PRELIMINARY REPORT ON THE GEOLOGY AND SEDIMENTOLOGY OF SELECTED SITES ASSOCIATED WITH THE WRECK OF THE VOC SHIP "ZEEWIJK", GUN ISLAND, WESTERN AUSTRALIA.

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April 1978.

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Contents

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INTRODUCTION

Geological work was undertaken on Gun Island, Murray Island and a number of offshore sites between Gun Island and the "Zeewijk" wreck site over a one-week period in April 1978, as part of a Western Australian Museum marine archaeology survey. Onshore work consisted of measuring rock and sediment sections in coastal cliffs, rock holes and archaeological excavations, examination of stone heaps, and assessment of sediment-fill in water-wells. Offshore work consisted of assessing sediment and substrate characteristics at surveyed localities approximately aligned along a 1600 m line extending leeward from the inner edge of the reef rim along the distribution trend of "Zeewijk" wreckage.

This report summarises field observations and some initial laboratory analyses arising from onshore and offshore operations.

ISLAND GEOMORPHOLOGY

Much of the upper surface of Gun Island was modified by guano mining in the late 19th Century when a layer of loose or friable material was largely removed to leave a hard limestone surface, with heaps and scatters of unwanted stone over the mined area and some adjoining areas. However, since Dutch ship-wreck survivors may have built stone heaps during their occupancy in the 18th century, precise identification of the origins of specific stone heaps is a problem of some interest. A nearby island, Murray Island, was not mined for guano, and its undisturbed surface may have some potential as an indication of likely conditions on Gun Island during the period of Dutch occupancy and as a source of information on some features of Gun Island which are of doubtful age or origin.

Gun Island

Gun Island now consists of a near flat-topped limestone platform a few metres above sealevel, delineated along its eastern and northern sides by cliffed coastlines and along its western and southwestern sides by a low sand ridge (5 m max. elevation). Detailed surveys recorded in an earlier expedition (Ingleman-Sundberg, 1977) indicate a slight topographic crest about 4-5 m above sealevel. This extends approximately N-S along the length of the island about 100 m inshore from the eastern cliff-line, with a crestal peak at mid-length. The limestone slopes gently from the crest, eastward to meet the coastline in cliffs 2-4 m high, and westwards as a more protracted slope to within 1 m. of sealevel along much of the western and southwestern coastline. Around the latter coastline, a narrow beach ribbon and supratidal sand ridge cover the limestone. A rock platform surrounds the island, with a distinct notch marking the passage of the limestone surface through the present intertidal zone.

The main geomorphic features of significance to this report are the limestone surface, the western sand ridge and the stone heaps.

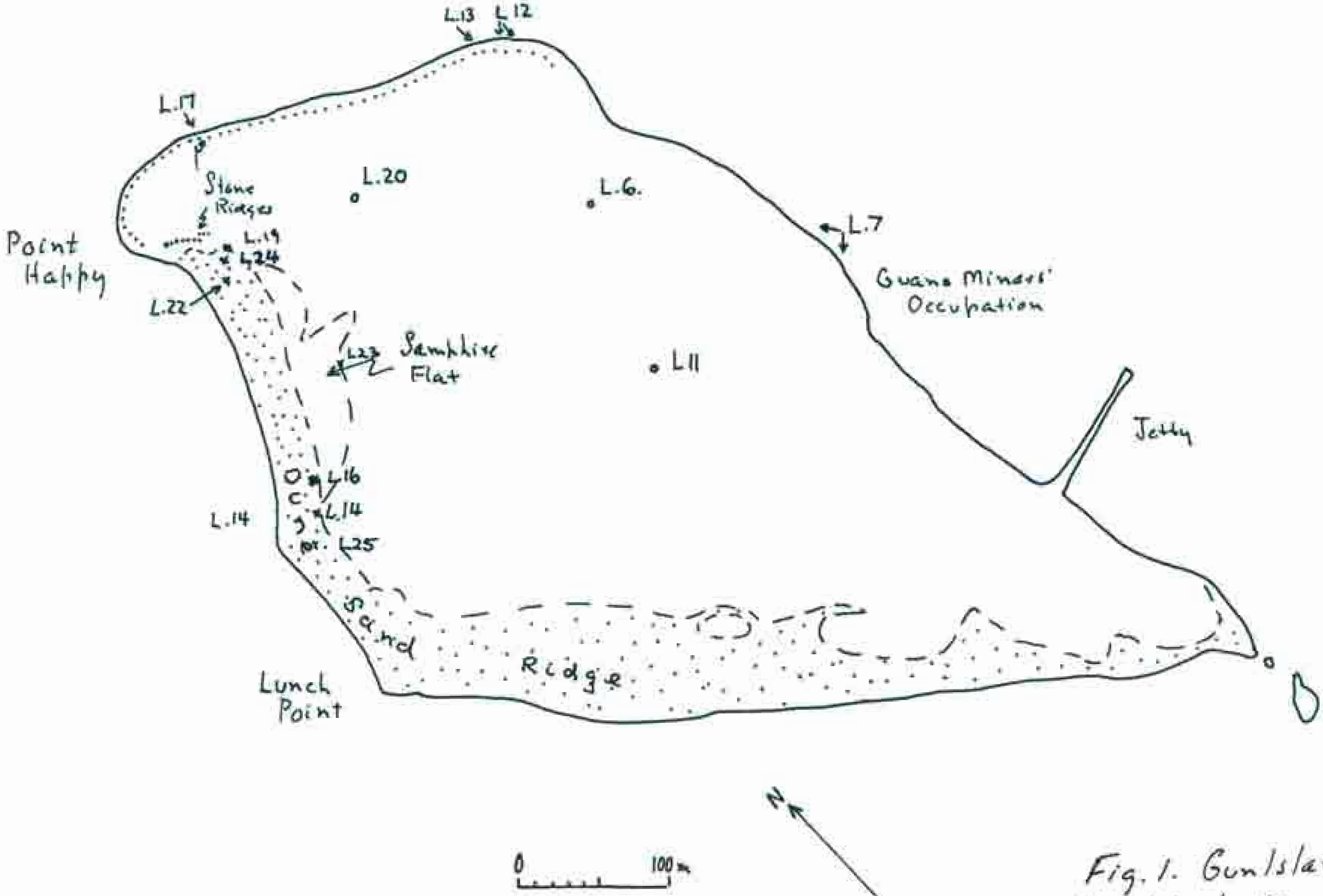


Fig. 1. Gun Island
Locality Index.
(After Ingleman-Sundberg, 1977)

Limestone Surface:

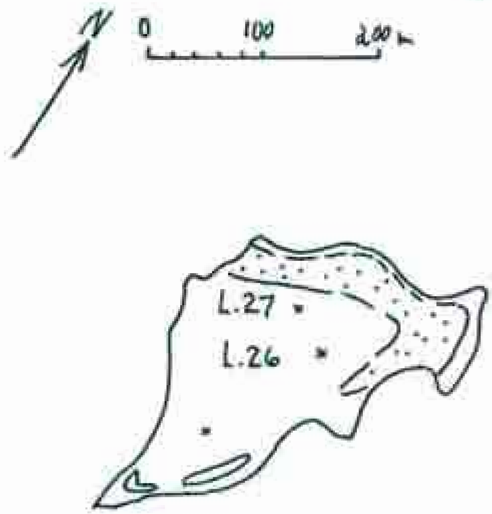
The limestone surface mainly consists of a very coherent, impervious rock with surface irregulariiies indicative of a an exhumed karst surface. Shallow solution-depressions are numerous, and about 20 of the more sharply defined and deeper depressions have been specifically identified as numbered "rock holes" by earlier workers (Ingleman-Sundberg, 1977). The deepest of these, rock hole 20 (at locality L20 in Fig. 1) has a proven depth of 4.1 m below the present surface and has served as a water-well for the various occupants of the island. The location and shapes of solution-depressions is in part controlled by fractures in the limestone, along which both rock holes and shallower depressions can extend over distances of several metres.

Stone Heaps:

Broken stone, usually as slabs ranging up to a metre across, was left as unwanted spoil littering the limestone surface of the mined area as isolated blocks, low heaps or infillings in depressions. Other stone heaps lie beyond the limits of mining and some of these possibly date back to the period of Dutch occupancy. A number of relatively small heaps lie within or near the edge of the western sand ridge and mainly consist of linear mounds 2-3 m wide, a few metres long and 1-2 m high. Near Point Happy, longer heaps are present - one is a U-shaped mound about 14 m around its axis which rises progressively to nearly 1 m high, and another forms a linear ridge about 25 m long. A near-continuous ridge of stone, mainly less than 1 m high, borders the northern cliff line for a distance of a few hundred metres, and other long ridges are found along the eastern cliff-top at locality L 7 of Fig. 1.

The composition and basement characteristics of these heaps will be discussed in a later section after description of the main rock types of the island has been presented.

Fig. 2.
Sketch Map of
Murray Island
(based on enlarged
aerial photograph).



Sand Ridge (Dune Ridge and Beach):

The sand ridge on the western and southwestern coastal belt consists of a narrow beach that partially covers the erosional notch in the limestone surface within the upper half of the intertidal zone, and a belt of supratidal sand up to 70 m wide that rises to a maximum elevation of about 5 m above sealevel. Parts of the ridge, particularly the higher and more inland parts, show typical hummocky profiles of coastal dunes, but much of the northerly sector shows a relatively smooth upper surface gently sloping inland. The internal stratigraphy discussed in a later section shows aqueous depositional processes are involved in the lowermost layers of the ridge, but the bulk of the mass is probably an aeolian accumulation and the term dune ridge is applicable. Nesting birds tunnel into the sand, generating a hummocky surface within a low scrub cover.

Murray Island

Murray Island is a limestone platform that appears to be more flat than Gun Island and at a slightly lower elevation. It is almost completely encircled by a 2-m high cliff line with an intertidal - shallow subtidal rock platform extending beyond the cliff base. A belt of gravelly sand around the northern tip of the island affords the most pronounced surface relief away from the cliff edge. Elsewhere, the island is a near-flat limestone surface lacking the stone heaps of Gun Island, and carrying a very low vegative cover.

Limestone Surface:

The limestone surface consists of a mosaic of metre-scale and decimetre-scale limestone slabs delineated by cross-cutting fractures and marked by shallow solution etching. A brown sandy soil infills elongate solution depressions a few cm deep that extend along some fracture lines, and narrow cylindrical depressions a few cm in diameter, or accumulates as extensive thin sheets across the limestone. Only two depressions, provide access below the island surface. The larger, at locality L28 of Fig. 2, consist of an opening 1-2 m across that contains nearly 30 cm of water at a depth of 80 cm below the ground level, with an underlying sediment fill that was cored to hard rock at a depth of 2.5 m below ground level (Figure 13). The second, at locality L27 some 40 m to the northwest of L26 , is a narrow, 60-cm diameter opening that contains damp sediment at a depth of 1.2 m below ground level. The sediment was probed to 2.2 m below ground level without encountering rock.

Sand Ridge:

A low ridge of sand and gravel extends around the northern coastline of the island as a continuous arcuate belt 20-40 m wide that rises 30-50 cm above the adjacent limestone surface (Fig. 2); the ridge extends down the eastern coastline as thin, discontinuous lenses. This ridge is significantly more coarse grained than the analogous ridge of Gun Island, containing an abundance of 1-2 cm sized skeletal gravel, mainly gastropod and mussel shell. The structure is largely forming as a storm-beach ridge rather than as an aeolian ridge. On the eastern side of the island, a small embayment with a sandy beach borders the ridge, and some aeolian sand sand accumulation is taking place. Elsewhere the ridge is separated from the cliff edge by an eroded rocky surface ranging up to a few metres wide. The upper surface is vegetated and burrowed in a manner comparable with the Gun Island dune ridge.

