg. 1936 in Steers 1938; 1967 cyclone; 1976 cyclone "David").

Fig. 2 Fairfax (east) Island, a shingle cay showing concentric arrangement of beach ridges (now lithified) and two brackish pools. This cay was mined for guano and until recently it was used by the Military Forces as a bombing target.

Both figs to the same scale 1.2 cm represents 100 m. Orientation right to left is approximately W to E for fig. 1 and E to W for fig. 2. (R.A.A.F. Sept. '73).

1

2

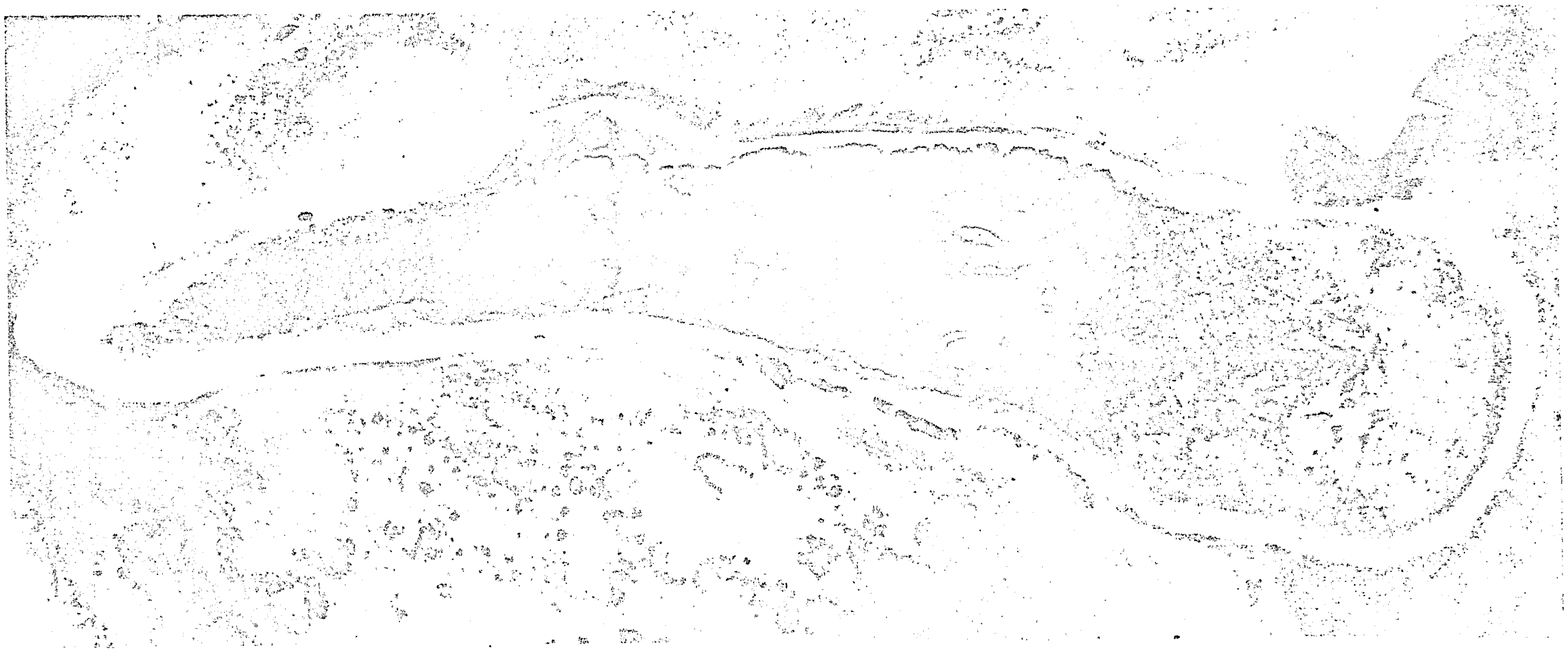
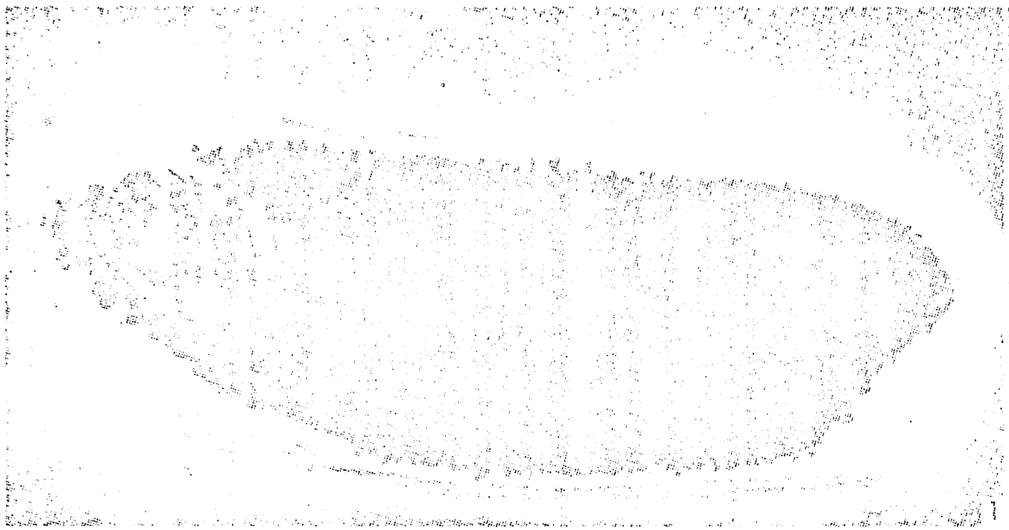


Plate 4 Cays or Islands

Fig. 1 Heron Island, a sand cay showing the development of the tourist resort and research station on the western end. Prominent beachrock development on the southern and northwestern beaches. Scale 1 cm represents 100 m. (R.A.A.F. Sept. '73).

Fig. 2 Erskine Island, a mixed shingle/sand cay. Scale 1.4 cm represents 100 m. (R.A.A.F. November '74).