Summary

The basic form of the two islands is similar and the undisturbed surface of Murray Island affords a useful contrast with the mined surface of Gun Island. However, the extent of similarity between the Murray Island surface and the pre-mining surface of Gun Island is considerably lessened by differences in the sedimentation history of the two islands that will be discussed in the following sections.

STRATIGRAPHY

Rock Exposure on Gun Island is well developed across wide surface expanses in the mined area and in vertical profiles down to about sealevel in coastal cliffs and inland rock holes. Earlier work by Moncrieff (1977) had differentiated and mapped the limestone as two units, a "reef limestone" and a "shell Limestone". This report will utilise this differentiation and terminology, but with some modifications since further differentiation will facilitate discussion of the island's history and is relevant to problems such as the origin of stone heaps.

The stratigraphy of the island can be most readily assessed by progressively characterising stratigraphic units based on exposures within three general regions -

1. the coastal cliff-line of the northern and eastern sides;
2. the rock surface exposed in the central area;
3. the western coastal belt.

COASTAL CLIFF-LINE

The coastal cliffs of the northern and eastern coastline are limestones comprising Moncrieff's reef limestone. In places, the top of the section consists of limestone that lacks typical reefal characteristics and is separated from reefal limestone by a significant time break. This unit will be separately identified in this report as the "Upper Cliff Limestone". The underlying unit, comprising the greater part of the cliff section (Fig. 3), will be referred to as the "Reef Limestone", thus utilising the established nomenclature for the most significant part of the island core. In summary, the coastal cliff consists of the following units, listed from the top downwards:

Upper Cliff Limestone;	equivalent to the upper part of Moncrieff's "reef Limestone:;

Fig. 3 Generalised Cliff Section Northeastern Gun Island. L12-13

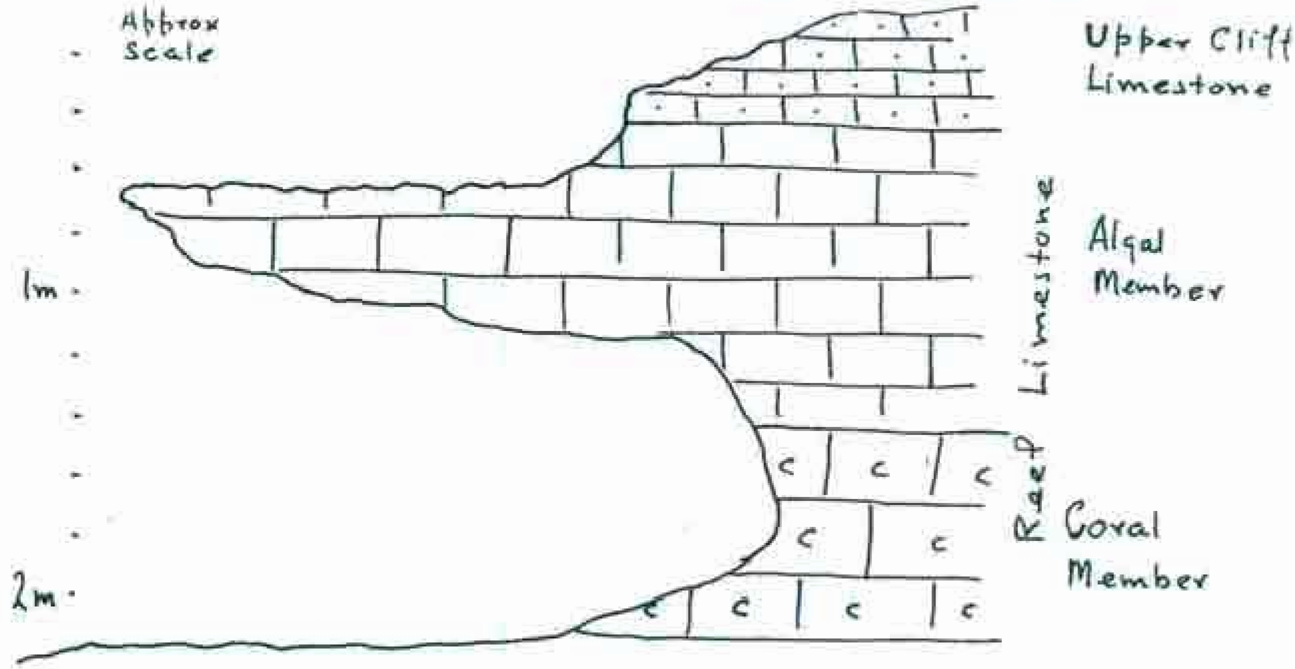


Fig. 4. Relationship Between Limestone Units in Rock Hole 6, L.11.

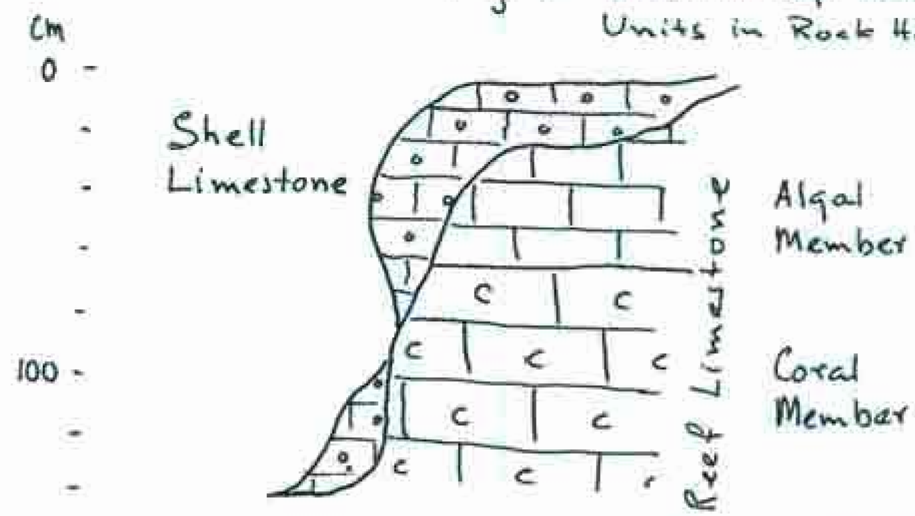
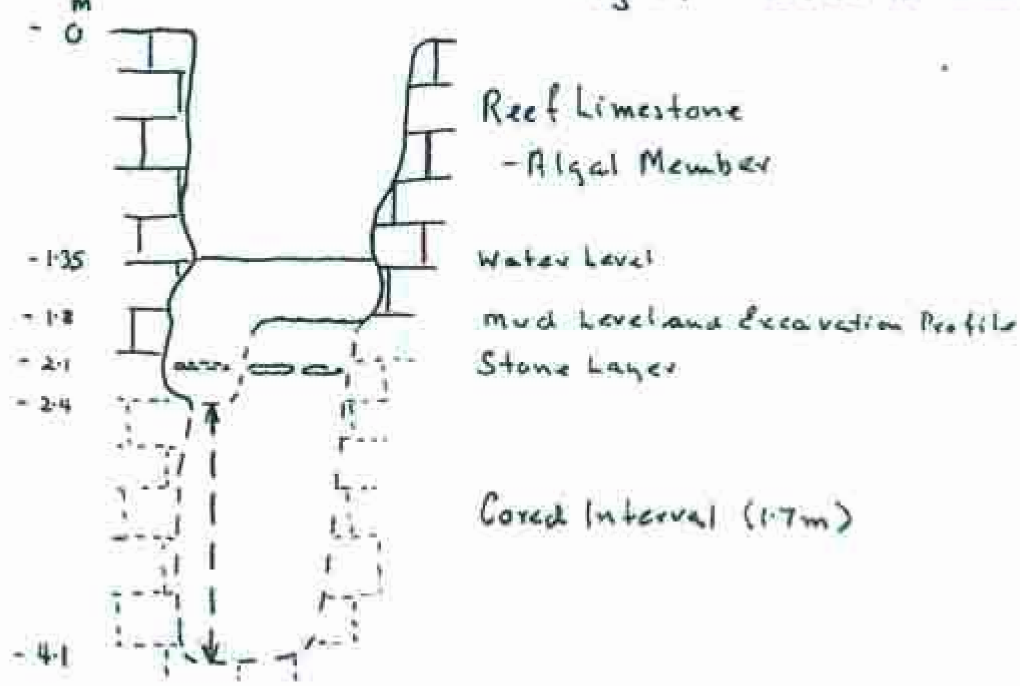


Fig. 5. Profile at Rock Hole 20, L



Reef Limestone:	equivalent to the lower part of Moncrieff's "reef limestone", and divisible into two sub-units:-
A. Algal Member	- the upper sub-unit,
B. Coral Member	- the lower sub-unit

The contact between the Coral and Algal Members appears to be conformable, i.e. marks a change in sediment type without a break in deposition. The contact between the Upper Cliff Limestone and the Algal Member is an unconformity, i.e., a major break in sedimentation occurred at this level.

The following sections summarise the lithological characteristics, stratigraphic relationships and depositional history of the coastal cliff units. Supplementary details are provided in Appendix A of the report.

Reef Limestone

The Reef Limestone constitutes the main framework of Gun Island, and it appears as the basement rock through many of the archaeological excavations. Its two sub-units are clearly developed in ordered sequence inland across the mined area, and less clearly in outcrops around the western and southwestern beaches. Equivalents of the two sub-units also comprise a major part of Murray Island (Fig.10).

1. Coral Member

Lithology:

The Coral Member of the Reef Limestone is a coarse-grained skeletal-fragment limestone that is moderately densely cemented, coherent and slightly porous. It is pale cream-coloured when fresh, weathering to light grey surfaces, and is massive or faintly mottled. Coral, coralline algae and molluscs are major coarse skeletal components.

Depositional Characteristics:

The field assessment of the rock (see Appendix A) suggests a very close similarity to sediments accumulating in shallow subtidal coral platforms subjected to minimal substrate movement.

2. Algal Member

Lithology:

The Algal Member of the Reef Limestone is a pale-cream coloured, very coherent limestone of densley cemented, fine-grained appearance, typically impervious and lacking a dominant fragmental character. It is mottled and irregularly laminated by coralline algal masses. Coralline algae are a major skeletal component, binding sand-sized (0.06-2mm) skeletal fragments and locally gravel-sized (> 2 mm) gastropod and pelecypod shell. Coral detritus is rare, but decimetre-scale heads and branched masses of coral extend up into the unit from below its base, or more rarely are completely enclosed within the Algal Member.

Depositional Characteristics:

The field assessment (see Appendix A) suggests a close similarity to the coralline-algal encrusted intertidal rim of the present reef terrain. Its dense, fine-grained appearance suggests a post-depositional phase of recrystallisation, possibly in association with subaerial weathering.

Contacts and Distribution:

Both members of the Reef Limestone are widely distributed across Gun Island, and their mutual contact is seen as a conformable contact in several rock-holes in addition to the coastal cliff exposures (details in Appendix A). The base of the Coral Member was not observed. The top of the Algal Member forms the present surface of the island across much of the mined area and is exposed in the coastal cliff line.

The exposed thicknesses of both the Coral and Algal Units vary. Maximum thickness of the Coral Member increases to nearly 2.5 m along the eastern cliff line, where the Algal Member develops a thickness of about 0.5 m. The Algal Member maintains a thickness of 0.5 - 1.2 m in rock holes across the centre of the mined area, where observed thickness of the Coral Member is limited to 0.5 m or less by the limits of exposure. Along the northern coastline and in rock hole 20 at the northern end of the mined area, the Algal Member increases to about 2 m thickness, and there is a corresponding decrease of Coral Member exposure to 0.5 m or less. Maximum observed thickness of the Coral Member, and conversely minimum thickness of the Algal Member, corresponds approximately with the crestal peak of the islands present topography.

Upper Cliff Limestone

The Upper Cliff Limestone is a clearly defined unit of fragmental limestone - usually a coarse calcarenite - forming the uppermost sediment unit in a restricted bank around the northern end of the island.

Lithology:

The Upper Cliff limestone is a dark-cream coloured, sometimes cross-stratified calcarenite or fine gravelstone with obvious fragmental fabric and porosity. Angular to rounded coralline algae and molluscan fragments are major components. Locally calcrete and limestone fragments are present as minor components.

Depositional Characteristics:

The field assessment of this sediment type suggests deposition of wave- and current- worked skeletal detritus as a thin sheet above a rock surface.

Contacts and Relationships:

The upper limits of the unit are the present island surface around the outcrop area which extends along the northern liff line and about 200 m southward along the east coast. The lower contact delineates the top of the Reef Limestone, where it is marked by a sharp break at an elevation of about 2 m above sealevel, commonly above the cliff visor, (Fig.3). In places the contact is marked by a thin layer of laminated calcrete, but it is occasionally revealed as a smoothly planated surface truncating skeletal frame and grains in the underlying limestone unit, suggesting erosion of a well indurated basement prior to sand deposition. The thickness of the unit varies according to erosion of its upper surface, but observed thickness ranges to 0.6 m.

Inland from the coastline, this sediment unit can be traced for a few metres towards the limits of the mined area. Beyond this, the following sediment types are characteristically found unconformably overlying the Reef Limestone.

CENTRAL REGION

The mined area of the central region shows that the typical limestones of the Reef Limestone members extend inland to become patchily covered by skeletal limestones that are coarser grained than the Upper Cliff Limestone and are extensively phosphatised. This cover appears to be a remnant of a formerly extensive unit that was largely removed by guano mining, and which appears as a component in some stone heaps. The unit was termed the "shell limestone" by Moncrieff (1977), and this term will be retained in the present summary report largely in the sense of the original usage.

Shell Limestone

The Shell Limestone is regarded as consisting of coarse skeletal limestone together with a wide range of alteration products that appear to be related to phosphatisation of this coarse limestone. These latter include phosphate-cemented limestone, phosphate rock with scattered skeletal fragments and phosphate rock lacking obvious calcareous components. (Thus, the stratigraphic term is used in a wider sense than a straight lithological description; this is normal usage and applies to the other units described, but to a less strikingly obvious extent).

Lithology:

The unit's primary lithology is a grey to brown coloured skeletal fragment limestone, with gravel- and sand-sized coral, coralline algae and molluscan species components similar to those of the Coral Member of the Reef Limestone. However, the Shell Limestone is more obviously fragmental in appearance, partly because of a lower content of lime-mud between the larger grains, and partly by accentuation of grain outlines by dark phosphatic cements. The unaltered limestone locally grades to moderately sorted sand and fine gravel with some grain rounding, and rarely it shows stratification.

Phosphatised derivations of the limestone range from limestone with obviously delineated skeletal grains infilled and partly replaced by brown, fine grained phosphates, to brown phosphate rock, composed of a fine porcellanous material riddled with mm-scale tubular voids and occasional larger cavities.

Depositional Characteristics:

The Shell Limestone has textural and biotic characteristics suggesting deposition of coral-reef or coral-platform derived detritus under conditions involving a moderate degree of sorting and transportation. The unit lacks *in situ* skeletal frame networks, and its relationship with the underlying surface (Fig. 4) suggests deposition across a highly irregular rock surface, possibly kept clean of encrusting calcareous organisms by water and sediment movement. However, the incomplete nature of the unit as preserved may be misleading in this last respect.

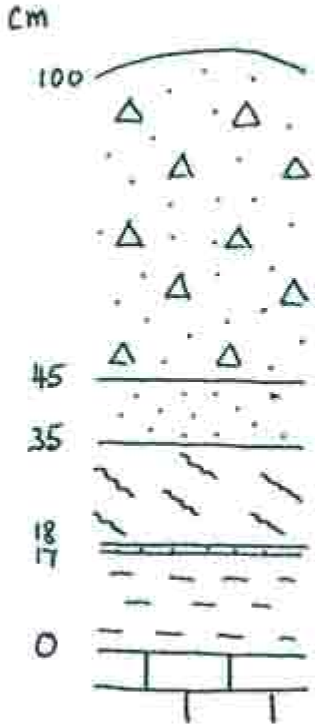
Contacts and Distribution:

The Shell Limestone occurs patchily across much of the mined area as a surface veneer on the Reef Limestone - mainly on the Algal Member, but in some of the deeper rock holes in contact with the Coral Member (See Fig. 4). Its base clearly marks an unconformity, sharply delineating a markedly irregular surface. The presently preserved thickness is commonly limited to a few cm, but outcrop configuration around rock holes (Fig. 4) suggests it probably infilled these structures, thus locally achieving a thickness of 1-2 m or more. Extent of the unit over the present topographic crest is uncertain, but it is possible that the unit may not have been developed across the higher parts of the crest. No direct relationship could be established with the Upper Cliff Unit, but it is likely that the two units are stratigraphic equivalents (see Appendix A).

WESTERN COASTAL REGION

The western coastal region shows a further continuation of the Reef Limestone downslope to become covered by a range of less strongly indurated sediment. Its former cover has been removed except in a small area of samphire flat, in the coastal dune belt and in isolated areas now buried beneath stone heaps. Excavations in these areas revealed sediments that are best considered in terms of specific lithological sequences (figs 6-8) before establishing a generalised stratigraphic correlation in this area. For the purposes of this report, only one stratigraphic unit need be characterised in this area. Unlithified sediments can be sufficiently recognised on the basis of their local characterisation.

Fig. 6. Locality L14.



Heaped stone and soil

Brown Earthy Sand

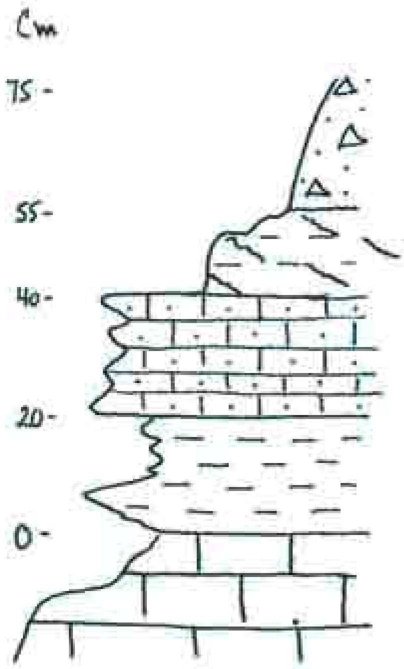
Brown Phosphate Rock

Brown Earthy Sand

Soft White Clay

Dense Limestone

Fig. 7. Locality L.24



Heaped Stone and Soil

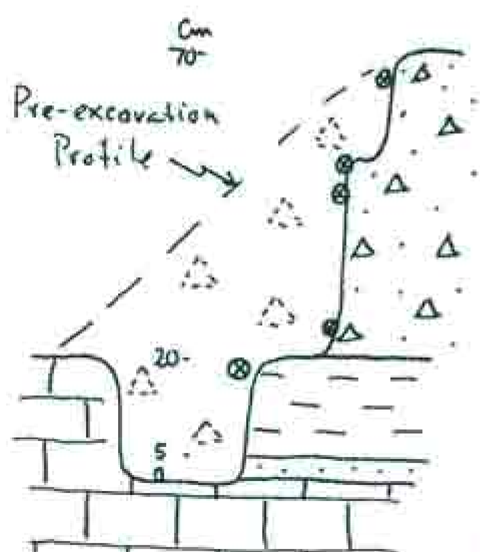
Blocky Brown Phosphate Rock

Brown Shelly Calcarenite

Soft White Clay

Dense Limestone

Fig. 8. Locality L.16



⊗ Glass/Pottery Fragments

Heaped Stone and Soil

Soft White Clay

Brown Earthy Sand

Dense Limestone.

Modern Beach Sediments

Beach sediments form a virtually continuous thin ribbon above the Reef Limestone extending upslope from about mid-tide level to the foot of the dune ridge, but the cover is thin and limestone frequently protrudes through to the surface.

Lithology:

Beach sediments are skeletal-fragment sands and gravels with only a minor content of limestone fragments. They show a progressive fining southwards from Point Happy that suggests a decreasing onshore impact of wave energy in that direction. Near Point Happy the sediment is a sandy gravel with abundant 2-4 cm sized fragments of gastropod tests and opercula, coral, coralline-algal nodules and calacareous worm tubes, along with 5-8 cm sized limestone clasts. Gastropods include species of Subninella. Tectus Bellastrea, Melo, vermetid and pattellid forms consistent with derivation from shallow subtidal and intertidal rocky substrates. Sand becomes increasingly predominant southwards as gravel becomes restricted to strand-line concentrates of smaller (1-2 cm) and thinner skeletal fragments, chiefly coralline algae, echinoid fragments, patellid shells and other thin walled gastropod remains.

Coastal Dune Sediments

The coastal dune belt sediments are predominantly sand-sized skeletal debris with only a minor gravel content. An archaeological excavation at locality L25 of Fig. 1 (site 1559/10 of the W.A. Museum 1978 survey) showed a complete vertical profile through the dune revealing a thin layer of skeletal gravel at the base.

Lithology:

Figure 9 summarises the vertical section, which lacks induration through its full extent. Remnants of stratification are present in spite of extensive plant-root disturbance and burrowing by nesting birds. Effects of the latter are probably responsible for a 3-4 cm thick concentration of charcoal and skeletal gravel at a depth of about 50 cm below the surface at this site, and possibly contribute to the distribution of artifacts relating to the Dutch occupation through the upper half of the section.

The base of the section consists of a 10-15 cm layer of gravelly sand resting on mottled red and white clayey soil. The basal layer contains 40% by weight skeletal gravel, 2-20 cm in size, that consists predominantly of discoid Marginopora-like foraminifers and thin-walled pelecypod and gastropod fragments. Similar skeletal gravel is scattered as a minor component through the overlying 50 cm of sand and as slight concentrations delineating 1-2 cm thick stratification towards the top of that interval.

Grain-size determinations carried out by dry sieving of samples from depths 10, 50 and 90 cm below the surface show a consistent pattern of good sorting, with a pronounced modal size in the medium sand class (0.25-0.5 mm), represented by almost 50% of the sample weight in each case.

Depositional Characteristics:

The dune section represents a short interval of marine gravel deposition on a pre-existing soil surface, followed by sand deposition that was probably an aeolian process. In the lower half of the interval, short periods of stronger marine influence were likely. Specific intervals reflecting the initial impact of Dutch occupancy or mining operations on the island are not obviously developed.