Fig. 3 North West Island, a sand cay and the largest island of the Capricorn-Bunker Group. Three ridges of beachrock are conspicuous on the eastern end. Scale 0.7 cm represents 100 m. (C.O.G. June '72).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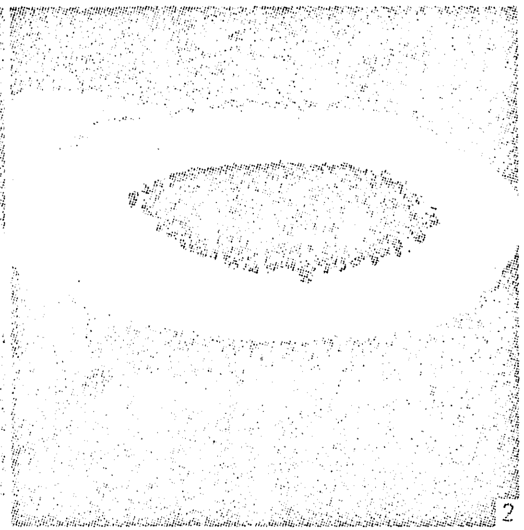
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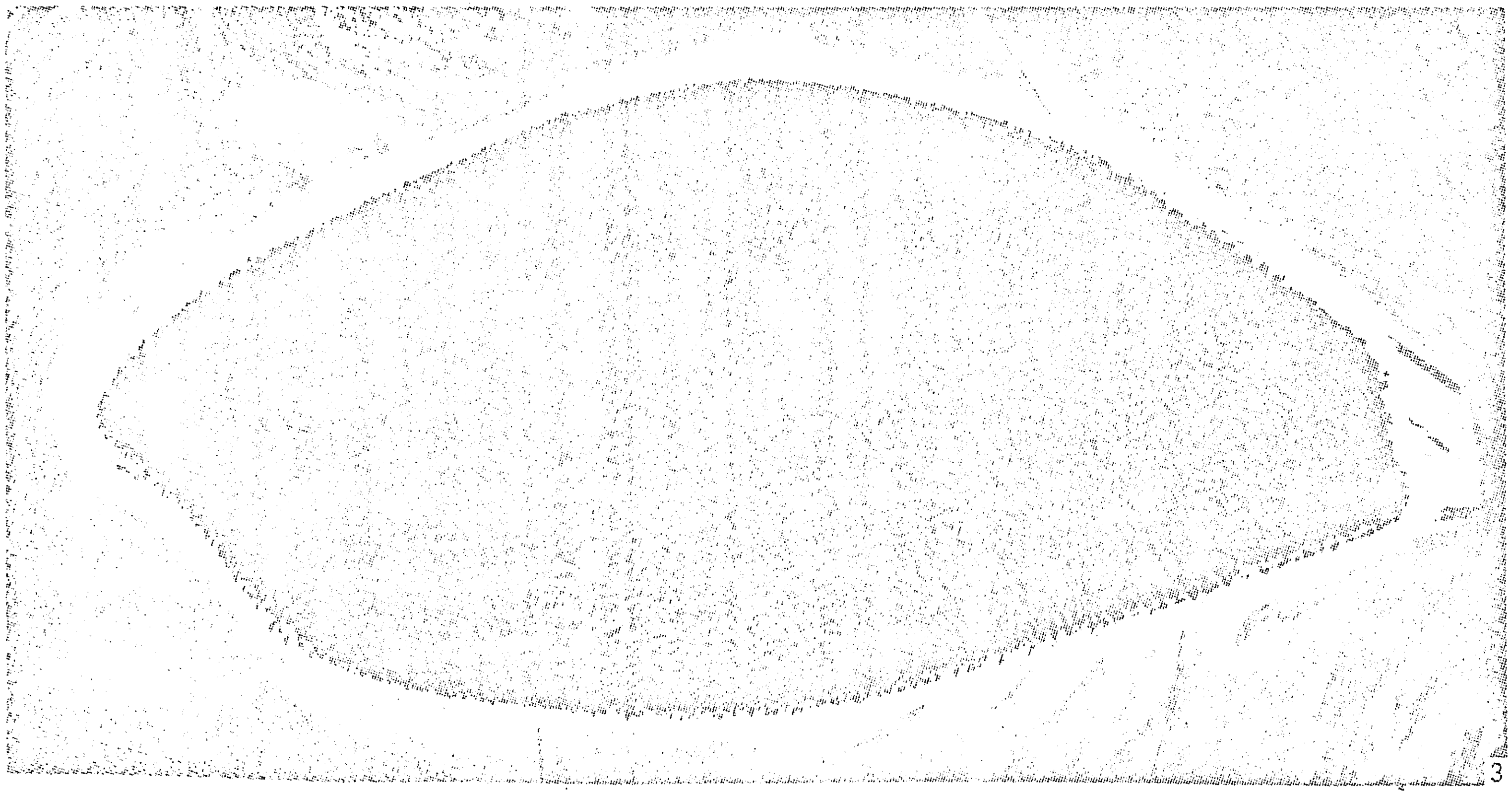
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Plate 5 Cays or Islands

Lady Elliot Island and reef, a shingle cay with an airstrip, manned lighthouse, and buildings of a tourist business. A sequence of lithified beach ridges are clearly obvious. The island was mined for guano between 1863 to 1873. Eroding cay rock is evident at the eastern and southwestern corners. Scale 0.9 cm represents 100 m. Orientated right to left E to W. (R.A.A.F. April '75).

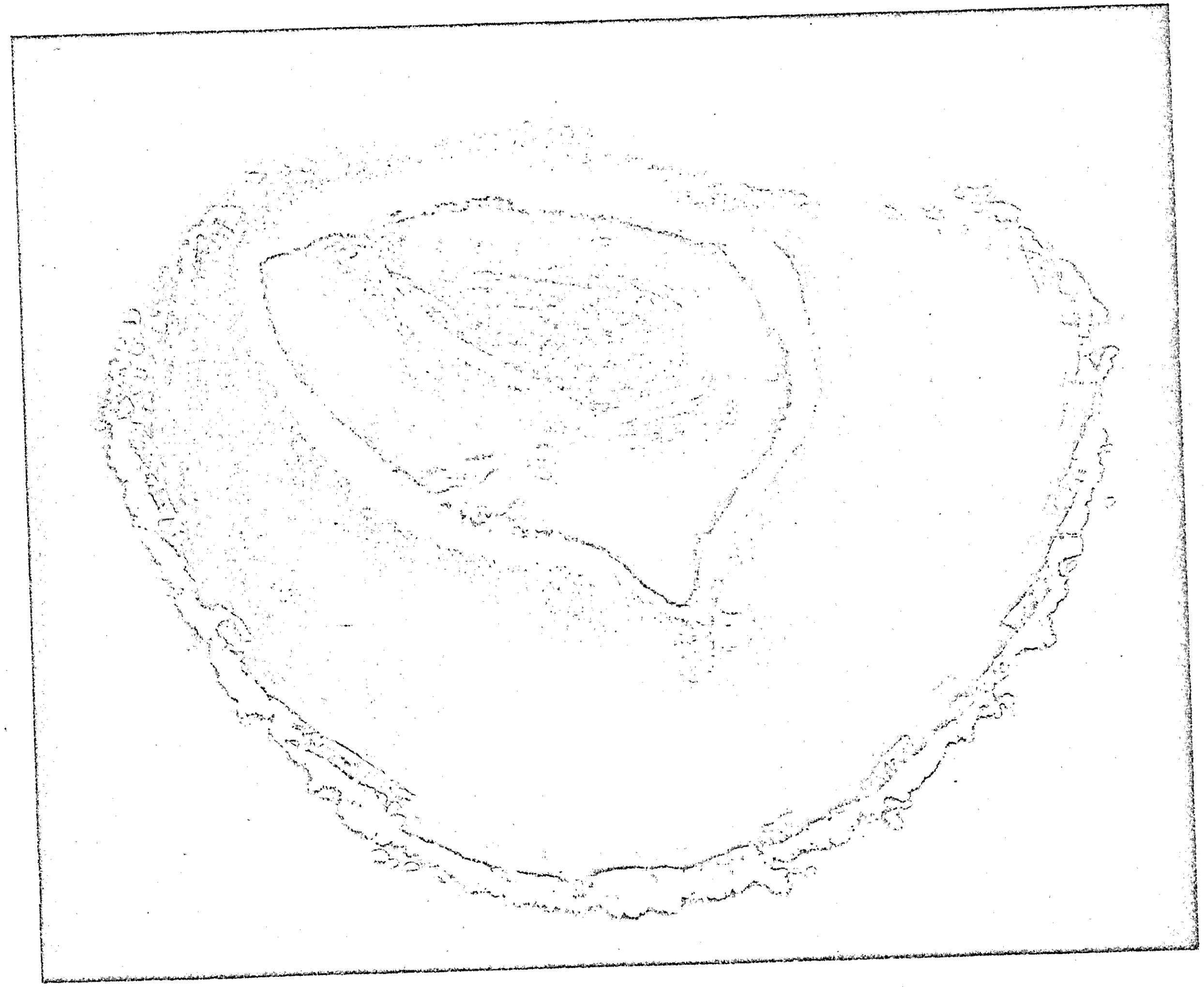

Plate 6 Reef Types

Heron Reef, a lagoonal platform reef type displaying the clearly marked physiographic zonation. Scale 1.6 cm represents 1 km (approximately) and long axis runs E-W. Sand Cay is located near the northwestern (leeward) corner. (C.O.G. June '72).