Fig. 9. Dune Section at L.25 (1559/10)

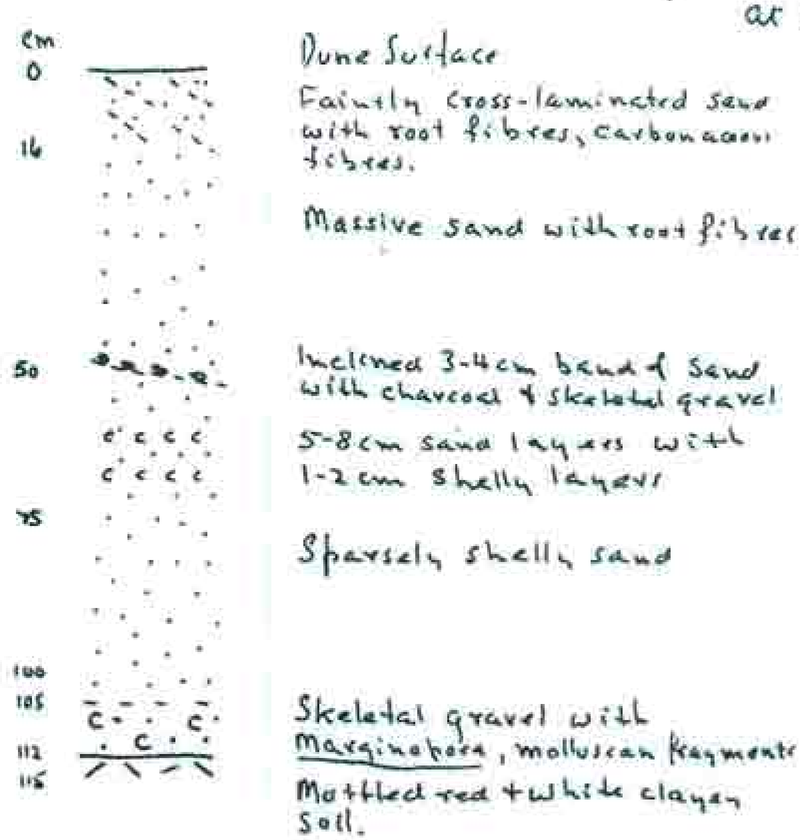


Fig. 10. Cliff Section Northern Murray Id.

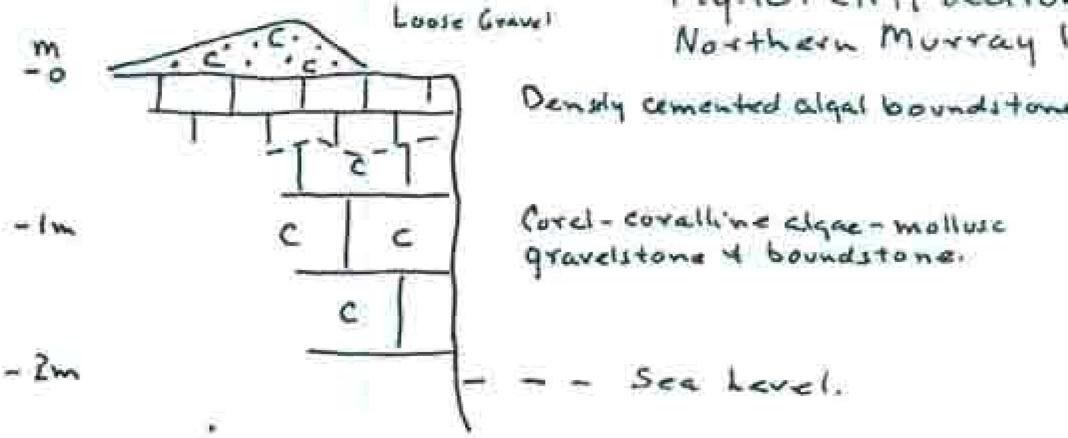


Fig. 11. Summary of Stratigraphic Units Gun Island.

HOLOCENE MARINE AND DUNE SEQUENCE

— ? — ? Unconformity — ? —

WESTERN CALCARENITE

— — Unconformity — — —

UPPER CLIFF LIMESTONE AND SHELL LIMESTONE

— — Unconformity — — —

REEF LIMESTONE < ALGAL MEMBER / CORAL MEMBER

Samphire Flat Sediment.

The samphire flat adjacent to the inner dune edge along the north-western side of the mined area shows a 30-cm thick layer of damp, puggy white clay above dense limestone at locality L23 of Fig. 1. The clay is cut by abundant tubular cavities and peaty fibres apparently generated by roots of the halophytic plant cover. The clay is non-reactive with dilute hydrochloric acid (hence is not lime-mud) and is of undetermined composition - possibly gypsiferous or phospatic. Similar material occurs in nearby excavations, and in the water-well sequence of rock-hole 20.

Stone-Heap Basement Sediments.

Sedimentary sequences have been preserved from later disruption by burial beneath stone heaps in the western coastal area close to the inner dune margin between Lunch Point and Happy Point. Three such sequences summarised in Figs. 6-8 show a relationship of sediment types that is suggestive of an ordered sequence that apparently relating to the samphire flat and possibly also to the coastal dune belt. The principle sediment types involved are sandy soil, phosphate rock, white clay, semi-consolidated limestone and densely cemented limestone.

Lithologies:

Sandy Soil:

A loose admixture of predominately medium to fine sand with fine gravel and silty and clayey matter that imparts a brown colouration similar to that of guano rock.

Phosphate Rock:

A deep brown pocellaneous to earthy, grading to pale brown or white earthy, coherent rock riddled by cylindrical to irregular cavities commonly about 1 mm in diameter but ranging up to several mm wide. It often contains a sparse scattering of thin Marginopora-like formanifers and thin patellid gastropod tests ranging up to about 1 cm in size, together with a few % smaller coiled gastropod tests and other sand-sized skeletal fragments.

White Clay:

Massive white clay lacking the tubular voids and peat content of the samphire flat clay, but otherwise similar. The clay grades from puggy when damp to crumbly when dry.

Semi-consolidated Limestone:

A range of brownish-coloured skeletal sands and gravels that are characteristically very porous and generally can be readily disaggregated by hammering. Further details are outlined below and in Appendix A.

Densely Cemented Limestone:

Very coherent, generally impervious limestones that can be ascribed to one of the members of the Reef Limestone in most cases.

Sequential Development:

Dense limestone of the Reef Limestone unit constitute a basement to subsequent depositional episodes in this region. The next oldest sediment represented in these sections is probably the white clay, with the possibility of an intervening soil layer suggested at locality L16 (Fig. 8). At L14, phosphate rock overlies the white clay (Fig. 6), while at L24, brown shelly calcarenite intervenes between white clay and phosphate rock (Fig. 7). Comparison of the textural and fossil characteristics suggests that the semi-consolidated limestone and the phosphate rock are representatives of a single unit. This unit, defined below as the "Western Calcarenite", is a major component of stone heaps. It appears to have been a widespread unit that was variably phosphatised and once formed the upper surface of the western region inland from the dune ridge, with which it has some similarities.

Western Calacarenite

The Western Calacarenite is a lithologically variable unit now rarely exposed that represents a major phosphate host-rock in western Gun Island.

Lithology:

The unit is brown to orange-brown or rarely whitish in colour, but it alters to grey on weathered surfaces. It is porous and ranges from semi-coherent to coherent, but is usually friable and readily disaggregated by hammer blows. Sand-sized skeletal fragments are the major component, and these are commonly sorted to form fine, medium and coarse grained calacrenites in which gravel-sized skeletal elements, almost exclusively less than 1 cm in size are widespread as a minor component. Stratification is faintly to strongly developed on mm- and cm- scales by textural variation of calcarenite and formation of gravel-rich beds.

Skeletal elements of sand-size are not readily recognised, but the gravel-sized components indicate a restricted range of dominant elements. Marginopora-like formanifers, thin patellid gastropods and small coiled gastropods are abundant, with rare coralline-algal, pelecypod and robust gastropod fragments.

Depositional Characteristics:

The Western Calcarenite shows lithological and fossil characteristics indicative of a near-littoral depositional site, possibly a beach, to which only a limited range of coarse detritus was available. The non-crustose epibiotic character of the recognised forms suggests a lower-energy and/or more selective depositional regime than the present beach-face and adjacent sub-tidal zones of Gun Island.

MURRAY ISLAND

The stratigraphy of Murray Island is relatively more simple than that of Gun Island. Both members of the Reef Limestone unit are represented, Fig.10 , but these have been overlain only by Holocene sand-gravel deposits, and extensive units of intervening age are not present.

GEOLOGICAL HISTORY

The geological history of Gun Island is summarised in conjunction with the stratigraphic table of Fig. 11. The island was initiated as a reefal mound, probably during one of the high sealevel periods of mid-Pleistocene age; it shows a progressive build up of the Reef Limestone through an initial coral-dominated phase to a coralline-algal dominated phase. A period of emergence followed, with development of a karst surface marked by extensive solution effects . A second Pleistocene marine transgression left reef-derived detritus filling surface irregularities and generated the Shell Limestone and probably the Upper Cliff Limestone. Again emergence followed; subaerial modification produced some calcrete development on the Upper Cliff Limestone. Deposition of the Western Calcarenite marks a third marine episode that was probably less extensive than the two previous transgressions. Phosphatisation of the Shell Limestone probably occurred during this time, although it may have been initiated at an earlier stage, and once initiated was probably a more or less continuous process. The basal marine layer of the dune belt indicates a Holocene transgression beyond the present strandline. Whether this is equivalent to the Western Calcarenite transgression is not clearly indicated, but the contrast in degree of alteration slightly favours a pre-Holocene age for the Western Calcarenite.

STONE HEAPS

Mined Area

The broken stone heaped and scattered on the mined area consists almost exclusively of angular, dense limestone pieces, some up to nearly 1 metre long but more usually 10-15 cm long, that are derived from the Algal and Coral Members of the Reef Limestone unit. Many carry plasterings of phosphatic material apparently related to the Shell Limestone unit, and a few are densely cemented masses of the latter unit. These, together with similarly composed heaps peripheral to the mined area are remnants of the guano mining operations.

Cliff-Top Ridges

A virtually continuous ridge of stone up to 1m high and 2-3 m wide at its base runs along the northern cliff edge and part way down the eastern cliff edge. The composition of this ridge was not fully assessed in terms of stratigraphic-unit lithologies, but spot-observations and photographs suggest that it consists largely of porous limestone lithologies with an admixture of densely cemented limestones, often as large pieces apparently derived as mining spoil. The ridge is commonly set back a few metres from the cliff edge, with an intervening surface of very irregularly eroded limestone. It is likely that this ridge may in part represent a naturally formed boulder mound associated with marine erosion of the upper cliff surface; its upper surface appears to have been the locale of spoil-deposition during mining operations.

A discontinuous line of lower and narrower ridges along the cliff top adjacent to the former guano diggers' occupation site midway along the east coast may represent protective walls between the former guano diggers' occupation site and the cliff edge. One of these ridges is cut by a fissure delineating a collapsed cliff-top visor suggesting that some visor collapse has post-dated this structure.

Point Happy Rock Wall

A linear stone heap about 25 m long at Point Happy consists of brown-coloured phosphate rock and phosphatised limestone. Sampled lithologies represented in the less phosphatised limestones are obviously-fragmental, coarse calcarenites and gravelly calcarenite with robust turbinid gastropod shells and opercula ranging up to several cm in size. They lack large coral and coralline algal fragments, but are coarser in grain size than the typical Western Calcarenite lithologies, and appear more similar to the Shell Limestone lithologies.

U-Shaped Rubble Mound

At Locality L22, near Point Happy, a U-shaped rubbly stone heap with limbs 4-5 m long encloses a 1.5 m-wide area opening westwards. The continuous ridge rises progressively from a 0.5 m elevation on the northern arm to 0.08 m elevation on the southern limp, while its basal width increases from 1.5 m in the northern limb to 3 m in the southern limb.

The ridge is entirely composed of pale grey-coloured stone up to 30 cm in size, that is semi-consolidated and breaks readily to reveal an orange-brown interior. Lithologies sampled at this site are well-sorted medium, rarely coarse, grained calcarenite with varying contents of 2-10 mm sized skeletal gravel. One fragment contains about 50% of 2-5 cm sized small gastropods, and another a single large turbinid gastropod 5cm across, but in each case well-sorted medium calcarenite is present as the interstitial material. The lithologies represented here are most like those of the Western Calcarenite.

Linear Rubble Mounds

A number of stone heaps along the eastern side of the dune belt around localities L.14 to L.16 of Fig. 1 have been grouped (for convenience of discussion) under this heading. They are generally a few metres long, 2-3 m wide and 0.5-1 m high, are surfaced mainly by grey porous stone up to 30-40 cm size, and they show a rubbly interior of admixed stone, soil and disaggregating rock.

L.14:

A group of 3 mounds are located a few metres east of the 1265 m N survey peg within the low scrub-cover of the dune belt. Two of these, show surface stone consisting of phosphatised calcarenite and rock phosphate. The third shows these two lithologies together with dense limestone. Excavation of this mound revealed the section shown: Fig. 6. Fragments of rock phosphate, phosphatised calcarenite and dense limestone 10-30 cm in size were admixed with brown sandy soil and white-clay. Six flat-slabs of dense limestone, the largest measuring 80 x 60 x 20 cm, were enclosed within the heap, but in no obviously apparent array.

L.16:

A 4 m x 3 m x 0.5 m mound lies N-S along the eastern edge of the dune belt 8 m E of the 1295 m N survey peg. The mound consists of phosphate rock, phophatised calcarenite and dense limestone (some phosphate-coated) fragments, admixed with a sandy interstitial fill. An excavation made at the southern end showed glass and pottery fragments of the Dutch occupation period scattered through the full vertical section of the mound, which rests on white clay above dense limestone (Fig. 8).

Origin:

The predominating lithologies - phosphatised calcarenite and phosphate rock - are closely comparable with the Western Calcarenite, strongly suggesting a local origin for most of the rubble material from a unit that was probably developed on or close to the pre-mining surface. The dense limestone that appears prominently in two of the mounds is closely comparable with the Reef Limestone. Although this unit occurs locally in the subsurface, it was probably less readily available in the immediate vicinity of the mounds without deliberate excavation.

Two likely explanations should be considered for those mounds lacking a significant content of dense limestone-

1. They are structures of the Dutch occupation built from the most readily available material; or

2. They are selectively dumped products of guano mining, possibly stock-piles of marginally valuable or potentially useful phosphate ore.

The presence of a significant content of dense limestone probably increases the likelihood that a mound is related to guano mining, suggesting an origin as a spoil heap. It certainly rules out the possibility that a mound is a stock-pile of useable phosphate. In the case of one mound at L.14, the presence of large limestone slabs raises the possibility of deliberate transportation and incorporation of dense coherent rock slabs to enhance a structural-supporting role for that mound.

Summary

The Stone heaps considered to hold most potential as possible remains of the Dutch occupation are those consisting of a major proportion of semi-coherent phosphatic rocks. Although these materials have low cohesion and limited compressive-strength characteristics, consideration of the likely pre-mining morphology of the island through comparison with Gun Island and "stratigraphic reconstruction" suggest the phosphatic rocks were probably the most readily accessible material that could be easily obtained as existing loose stone or by working. However, a feasible origin as stock-piled mining derivatives is a likely possibility, and the shape characteristics of most such mounds does tend to support this origin. Hence it must be considered that unless there are unusual shape characteristics or unusual internal characteristics the probability of a relation to the mining period must be considered the more likely proposition. The only exceptional cases examined in this study are the U-shaped rubble mound at L22 and the rubble mound containing limestone slabs at L14; both appear to have been of more positive functional significance, but neither can be firmly ascribed to either the Dutch occupation period or the mining period.

WATER WELL SEDIMENTS

The possibility of recovering relics of the Dutch occupation from sediment in the water well of Gun Island lead to partial excavation of the well at L.20. Exposure of a rock-slab floor at 30 cm below the mud surface (Fig. 12) raised the question of whether that level marked the base of a Dutch excavation or of a miners' excavation. A core was sunk into the base of the present excavation showing a mud sequence that extended to a depth of 2.3 m below the present mud surface. In order to establish whether or not the sequence is a local pecularity of Gun Island, a core was taken in the eastern well of Murray Island (at L.26, Fig. 2).

The Murray Island core (Fig. 13) showed a sequence of 1.4 m of dark muds similar to those of Gun Island, with a basal peat layer on hard rock. However, the prominent white clay layer was not developed.

Age of the Sequence:

The presence of a prominent white clay layer in the Gun Island well suggests four distinct possibilities, three of which involve a detrital origin:-

1. The clay reflects guano-mining operations and hence post-dates the Dutch occupation;

2. The clay may reflect mobilization of the island surface as a result of the Dutch occupation;

3. The clay is an indication of an earlier mobilization of the island surface by natural causes, such as climate change or onset of marine influences on the island vegetation during the Holocene transgression.

Fig. 12. Well Section L20, Gun Island.

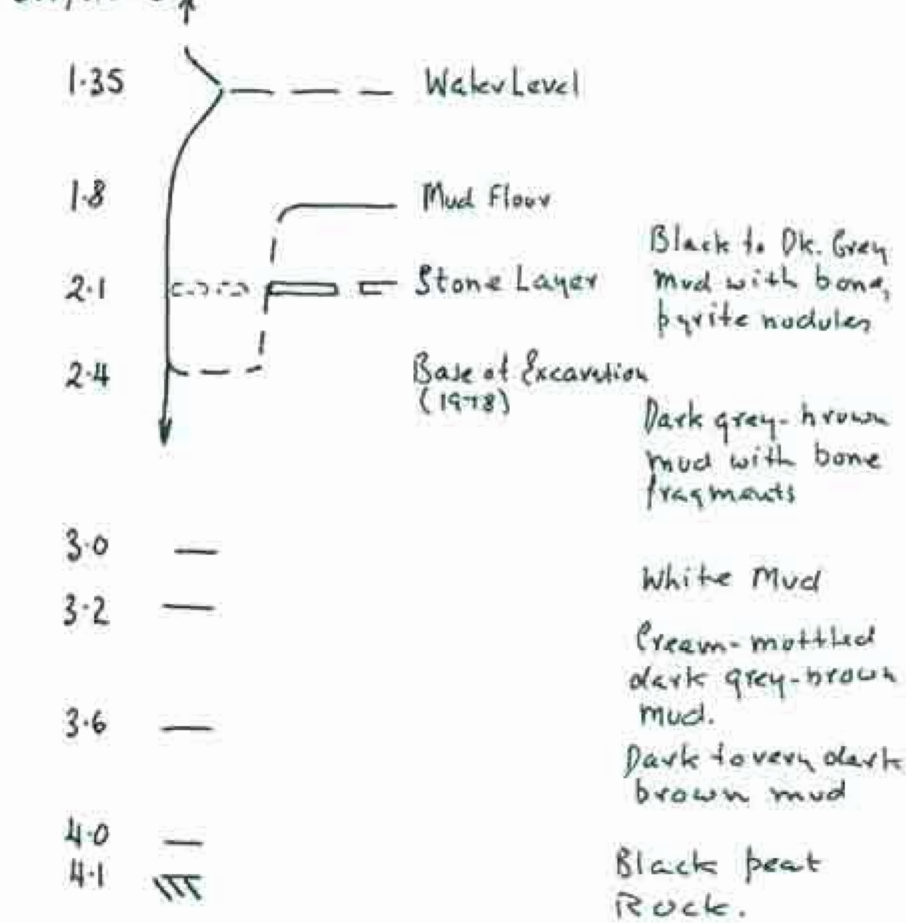
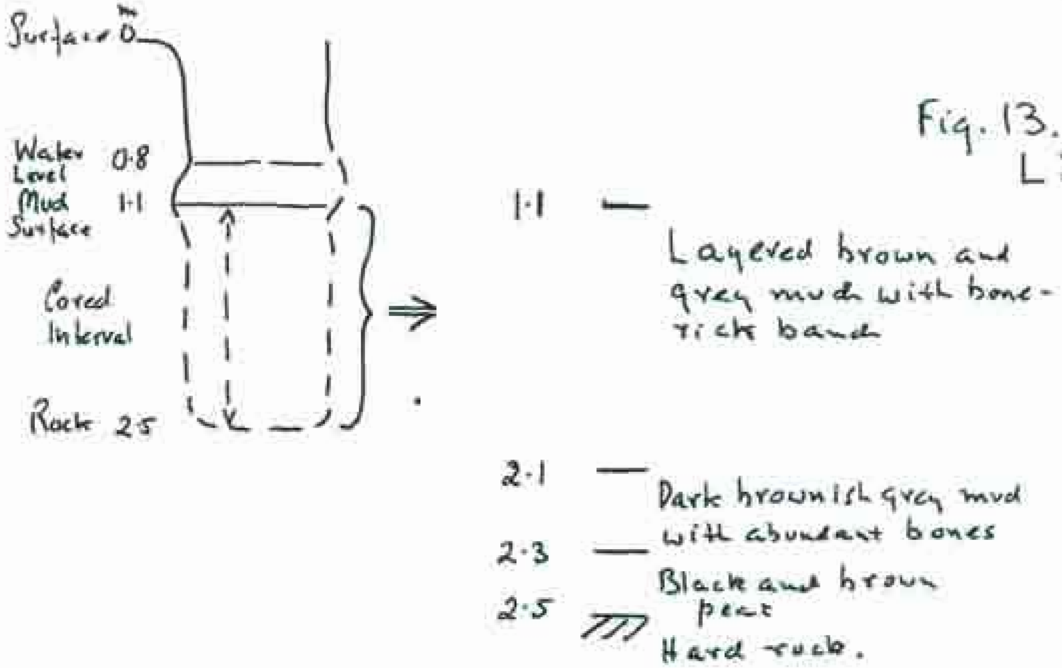


Fig. 13. Well Section, L26, Murray Is



4. The clay is not detritus washed in from shore, but was chemically precipitated during a period possibily represented elsewhere by the white mud of the samphire flat.

Unfortunately, the well at Murray Island does little to resolve these possibilities, and some further analysis of the well sediment is required to establish the age of the sequence.

OFFSHORE SEDIMENTOLOGY

Aspects of the offshore sediments will be summarised within a generalised bathymetric and biotic zonation involving the reef rim and a back-reef slope. Descriptions of specific localities are included in Appendix B. A transect eastwards from the crest of the reef rim shows a flat crest close to water level, passing across a moderate, smooth slope down to a depth of about 50 cm, where a steep slope or vertical rock face delineating a sharp drop of about 40 cm is taken as the leeward edge of the reef rim. Beyond this the surface slopes downwards as a long, gentle back-reef slope, progressively developing a cover of coral heads in depths of 1-1.5 m over a width of 20-50 m. Beyond the coral, gravelly sands and sands extend across the remainder of the reef platform towards Gun Island.

Reef Rim

Substrate:

The reef rim is underlain by coral-rock subjected to intensive boring, and extensive encrustation by coralline algae and possibly other calcareous organisms. The surface is highly irregular on a small-scale, pock-marked by cavities usually a few centimetres in depth and width that can become more subdued by epiphytic algae (calcareous algae or dense covers of short-leafed and filamentous algae that bind-down a thin layer of sand).

Biogenic Influences:

A wide range of boring organisms internally modify the reef-rock lithology, while numerous echinoderms lodged in crevices appear to be in part responsible for the surface irregularities. Coralline algae are a major contributor of sediment, encrusting all bare hard surfaces including some of the living skeletal-bearing organisms. Corals are very sparse and restricted to thinly crustose sheets. Large gastropods, mainly a *Tectus*-like species, are numerous. Non-calcareous algae form a dense carpet, particularly up on the rim crest, binding a thin veneer of sand to the surface.

Sediment Character:

The contemporary sediment of much of this zone is algal boundstone resting directly on coral rock. Within depressions gravels of skeletal detritus and small quantities of reef-rock are locally concentrated with some potential for being encrusted into the rock mass.

Hydrodynamic Influences:

The reef rim is exposed to intensive water movement that is virtually continuous and unidirectional, interspersed with strong surges as wave bores pass across the reef.