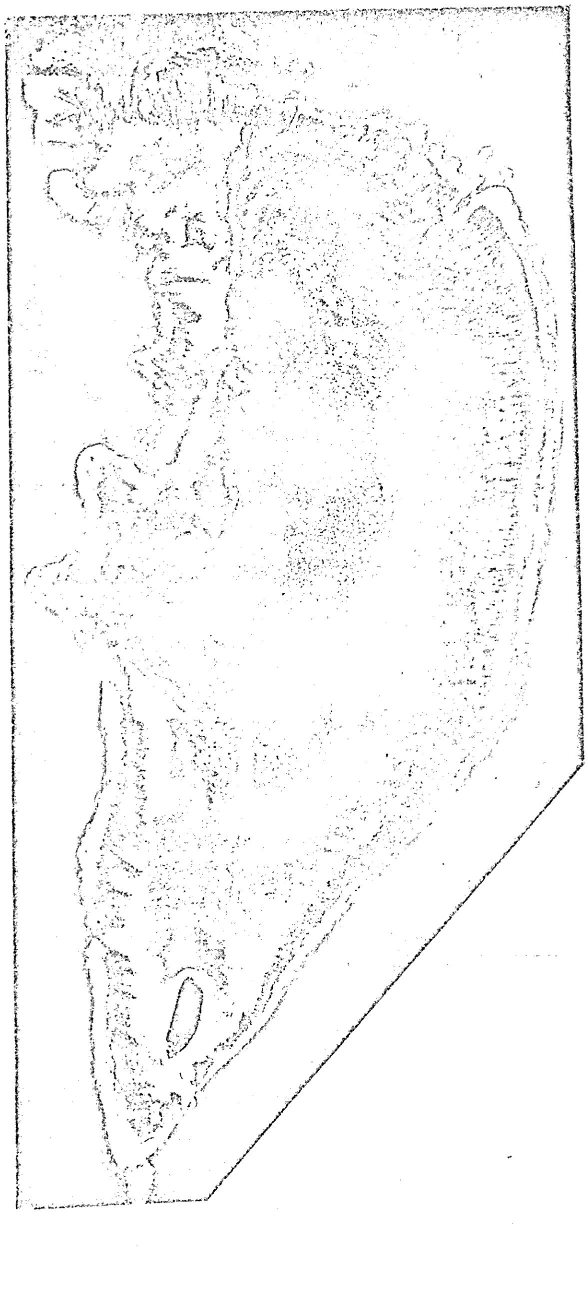

Plate 7 Reef Types

Fig. 1 Llewellyn Reef, a closed ring (platform) reef type.

Fig. 2 Lady Musgrave Reef, a closed ring (platform) reef type (studied by Orme *et* al. 1974). The entrance to the lagoon is a natural passage maintained by a vigorous current approaching 6 knots on the ebbing tide (similar to those on Fitzroy Reef - see Davies *et al.* 1977).

Fig. 3 Fitzroy Reef, a closed ring (platform) reef type.

Fig. 4 One Tree Reef, a reef transitionary between a closed ring (platform) type and a lagoonal platform type (studied by Davies *et al.* 1976, 1977).

All reefs to same scale 1.6 cm represents 1 km. Long axes are orientated approximately E-W from right to left. (All Dept. National Mapping 1964).

PLATE 7

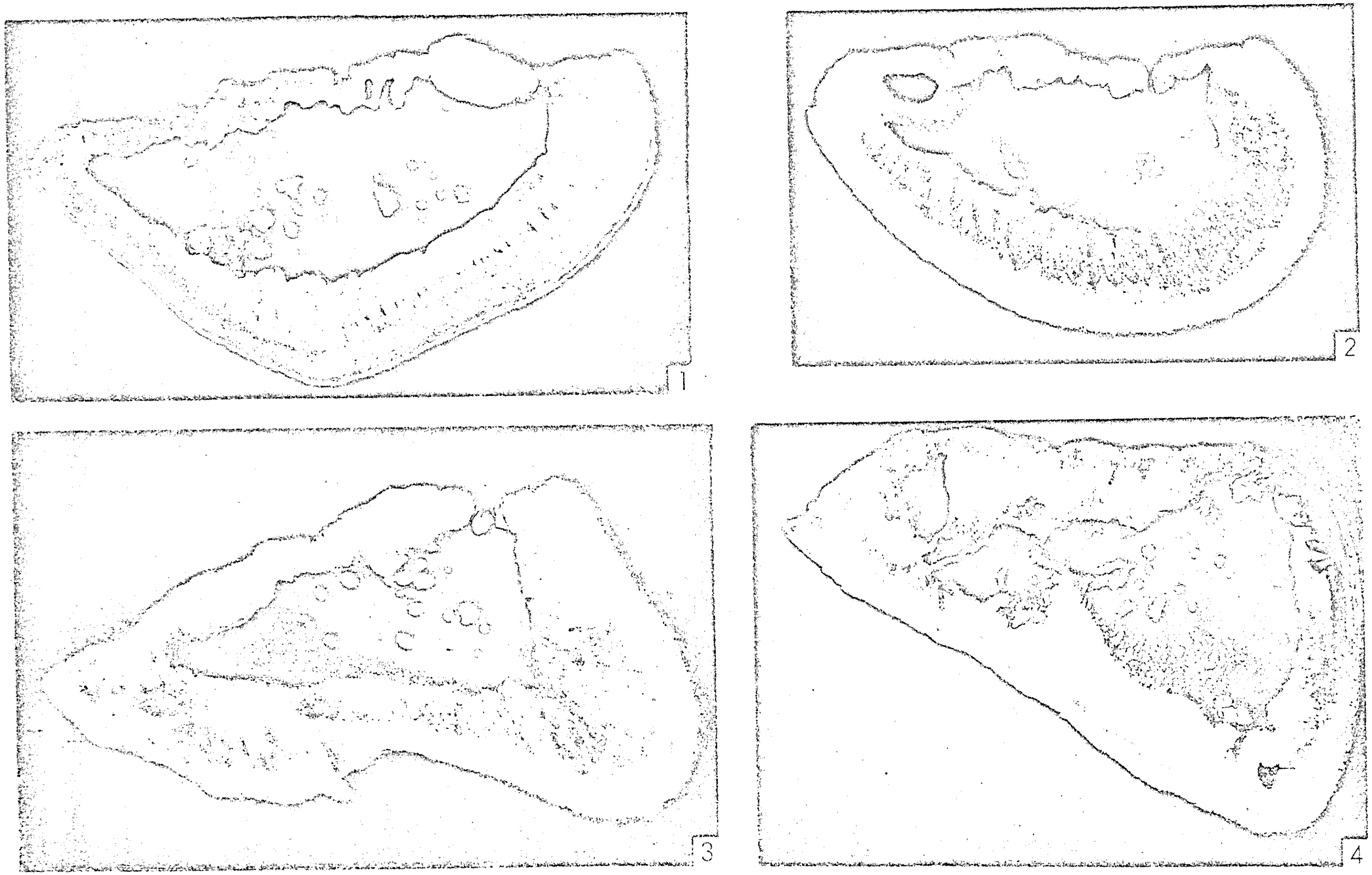

Plate 8 Reef Types

Fig. 1 Broomfield Reef, a lagoonal platform reef on which the lagoon has almost been infilled by skeletal carbonate sand (see Plate 16 fig. 2).

Fig. 2 North Reef, a platform reef showing the development of a shingle spit and a sediment veneer on the reef flat in addition to the sand cay.

Fig. 3 Wilson Reef, a platform reef.

Fig. 4 Erskine Reef, a platform reef.

Fig. 5 Tryon Reef, a platform reef.

Fig. 6 Lamont Reef, a linear or wall reef.

Fig. 7 Hoskyn Reef, an ingrown closed ring (platform) reef.

Fig. 8 Boult Reef, a closed ring (platform) reef.

Fig. 9 Wreck Reef, a platform reef showing the marked radial pattern developed on the reef flat coral zone.

Fig. 10 Fairfax Reef, an ingrown closed ring (platform) reef.

All reefs to same scale 1.6 cm represents 1 km. Long axes are orientated approximately E to W from right to left. (All Dept. National Mapping 1964).