Back-Reef Slope

In the immediate vicinity of the reef rim, the back-reef slope shows a pronounced zonation, with a 20-50 m wide band of coral growth across the transition from the reef rim to the sand surface that is most typical of the greater part of the slope. Small patch reefs exert a local control on sediment character.

1. Coral Zone

Substrate:

At the base of the reef rim, bare rock surface is progressively covered by coral heads, but patches of bare surface may extend across areas several metres wide along the coral edge or within the coral. The coral forms heads generally rising 10-20 cm high as discoid and delicately branched forms. Between the heads and in the larger bare rock patches, the rock surface is similar in character to the rim-surface, but away from the rim it progressively develops an increasing cover of gravel and sand, and supports an increasing cover of brown algae.

Biogenic Influences:

Corals predominate the skeletal-producing biota, with mainly discoid forms nearer the reef edge; longer-branched forms are present and locally become dominant with increasing distance from the reef rim and in association with an increasingly sandy substrate (see Appendix B). Coralline algae encrust rocky and other hard substrate, and commonly develop upstanding nodular forms. Gastropods and echinoids are numerous. Boring organisms are active in rock and dead skeletal carbonate.

Sediment Lithology:

Sediment characteristics in the coral zone are variable, ranging from living coral and algal frame-production with minimal detrital contribution around star picket 13, to a combined frame-production and sand-deposition at star picket 10. This range possibly reflects a combination of hydrodynamic influences and detritus-supply rate that would have to be sought outside the coral zone.

Hydrodynamic Influence:

The establishment of coral probably reflects a decrease in intensity of water movement relative to the reef rim, and within the coral zone a continuation of that trend is suggested by the progressive change in coral-growth form seen at star picket 10, see Appendix B.

2. Sand Surface

The sand surface of the back-reef slope shows a generalised trend in several characteristics that are consistent with a decreasing hydrodynamic influence on the substrate with increasing depth and distance from the reef.

Substrate Character:

Close to the reef, the sand surface is very much shaped by local factors, and reflects deposition of a restricted range of materials that may start within the partially

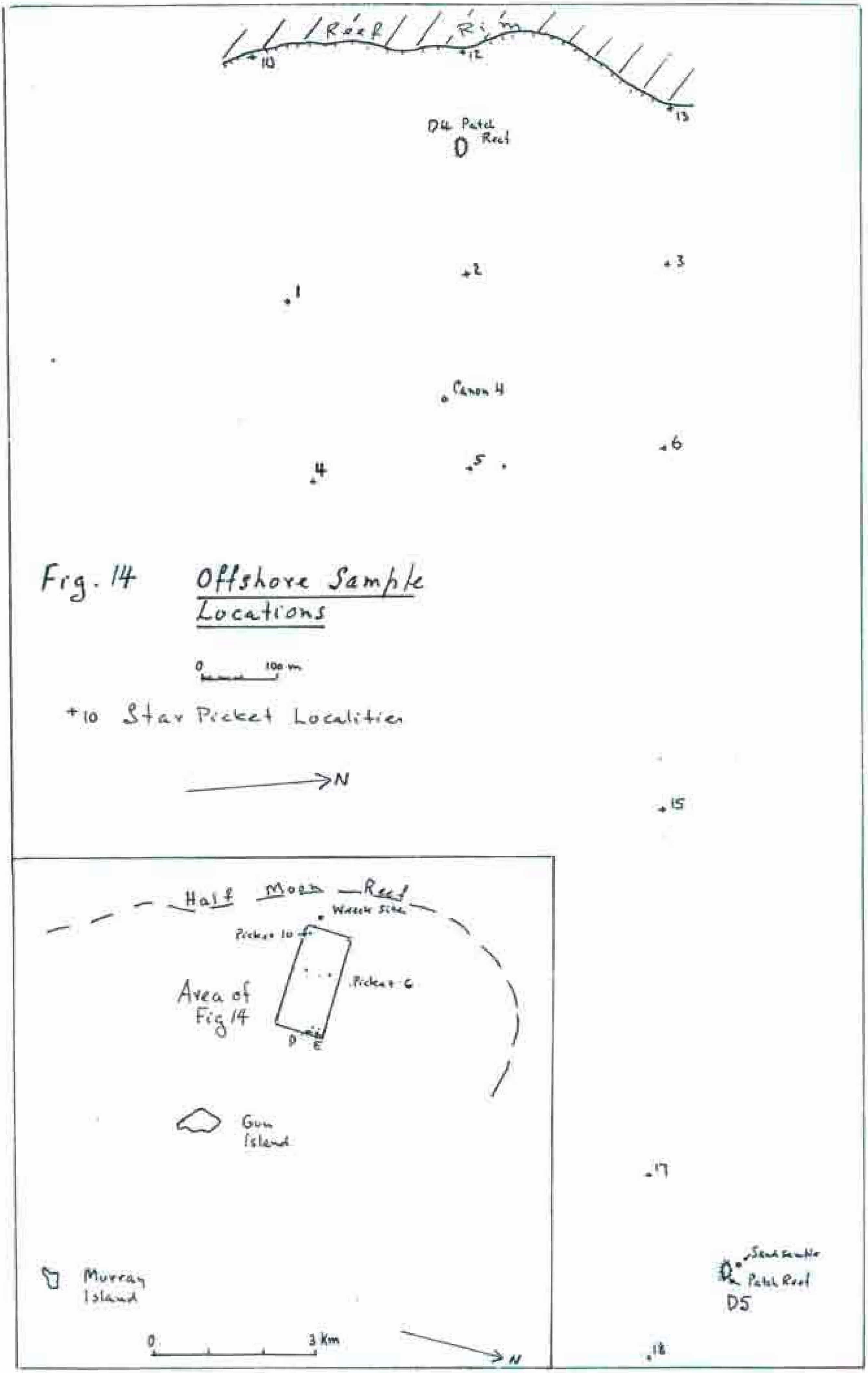


Fig. 14 Offshore Sample Locations

protected substrate of the coral zone. Beyond the coral zone, the sand surface is virtually continuous, with varying admixtures of coarser coral debris. A surface scatter of 5-20 cm long coral sticks appears to be most densely concentrated closer to the reef at star picket 1 and canon 4, see Appendix B; the scatter becomes sparse to the northeast at star pickets 6, 15 and 17. This change is accompanied by a change in the nature of surface structures, with large-scale ridges and shallow scours in the more reefward localities, and smoother surfaces marked by small-scale ripples to the NE, see Appendix B. The surface sand layer overlies gravel or a coral-frame network at shallow depth (about 5 cm in many localities, see Appendix B).

Sediment Characteristics:

Sediment samples collected for size-analysis consist of relatively small (1 kg or less) spot samples that are unlikely to show quantitatively the trends in content of larger coral pieces a few cm or more in length. However, they are representative of any textural trends in grain components less than 5 cm in size. Gravel content is patchy rather than trend-related, with an overall slight decrease (7% to 3%) along the line of star pickets 10, 1 and 4, but higher values of 17% and 23% are encountered at the sites of canon 4 and the patch reef north of star pickets 17 and 18. Since the surface sand sheet appears to be only a thin veneer above a coarser coral deposit, it is likely that gravel content may reflect local sediment contribution from below the present surface.

Textural characteristics of the sand fraction show a more systematic trend in which the canon 4 site appears to be anomalous. The modal sand size class clearly lies in the coarse sand grade nearer the reef at star pickets 1 and 10, while medium sand is the modal class or nearly equals the coarse sand proportion towards the southwest northeast (see Appendix B); the sample at canon 4 shows a dominance of coarse to very coarse sand. The very coarse sand content grades from highest concentration of 18% at star picket 10 to lower values in the range 5-9% further northeast , with an anomalously high 33% at canon 4. Sorting characteristics change from well sorted to moderately sorted away from the reef.

Hydrodynamic Influences:

Closer to the reef, the substrate shows evidence of strong influence from the unidirectional over-reef water movement, with the surface shaped to elongate scour and ridge structures that are commonly elongated in an approximately SW-NE trend around star pickets 1 and 4. Scouring is on the same scale at canon 4, but a major depression at this locality as directed N-S. Further to the northeast, the substrate shows more evidence of smaller scale effects that are likely to be more variable, with ripples indicating sand movement in response to contemporary wave patterns in any observation period.

3. Patch Reefs

Two patch reefs were examined in the area considered in the last section. Both are elongate structures about 30-50 m long showing a basal rock platform, standing about 0.5 to 1 m above the surrounding sand floor, overlain by about 1 m of dead and living coral growth that extends up to the present water level.

The basal platform shows a surface that is extensively overgrown by encrusting coralline algae and non-calcareous epibionts and is intensively bored. Obvious expression of coral surface morphology is lacking, but internally the rock shows coral skeletal structure that is fresh in appearance and lacks cementation.

The rock platform is overlain by dead coral that is heavily overgrown with epibionts and is intensively bored, but with an obvious expression of a growth structure similar to that of the contemporary living structures (see Appendix B). The differentiation of the basal rock platform from overlying growths appears to mark two stages in growth of the patch reefs, while the differentiation of a third stage is possibly suggested by the contrast between living and overgrown dead masses with growth morphology.

Each of the patch reefs examined is dominated by a single living species and growth form. The reef at D4, closer to the reef rim, shows smoothly surfaced masses that form bulbous vertical faces and a distinctively terraced form on near-flat surfaces (see Appendix B). At locality D5, further from the reef rim, large flat-conical forms are generated. The contrast of form is evident in the dead, overgrown masses, suggesting that the contrast developed as a result of persistent hydrodynamic influences on speciation and growth form.

APPENDIX A

LITHOLOGY OF SEDIMENT UNITS

This section summarises further details of sediment units encountered on Gun Island.

REEF LIMESTONE

The Reef Limestone constitutes the main framework of Gun Island. Its two sub-units are clearly developed in ordered sequence in coastal cliffs and many rock holes across the mined area, and less clearly in rock outcrops around the western and southwestern shoreline.

Coral Member

The Coral Member of the Reef Limestone is a coarse-grained skeletal-fragment limestone that is moderately densely cemented, coherent and slightly porous. It is pale-cream coloured when fresh, but weathers to a light grey surface.
Gravel - (> 2 mm particle size), sand - (2 mm - 0.06 mm) and mud - (< 0.06 mm) sized particles of skeletal debris are typically intermixed, but locally sand- or gravel- sized components become concentrated in small pockets. Coral, coralline algal and molluscan material are the most prominent recogniseable skeletal elements. Large gastropods appear to be comparable with species of the Holocene coral reef terrain, as do large pelecypods that are occasionally encountered in growth positions. Coral is abundant as short Acropora-like sticks, but also occurs as small- to medium- sized heads and branched masses up to a few decimetres across in both growth and displaced positions; more rarely thin sheets of coral extend up to about one metre across. Coralline algae occur as cm-scale Lithothamnium-like nodules, encrustations and smaller fragments, but only locally generated a skeletal framework binding together other skeletal fragments.

The rock is generaly massive or shows decimetre-scale mottling with textural and compositional contrasts often associated with infillings between coral heads or within branched masses, or formed by local concentrations of coral sticks, gastropod shells etc. Coral sheets and smaller flat-topped growth forms suggest depositional surfaces that were approximately horizontal. The rock is moderately coherent with a limited porosity, but some degree of differential cementation is suggested by development of surface irregularities and void development on weathering surfaces.