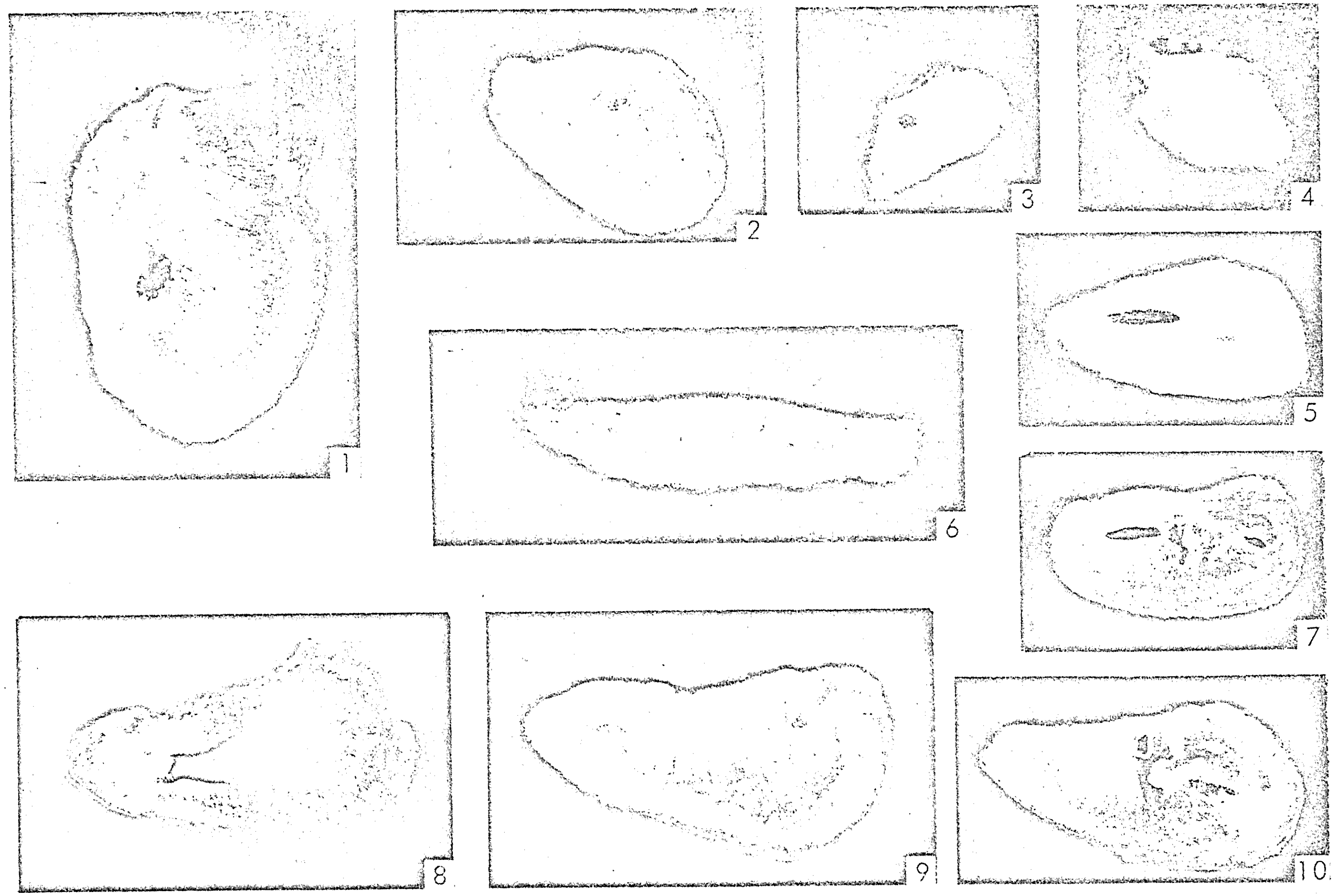
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PLATE 9 Reef Types

Fig. 1 North West Reef, transitional between a elongate lagoonal platform reef and an elongate platform reef. The lagoon is almost completely infilled and intertidal sand bodies are building up on the leeward reef flat.

Fig. 2 Mast Head Reef, an elongate platform reef. A sand wave field can be seen in shallow water to the north of the island. It represents [illegible] skeletal material which has been washed off the reef top by wave action and tidal currents.

Fig. 3 Sykes Reef, a wall or linear reef.

All reefs to the same scale 1.6 cm represents 1 km.
Long axes are orientated approximately E to W from right to left for figs. 1 and 2 but for fig. 3 it is N to S. (All Dept. National Mapping 1964).

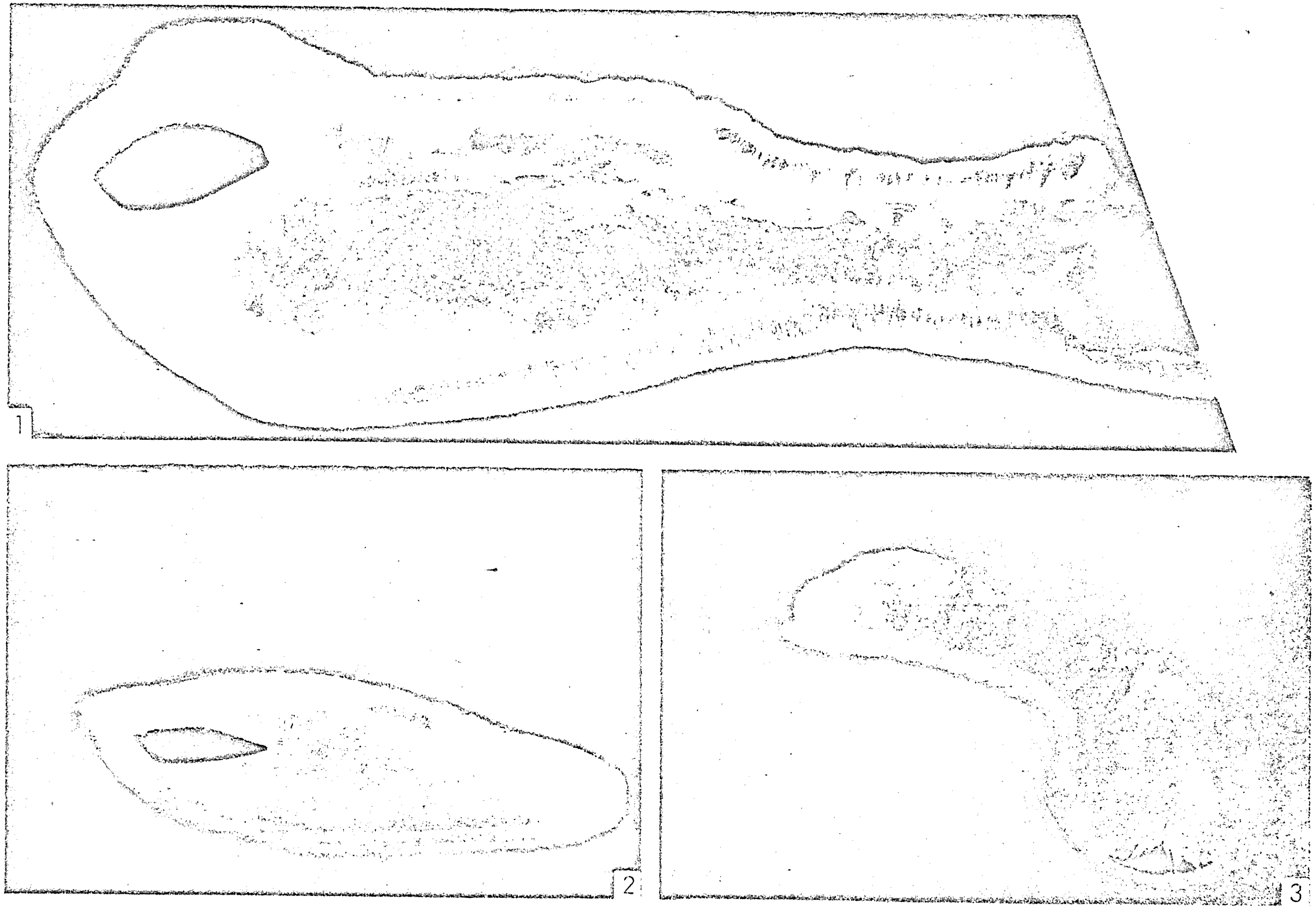
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Plate 10 Reef Types

Fig. 1 Wistari Reef, a lagoonal platform reef.

Fig. 2 Polmaise Reef, an elongate platform reef. A sediment wave is located in a similar position as with Mast Head Reef (Plate 9 fig. 2). Seismic profile (Text-fig. 10) passes over this sand wave. The dark area is Irving Shoal.

Both figs to the same scale 1.6 cm represents 1 km. Long axes are orientated approximately E to W from right to left - (Both Dept. National Mapping 1964).

1

2

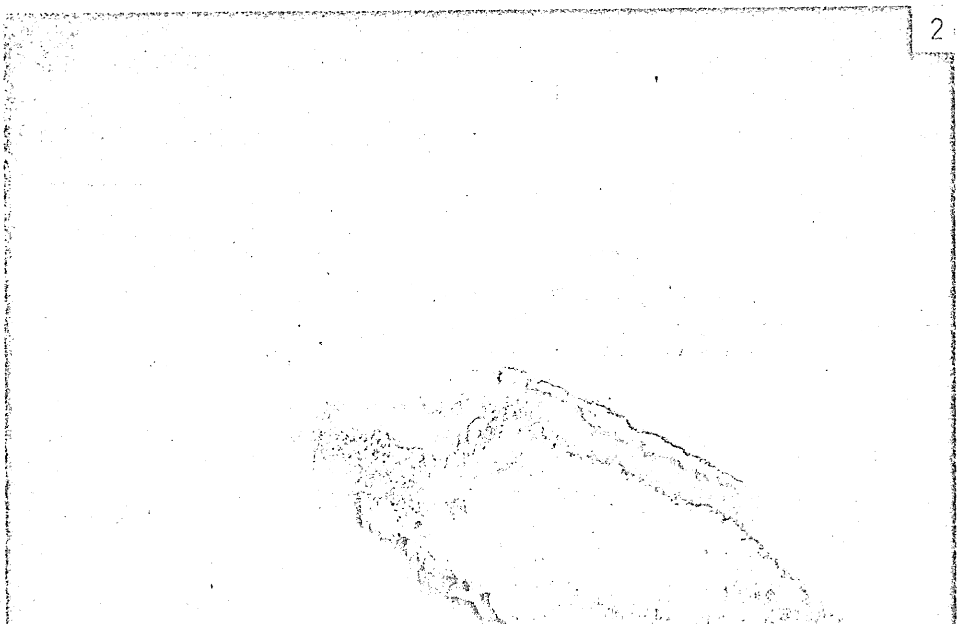

Plate 11 Reefal Shoal or Platform

Fig. 1 Underwater photograph taken at about 8 m and looking northward toward the drowned rim of the pre-Holocene platform (Text-figs. 4 & 5). Position is indicated by the arrow on fig. 3. It shows a cemented limestone with sparce growth of modern corals such as the dish-shaped Acropora sp.

Fig. 2 Underwater photograph taken at about 15 m showing the carbonate platform or reefal shoal between Heron and Sykes Reefs. Several varieties of corals are obvious (Diver H. Hekel).

Fig. 3 Vertical airphotograph showing the reefal shoal between Heron and Sykes Reefs and the sand wave field (see Text-fig. 4). (Dept. National Mapping '64).

Fig. 4 Diving on the windward side of the locality shown in Fig. 1 in a spur-and-groove structure at about 18 m.

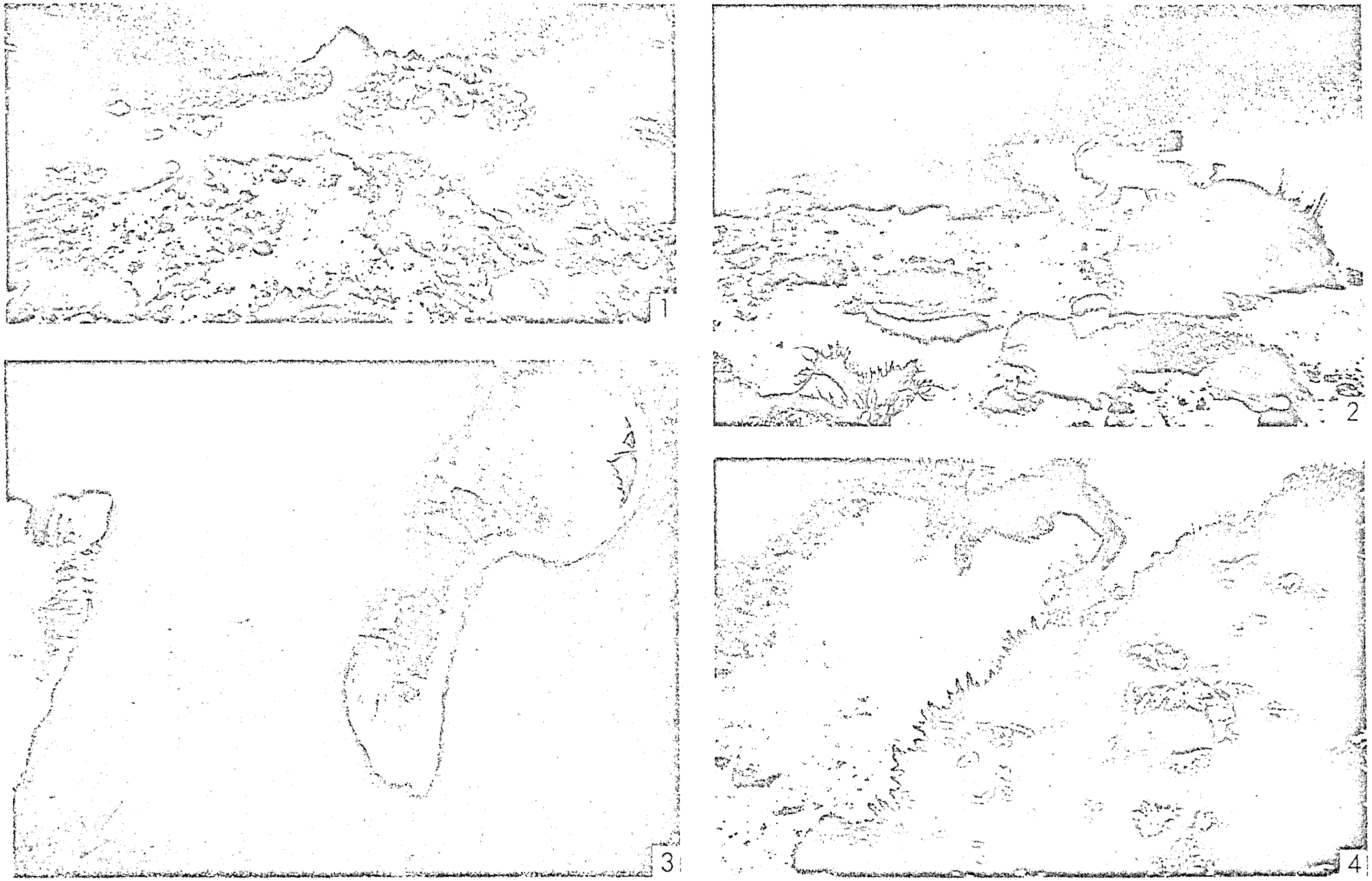
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Plate 12

Vertical airphotograph of the western end of Heron Reef showing details of the physiographic zonation, boat harbour, sand cay etc.

Scale 0.6 cm represents 100 m. (R.A.A.F. Oct '75).

Plate 13 Windward Reef Slope

Fig. 1 Showing spur-and-groove structure on the southwestern corner of Heron Reef. Photograph taken at low spring tide when the coral growth on the upper surface of the spurs was exposed. The flat surface behind the spur-and-groove is the reef rim.

Fig. 2 The coral cover decreases with depth below the terrace onto which the spur-and-groove structures open. Sediments is variable, sand to gravel (shingle) sizes. Depth approximately 10 m.

Fig. 3 Windward reef slope showing the profusion of living coral forming a strong rugged framework and associated coarse coral detritus (source of the coral shingle). Depth approximately 5 m.

Fig. 4 As above but slightly deeper and approaching the lower limit of the profusion of coral growth.