Algal Member

The Algal Member of the Reef Limestone is a pale-cream coloured limestone that has a dense, fine-grained appearance and typically lacks a dominating fragmental character and a variable coarse skeletal content. The rock consists of very fine grained carbonate studded by faintly differentiated cm-scale or smaller patches of coralline algae and sand-sized skeletal debris. Weathered surfaces locally reveal algal layering over distances of several centimetres sufficiently often to indicate than an extensive encrusting surface was typically developed during sedimentation, and the sediment is considered to be a coralline algal boundstone. Locally, coarse gastropods, calacareous worm tubes and pelecypod debris are concentrated in sandy or gravelly equivalents of the unit. Coral debris is rare, but occasionally decimetre-scale heads and branched masses of coral extend up into the unit from below its base, or more rarely are completely enclosed within the Algal Member.

The rock is massive apart from mottling and irregular lamination associated with the skeletal frame. It is very coherent, densely cemented or recrystalised and is highly impervious.

Contact Details

The contact between the Coral and Algal Members is locally irregular over a vertical scale of a few centimetres. It is sharp where the algal layer lies above fragmented detritus in the Coral Member but diffuse where it overlies coralline algal patches. Heads and branches of coral, and algal nodules protrude upwards from the uppermost Coral Member into the basal Algal Member. The latter may also extend downwards to infill depressions within the Coral Member. The scale and style of these irregularities are compatible with depositional surfaces on actively growing coral platforms, and extensive truncation of structures in the lower unit is not observed. Hence it is considered that the contact is conformable.

The top of the Algal Member is a relatively smooth erosional surface overlain by sediment of the Upper Cliff Limestone along much of the eastern and northern coastline, and details of this relationship are incorporated into discussion of the latter unit. Within the mined area, the top of the Algal Member constitutes most of the irregular exposure surface. It is pitted by solution effects delineating linear fractures several metres long or more circumscribed depressions that reach a maximum observed depth of 4.1 m below the surface in rock hole 20. Development of this karst surface clearly pre-dates deposition of brown-coloured skeletal gravels and related sediments, remnants of which plaster the surface irregularities as discussed in a following section.

UPPER CLIFF LIMESTONE

Rounded skeletal fragments of coarse to very coarse sand-size (0.5-2 mm) are the main component, but locally gastropod and coralline algal gravels are developed. Towards Point Happy, 1-2 cm sized fragments of cream- and black- coloured calcrete and skeletal limestone are rare components.

Stratification is commonly developed as texturally differentiated beds 2-5 cm thick, that in some localities dip gently northwards through the full thickness of the unit as crossbeds sharply discordant with the upper surface of the underlying Reef Limestone. The unit is moderately coherent, but incomplete cementation has left a prominent intergranular porosity through much of the unit. Locally it develops a chalky matrix/cement that suggests calcretisation.

SHELL LIMESTONE

The brown-coloured limestones consist of skeletal fragments of coral, coralline algae and molluscan species similar to those of the Coral Member of the Lower Cliff Limestone. However, the brown-coloured limestones are obviously fragmental in their fabric, partly because they have a lower content of lime-mud matrix between the larger grains, leading to patchy development of porosity, and partly because of infilling between grains by dark brown cement that is probably of phosphatic composition. Rounding is variable in intensity, and but locally coarse sand to fine gravel sized fragments are mainly rounded.

The sediment typically grades from massive to mottled on a decimetre or centimetre scale, with textural mottling tending to be secondarily accentuated by brown coloured cement. Very rarely stratification is developed, in association with local concentrations of rounded coarse sand or fine gravel. The presently preserved material is very coherent and usually densely cemented with minimal porosity, but locally voids up to cm-size are abundant. However, since these remnants are frequently in readily accessible surfaces in a mined area, it is likely that they are not representative of associated material removed during mining operations but are localised well-indurated pockets that could not be readily worked.

Contacts and Distribution:

The Shell Limestone occurs patchily throughout the mined area as a surface veneers down the sides of rock holes, wedged into fractures and sitting on surface irregularities of the Reef Limestone surface. Its relationship with the latter is clearly conformable. In rock holes it may be plastered onto Surfaces formed by the Coral Member, but more usually it contrasts strikingly with the dense, impervious Algal Member. Its present thickness is limited commonly to a few cm, rarely achieving a few decimetres, but its configuration around rockholes suggests that it probably infilled these structures thus locally achieving a thickness of at least 1-2 m.

The lack of *in situ* skeletal frame, and relation to the underlying surface suggest deposition on a highly irregular rock surface possibly kept clean of encrusting calcareous organisms by water and sediment movement. However, the incomplete nature of the unit as presently preserved may be misleading in this respect.

Inter-relationships of Shell Limestone with Upper Cliff Limestone:

No clear contacts of the Upper Cliff Limestone and the Shell Limestone were observed, and there are obvious lithological contrasts between the two sediments. However, aspects of lithological similarity and stratigraphic location suggest a possible correlation that would be consistent with the observed contrasts. Both sediments have comparable sediment-source substrates and both involve a predominance of transported detritus. The contrast in lithology can be resolved in terms of a depositional trend that would place the brown-coloured limestone of the mined area in depositional locality receiving a wider and coarser range of detrital components than the coastal calcarenite. Such trends are common in intertidal and shallow sublittoral substrates in association with dynamic energy clines upslope along sloping depositional surfaces, or laterally along littoral zones etc. In this case such a trend would be compatible with the gentle westward downslope of the island surface demonstrated by surveyed profiles of the 1976 Expedition to the Zeewijk Wreck Site.

APPENDIX B

SUMMARY OF OFFSHORE SITES EXAMINED APRIL 1978.

Star Picket 1
" " 4
" " 6
" " 10
" " 13
" " 15
" " 17
Canon 4 Site
Patch Reef at D4
Patch Reef at D5

Appendix Table B-1.

Textural Details of Sand Samples based on dry-sieve size analyses.

Size Grade: mm range	description	RA78001	RA78002	RA78004	RA78011	RA78013	RA78014	RA78015	RA78017
		Weight % for numbered samples							
>1cm	Coarse Gravel	–	3·9	–	9·3	0·9	–	–	13·9
2-10mm	Fine Gravel	3·0	2·1	6·5	7·5	4·1	5·3	10·7	9·0
1-2mm	Very Coarse Sand	1·8	11·1	17·5	32·7	5·5	8·7	6·9	5·0
·5-1mm	Coarse Sand	41·5	47·1	46·7	35·9	26·7	34·9	20·9	26·6
·25-·5mm	Medium Sand	34·7	30·1	25·6	11·0	41·5	34·0	36·0	30·6
·125-·25mm	Fine Sand	9·4	4·6	3·5	2·9	18·9	15·5	22·8	13·7
·06-·125mm	Very Fine Sand	0·1	0·1	0·1	0·1	0·2	0·1	0·2	0·1
<0·06mm	Mud = Silt + Clay	0·5	0·3	0·2	0·6	2·1	1·4	2·4	1·0
	Total.	100·0%	99·3%	100·1%	100·0%	99·9%	99·9%	99·5%?	99·5%
Modal Class		Coarse S.	Coarse S.	Coarse S.	Coarse S.	Medium S.	Cse-Med. S.	Medium S.	Medium S.
Sorting		Well Std	Well Std.	Well Std.	Moder. Std	Moder. Std	Well Std.	Moder. Std	Moder. Std
Location: Star Picket No		4	1	10		6	15	17	
Other Location No.					Canon 4				Patch Rf 05

Star Picket 1

Substrate:

Gently hummocky sand and gravel surface with dense patches of brown algae. Slight depressions 50-100 cm wide and 5-10 cm deep flooded by coral-stick gravel and surrounded by mounded sand, appendix Fig. B-1., (K134/6, 7, 2, 3)*. Brown algae established on sand hummocks (Fig. B-2) (K134/11, 4, 5) and on gravel (Fig. B-3).
Groups of Tectus occupy some depressions, among the gravel Fig. B-3 (K134/18, 17, 16, and some others). Abundant smaller gastropods. Live Coralline algae encrust coral sticks (K134/14, 15). Sparse living coral.
Coral sticks appear to be in process of exhumation in some areas, standing upright among the sand rather than lying prone in depressions Figs. B-4, 5. (K135/12, 13 and 8). An area bare of sand shows a network of interlocking and algal-bound coral including thicker sticks Fig. B-6, (K134/10).
One 20-m wide sand ribbon moving eastwards with a 20-30 cm high slip face constitutes a megaripple (K134/9 on slip face) moving across a gravelly depression (Fig. B-5).

Sediment Lithology:

RA78002.
Creamy white, well-sorted, slightly gravelly, coarse sand; with 6% gravel, and 47% by weight in the modal coarse sand fraction. The gravel fraction consists of coral sticks, coralline algae and small gastropod fragments. The sand fraction contains a predominance of probable coralline algae fragments, less than 5% pink-coloured, less than 10% obvious molluscan fragments and a trace of echinoid spines.

Star Picket 4

Substrate:

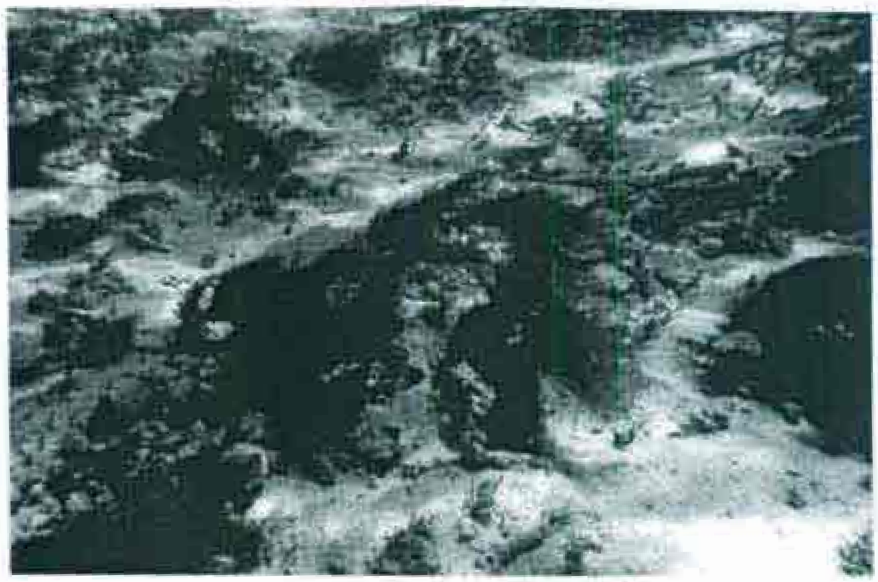
A sand surface sparsely scattered with coral gravel sticks, rare flat to equidimensional coral and isolated clumps of brown algae. Surface shaped as low ridges, 10-15 m wide, 2 cm high and

* Reference numbers to photograph negatives held by U.W.A. Geology Dept.

Appendix Figures B1-B3. Substrate at [illegible] 1.

B1 Ridged sand and scoured depression floored by flat-lying coral sticks.

B2 Brown algal growth on sand ridges, coral sticks in shallow depressions. Tectus shells 5 cm long.



B3 Group of Tectus shells in brown-algal covered depression beneath 30-cm long hammer.

Appendix Figures B4-6. Exhumed coral layer at Sturpicket 1.
B4 and B5 Coral sticks projecting up through sand in depression floors.

B6 Interlocking network of coral sticks and thicker branches.

30 cm apart aligned SW-NE (240°). Purple echinoids are common, clustered around coral gravel, brown alga plants; holothurians are very rare. Coral fragments are encrusted by live coralline algae.

Sediment Lithology:

Sample RA78001.
Creamy white, well sorted, coarse to medium sand; with 3% gravel, a modal coarse sand fraction of 42% and a medium sand content of 35%. The gravel fraction consists of fine (less than 1 cm) gastropod and coralline algal gravel, the sand fraction of lime sand of undetermined skeletal composition, with small percentages of pink coralline algal grains and echinoid spines.