PLATE 13

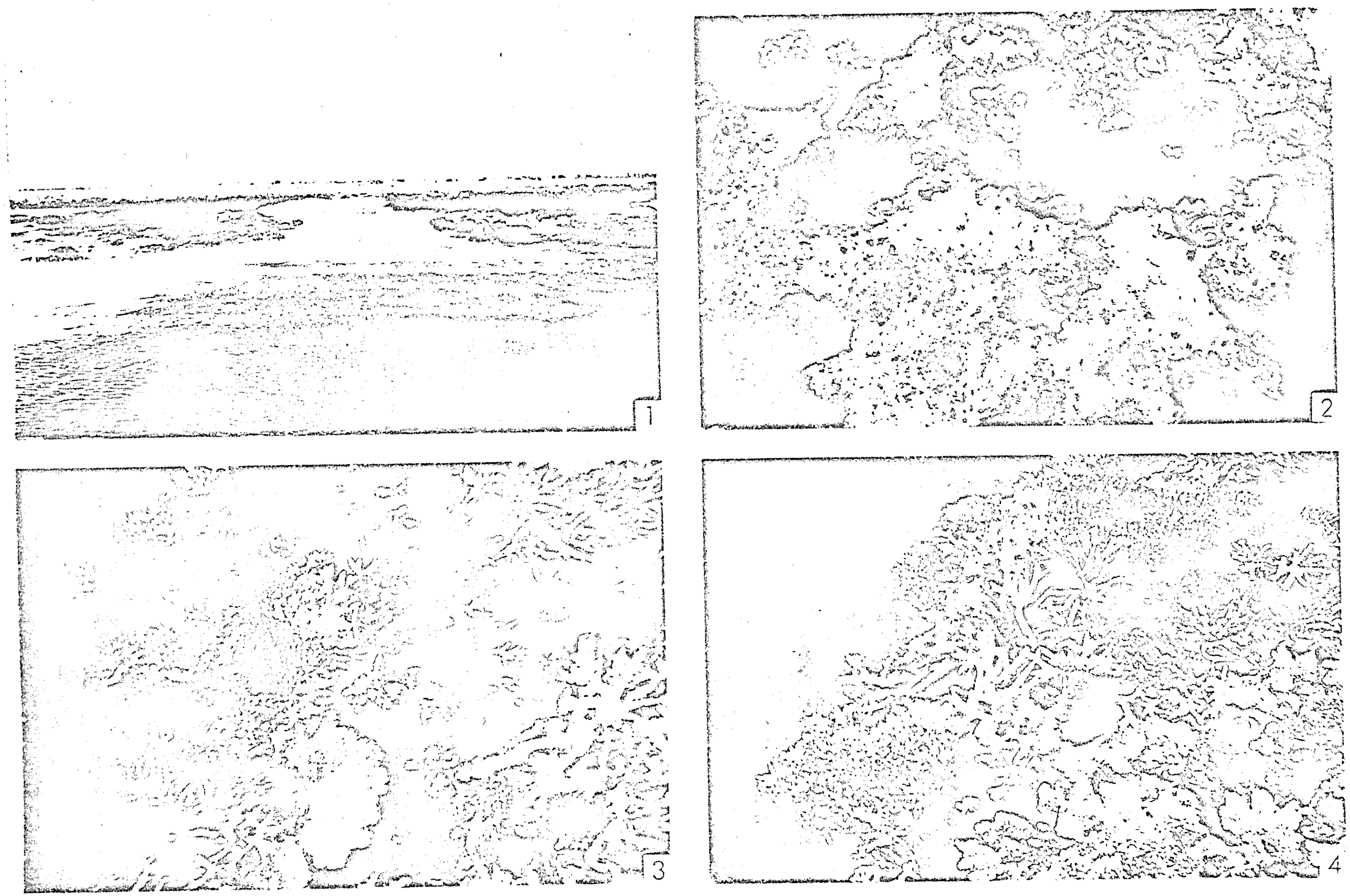

Plate 14 Leeward Reef Slope

Fig. 1 View of the leeward reef slope taken at about 5 m. Showing the incomplete cover of the coral growth on a cemented substrate. The gully to the right of the photographs carries sand-and gravel-sized material from the reef top down the reef slope to deposit it as a sediment wedge on the terraces below (eg. Fig. 3).

Fig. 2 Showing the cemented nature of the reef slope surface with sparce coral growth and the soft green algae Chlorodesmis sp, locally called turtle weed. Depth about 5 m.

Fig. 3 View of the sediment wedge or fan at the base of one of the gullies on the leeward slope. Sediment consists of coarse detritus of corals, algae, shells, bryozoans, etc, and is predominantly gravel-sized. Depth about 12 m.

Fig. 4 As for Fig. 3 showing the extremely coarse rubble at the base of an almost vertical reef slope. Fish are approximately 40 cm in length and depth about 15 m.


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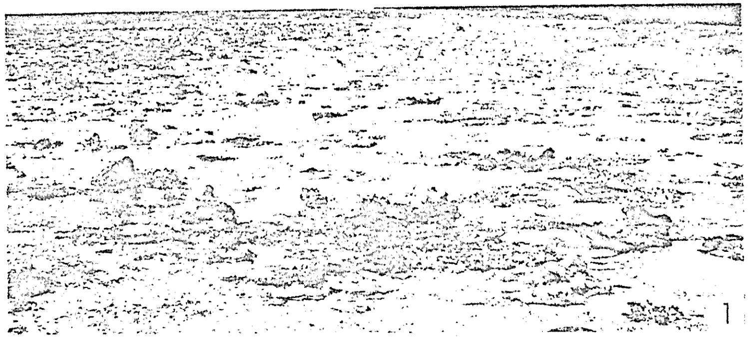
Plate 15 Reef Rim

Fig. 1 View of the windward reef rim on Heron Reef taken at low tide showing the breaking waves, the relatively flat reef rim which is covered by coarse coral boulders.

Fig. 2 View of the coral growth on the upper surface of the spurs, on the ocean side of the windward reef rim.

Fig. 3 View of the boulder zone on the reef rim on the leeward side of Heron Reef.

Fig. 4 View of the physiographic zonation on the leeward reef top; ocean and breaking waves, reef rim, seaward scoal, coral rubble zone covering the coral zone of the reef flat.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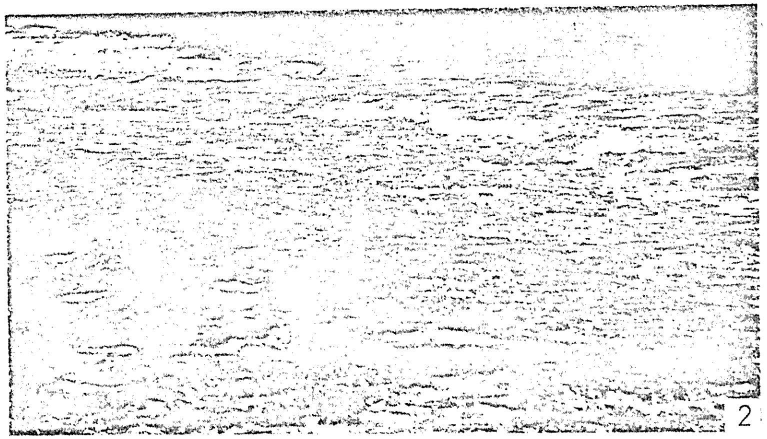
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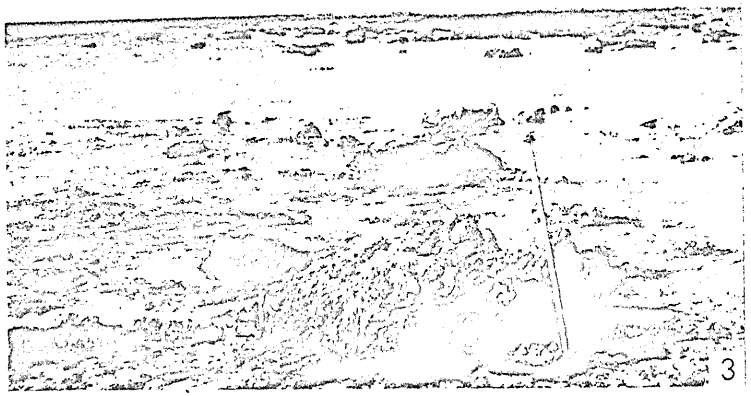
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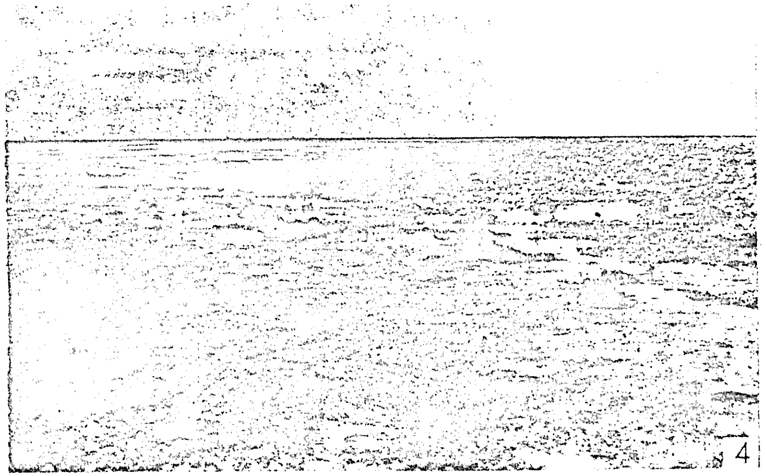
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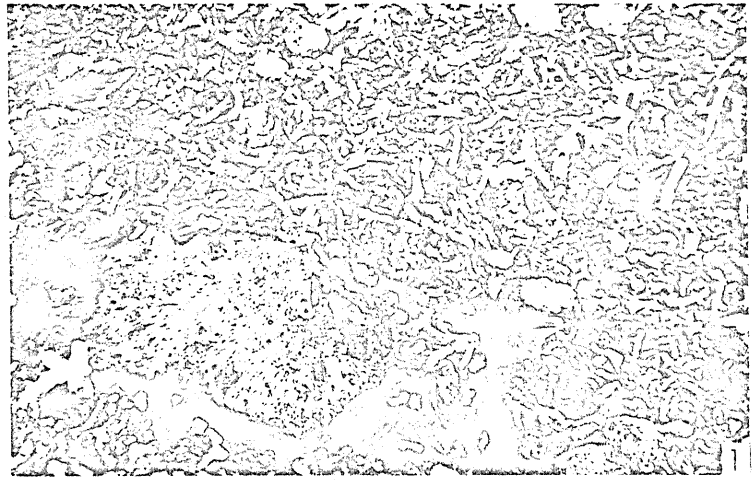
Plate 16 Reef Flat

Fig. 1 Showing the coarse coral sticks (shingle) and large coral heads that constitute the sediment forming the shingle spits on the western reef flat of Heron Reef.

Fig. 2 Oblique photograph showing the prograding nature of the skeletal carbonate sediment into a lagoon on Broomfield Reef. Orientation is windward to leeward from right to left.

Fig. 3 View of the reef flat coral growth on Heron Reef, near the "wreck". Shows the dead coralline algae encrusted upper surface of these large colonies and the rejuvination of living coral growth approximately 10 cm lower (indicated by arrow). Catastrophic mortality of the corals was produced by lowering the level of low water on the reef flat (western part) and was associated with the construction of the boat harbour (see text and text-fig. 24).

Fig. 4 General view of the reef flat (coral zone) on Heron Reef. Showing about equal coverage by corals and sand (with long black beche-de-mer).



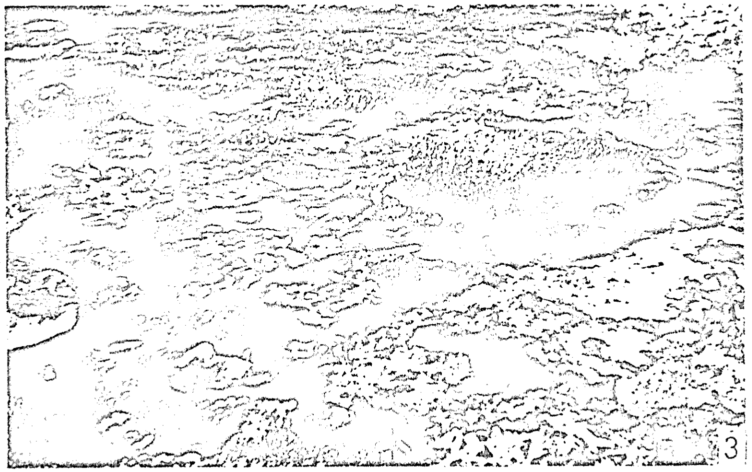
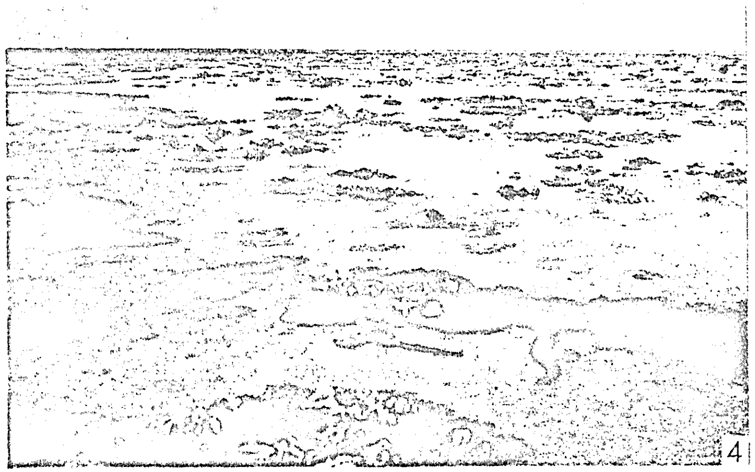



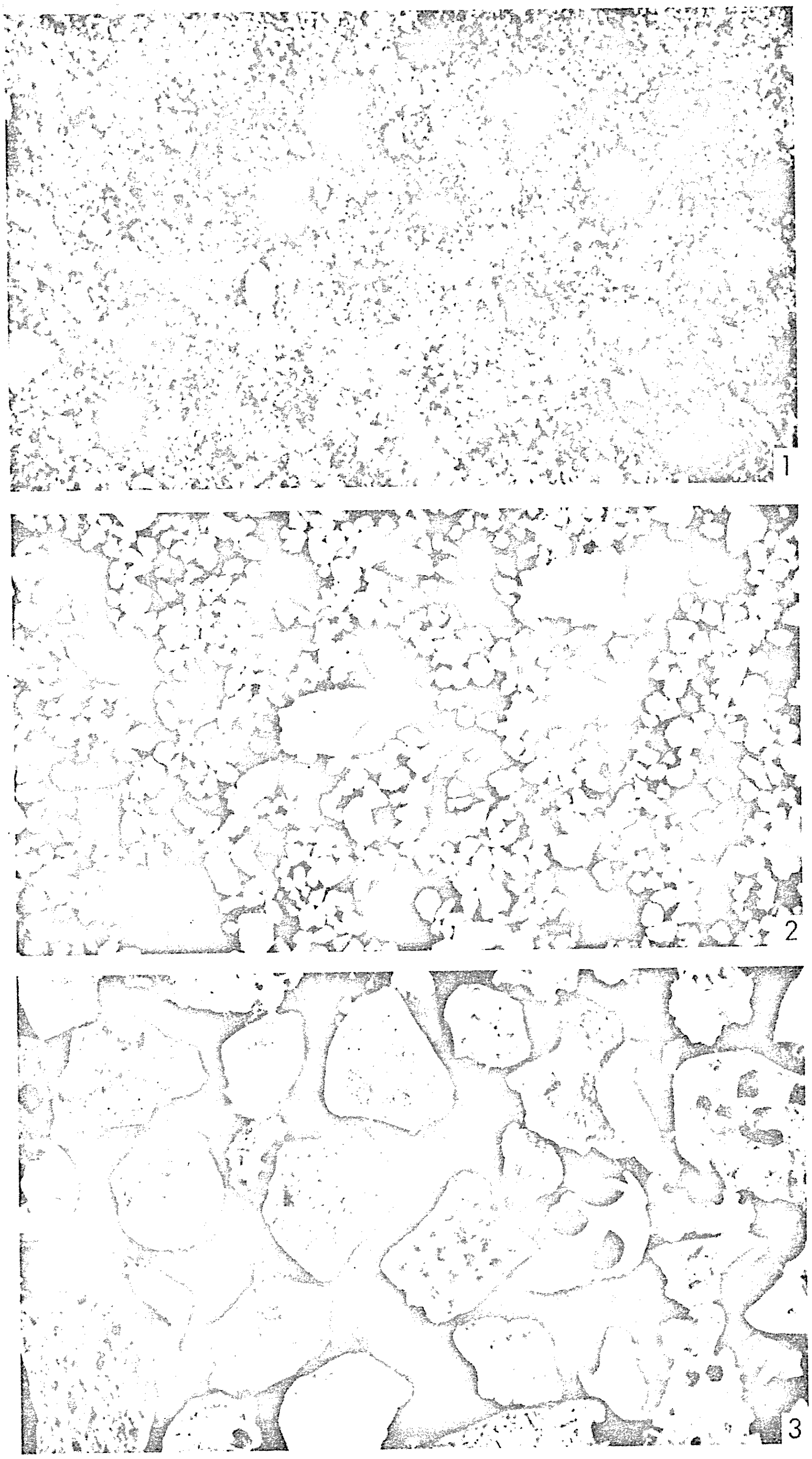
Plate 17 Grain-size

Fig. 1 Photomicrograph of sediment sample 394 from the lagoon. (X10 mag.) Skeletal-component types cannot be identified. Fine sand sizes.

Fig. 2 Photograph of sediment sample 206 from the shallow lagoon. (X12 mag.). Skeletal-component types are difficult to distinguish. Medium sand sizes.

Fig. 3 Photograph of sediment sample 196 from the windward reef rim. (X3 mag.). Coral, coralline algae, and molluscs are obvious. Gravel sizes.

Numbers refer to the collection made by Maxwell's et al. 1964.



130 mm

Plate 18 Skeletal-component composition

Fig. 1 Photomicrograph of sediment sample 378 (X20 mag.). Having 48.3% of coral detritus and belonging to component Group E.

Fig. 2 Photomicrograph of sediment sample 204 (X7.5 mag.) having a 45.3% of Halimeda detritus and belonging to component Group A.

Fig. 3 Photomicrograph of sediment sample 260 (X3 mag.) having 48.7% coralline algae detritus and belonging to component Group C.

Number refer to the collection made by Maxwell et al. 1964.

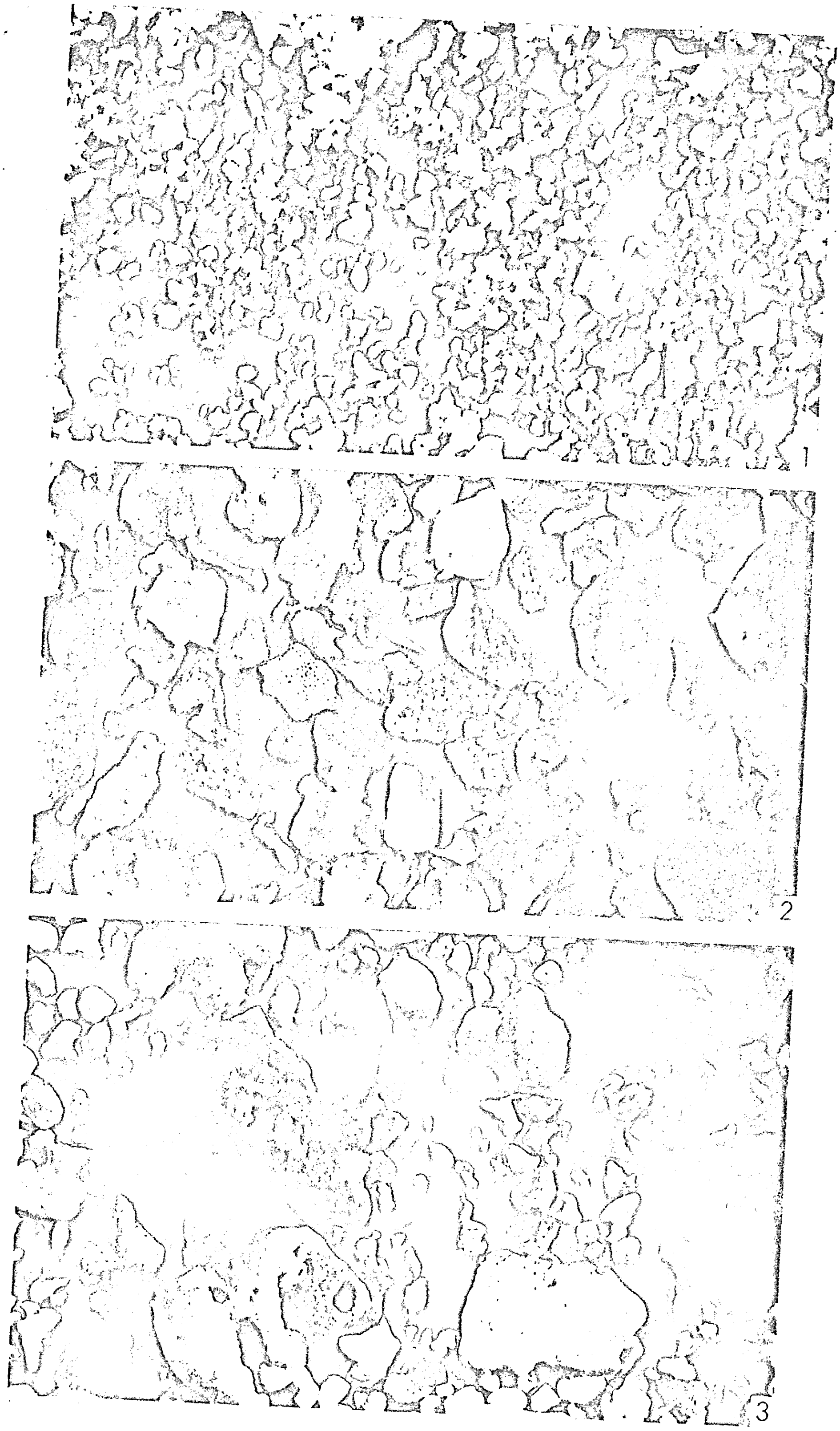

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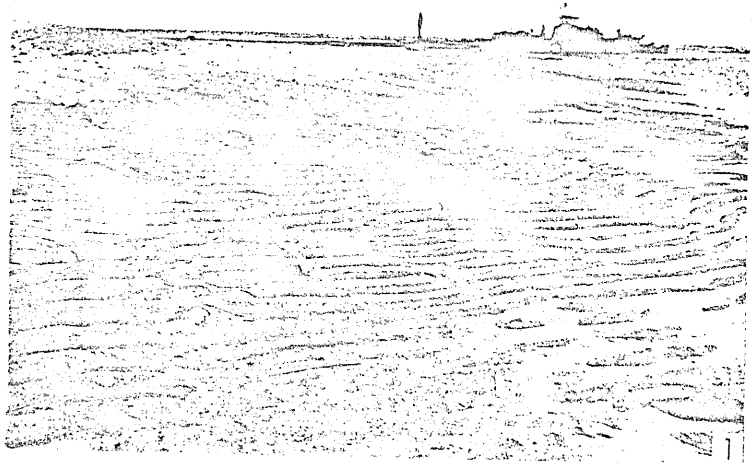
Plate 19 Cyclone "David", January 1976

Fig. 1 View at low tide immediately after the cyclone showing the sand-sized sediment moving as bed-load over the reef flat towards the boat harbour.

Fig. 2 At the height of the cyclone. 3 m waves and a 2 m storm surge piled debris onto the helipad (arrowed).

Fig. 3 The sand-blasting effect of the high velocity winds which accompanied the cyclone. Vegetation lost the majority of their leaves and fine sand piled up at the base of the tree trunks (arrowed).

Fig. 4 Beach-erosion at the southeastern corner of Heron Island. The high seas undermined the dunes and the trees (mainly Pandanus) collapsed onto the beach. The cay suffered severe erosion along its southern beach.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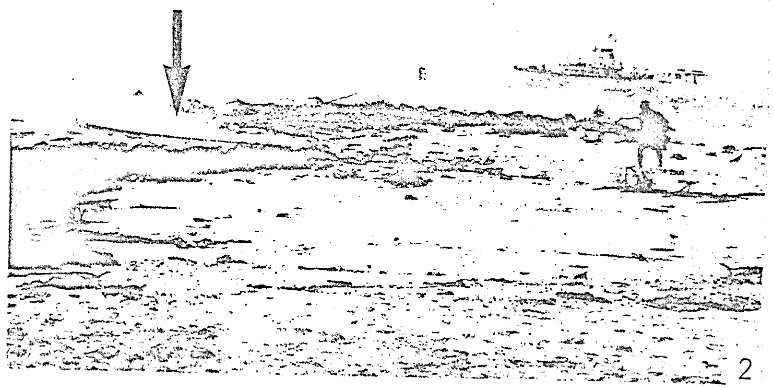
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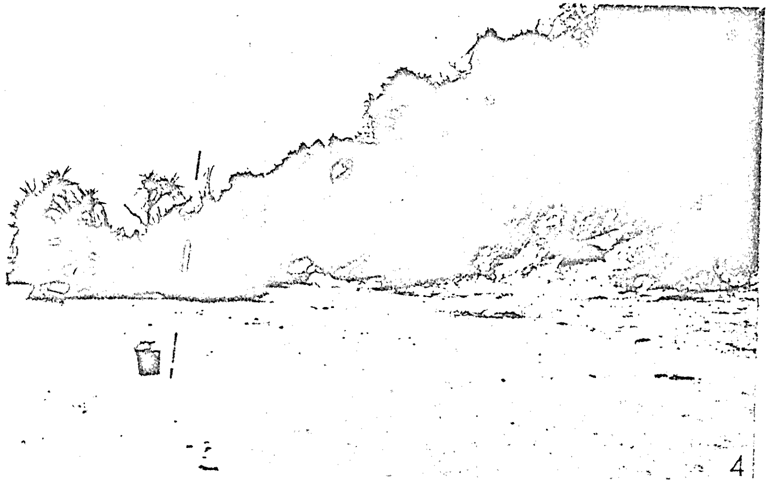
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