Star Picket 6

Substrate:

A flat to slightly irregular sand surface with patches of dense brown algae and near-bare sand patches. Sand surface in bare areas is rippled with 2-cm high ridges 5-10 cm apart that are straight, trending SW-NE.
Sticks of coral 5-10 cm long are sparsely scattered over the surface. Sand forms a layer 5 cm thick over a sand-filled network of coral sticks.
All skeletal fragments are encrusted by living coralline algae that rarely develop a nodular form 3-5 cm diameter. Thin worm tubes 1-2 mm diameter are dense in the subsurface sand where the surface veneer is removed. Holothurians are rare.

Sediment Lithology:

Sample RA78013.
Creamy white, moderately sorted, medium sand; with a gravel content of 5%, and the modal medium sand fraction constituting 42% of the sample weight. The gravel fraction consists of fine molluscan and coralline algal fragments. The sand fraction consists of lime sand of undetermined skeletal composition.

Star Picket 10

Reef Rim Substrate:

The reef rim is a rock surface, extensively honeycombed and covered widely by a carpet of soft algae with low ledges tracing a layer-like structure in the rock surface (Fig. B-7), or consists of a low bank cut into the rock which is largely devoid of non-calcareous algal epiphytes (Fig. B-8) as a 15-20 cm high face (locally up to 30 cm high above an irregular rock platform). (K134/29, 28, 30). The rock surface is honeycombed by boring organisms and encrusted by living coralline algae, with abundant echinoids, Tectus and other gastropods, particularly on the bare rock areas, Figs. B-7, 8. Corals are sparsely developed as flat encrusting sheets. The soft algal carpet binds fine sand to the rock surface, smoothing over some of the surface irregularities.

Coral Zone Substrate:

Corals form flat sheets and discoid mushrooms 10-15 cm high near the reef rim, Fig. B-9, and increasingly show more delicately branched stag-horn forms (Acropora) downslope, Figs.B10-11. Sand becomes piled around obstructions such as coral bases, approaching ripple-form locally, Fig. B-11.
Bare rock surface exists between coral heads less frequently away from the reef rim as a sand cover develops and thickens. Bare rock areas of about 20 m width within the coral zone and along the reef rim-coral contact show a transitional development of isolated or patchy coral; they are irregularly honeycombed and bored, encrusted by living coralline algae and other calcareous encrustations, and densely populated by echinoids and large gastropods, including Tectus.

Sediment Lithology:

Sand sample RA78004.
Creamy White, well sorted coarse sand, with 7% fine gravel (less than 1 cm size), and a modal coarse sand class containing 47% of the sample weight. The gravel fraction is predominantly coralline algae fragments (10-20% retaining pink colour). The sand fraction is lime sand, with 10-20% pink coralline algal fragments and 2-5% echnoid spines, together with white coralline algae, coral, molluscan foraminiferal and echinoid fragments.

Appendix Figures B7-8. Substrate at edge of reef rim west of Starpicket 10.

B7 Carpet of short soft algae over rocky surface.

B8 Bare rock surface and low vertical rock face.

Appendix Figures B9-11. Coral Zone at Sharpicket 10.
B9 Extensive flat sheets and flat discoid growth forms.

B10 Discoid mushrooms and branched stag-horn masses.

B11 Branched stag-horn masses with sand-pile on lee side.

Star Picket 13

Reef Rim Substrate:

Reef rim a relatively smooth slope on the large-scale, but on a smaller scale honeycombed by irregular cavities several cm in size, which may be grouped to produce decimetre-scale depressions with irregular protruberences (RA78KC2-28)ˣ. Rock surface encrusted by grey, pink or red calcareous encrustations dominantly of coralline algae. Localised brown fuzz of short algae. Abundant Tectus particularly concentrating in depressions, with cm-sized and larger gravel in deeper pits (RA78KC2-30). Rarely, thin sheets of favitid coral encrust the surface (RA78KC2-29).

Coral zone substrate:

Coral zone consists of low, (10-15 cm) Acropora discs up to 1 m long and scattering of other species (RA78KC2-22). Inter-head basement of encrusted irregular rock surface with Tectus KC2-23, and echinoids lodged in cavities, and traces of fine gravels and coarse sand (RA78KC2-23). Larger rock-surface patches devoid of coral show surface irregularities with pink encrustation, echinoids and coarse sand in cavity bases, (RA78KC2-24). Encrusting algae may smooth the surface of bare rock (RA78KC2-25). Canon 3 is located in a patch of algal-encrusted rock with a thick cover of brown algae.

Star Picket 15

Substrate:

A flat, rippled sand surface, with a sparse scatter of coral-stick gravel and rare brown algae. The ripples are straight to wavey, 3 cm high and 8 cm apart, aligned SW-NE. Echinoids are rare, living coralline algae encrust the gravel fragments.

ˣ Kodachrome numbers.

Sediment Lithology:

Sample RA78014

White, well sorted medium to coarse sand; with 5% gravel and subequal medium and coarse sand grades representing 70% of the sample. The gravel fraction consists of molluscan fragments and coralline algal fragments. The sand fraction is lime sand of undetermined skeletal composition with less than 1% pink coralline algal grains.

Canon 4 Site

Substrate:

In parts, shows alternating bands of gravel and sand surface, with gravel delineating current-swept scours containing localised lag-concentrates of gravel, coarse sand, and smooth sand delineating depositional ridges with a scattering of gravel. Relief is limited to a few cm, the width of the units a few metres, but their length is several tens of metres. Coral stick gravel shows a flat-lying, disoriented pattern (RA78KC2-35). Surface shows a very sparser sparse scatter of brown algae 2-3 m apart (RA78KC2-33). Other parts show sand surface with coarse sand and fine gravel patches a few decimetres across and locally large coral sheets and branches up to 30 cm size (RA78KC2-34). One deeper depression 5-6 m across and 10-15 cm deep, aligned approximately N-S, shows an exposure of upstanding coral sticks among flat-lying large branched and foliated forms, suggesting a more coarse-grained underlying sediment. Small pathes of gravel and coarse sand on the sides of the depression suggest recent scouring of the surface (RA78KC2-36). Coralline algal encrust coral sticks. Thin worm tubes are abundant below the surface sediment layer.

Sediment Lithology:

Sample RA78011

White, moderately sorted, gravelly coarse sand; with 17% gravel and sub-equal coarse and very coarse sand proportions. The gravel component consists of coral sticks, and fine (less than 1 cm) coralline algal (5% pink) molluscan fragments and minor coral.

The sand component is lime sand of undetermined skeletal composition, with obvious echninoid spines, pink coralline algae, small molluscs as minor components.

Patch Reef at D4

Reef Substrate:

Living coral forms a network of low terraces a few cm high (Fig. B-12) on the flat upper surface, and a smooth bulbous encrustation part way down steep sides (Fig. B-13). A basal platform about 30-40 cm high, encrusted by brown algae etc. and heavily bored, lies below the living surface down to the level of the surrounding gravel floor on the N side. On the south side, living coral overlies a 20-30 cm layer of foliated dead coral which in turn overlies a near vertical wall of dead, overgrown and bored coral, Fig. B-14. The same internal structure of finely cellular, laminated skeletal structure is shown by the living coral, the foliated dead coral and the basal rock platform.

Patch Reef at D5

A patch reef surrounded by a rippled sandy floor 3 m deep. (Fig. B-15).

Sand Substrate:

The sand is smooth with only a sparse scatter of coral gravel and a sparse scatter of brown algae. The long ripple-troughs may show a concentrate of gravel (1-2 cm size) crests long, straight to wavey, 1-3 cm high and about 6 cm apart. Denser clusters of brown algae are associated with more gravelly patches.

Holothurians work over the surface sand, and worms generate vertical tubes in the subsurface. Wreckage lies thinly burried across the sand surface.

Close to the reef, gravel content of the sand increases.

Reef Substrate:

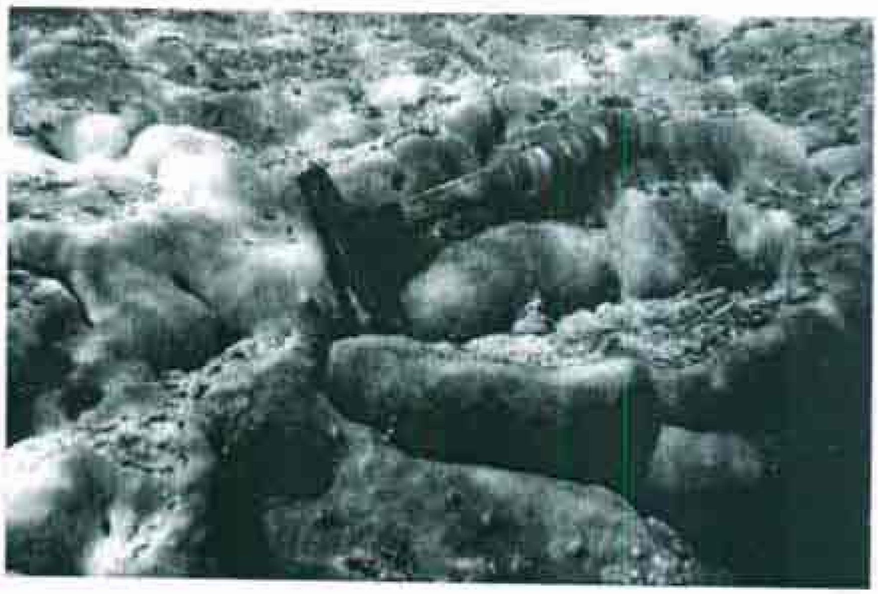
At the southern end and along its southeastern side the reef shows several large ramifying conical-fan heads (? Acropora) 1-3 m across and up to 1 m high, based on a tabular rock platform 0.5 m high, with smaller rounded to flattened discoid coral widely scattered across the platform.
A few large heads of an earlier generation of coral growth appear as upstanding and overturned mushroom heads 1-2 m across that are now dead and encrusted by epibionts generating a fuzzy, heavily overgrown appearance without obliterating the former growth form of the masses.
The basement platform of the reef is an extensively encrusted and bored coral-rock that lacks all obvious external growth character. Its outer edge, where not covered by the later growths, shows a slightly undercut or overhanging vertical drop of about 50 cm to a gravel-strewn surface at about the level of surrounding sand.

Sediment Lithology:

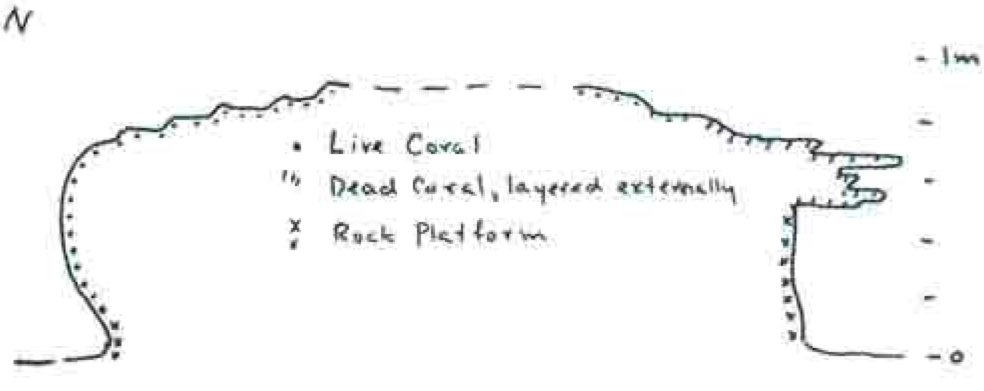
White, moderately sorted, gravelly medium to coarse sand; with 23% gravel, modal class medium sand but a subequal content of coarse sand. Gravel comprises coral and gastropod fragments with only a small fraction of fresh, unbored or uncoated fragments. Sand fraction pure lime-sand of skeletal fragments. Sample. RA78017.

Appendix figures 12-13. Patch Reef at D4.

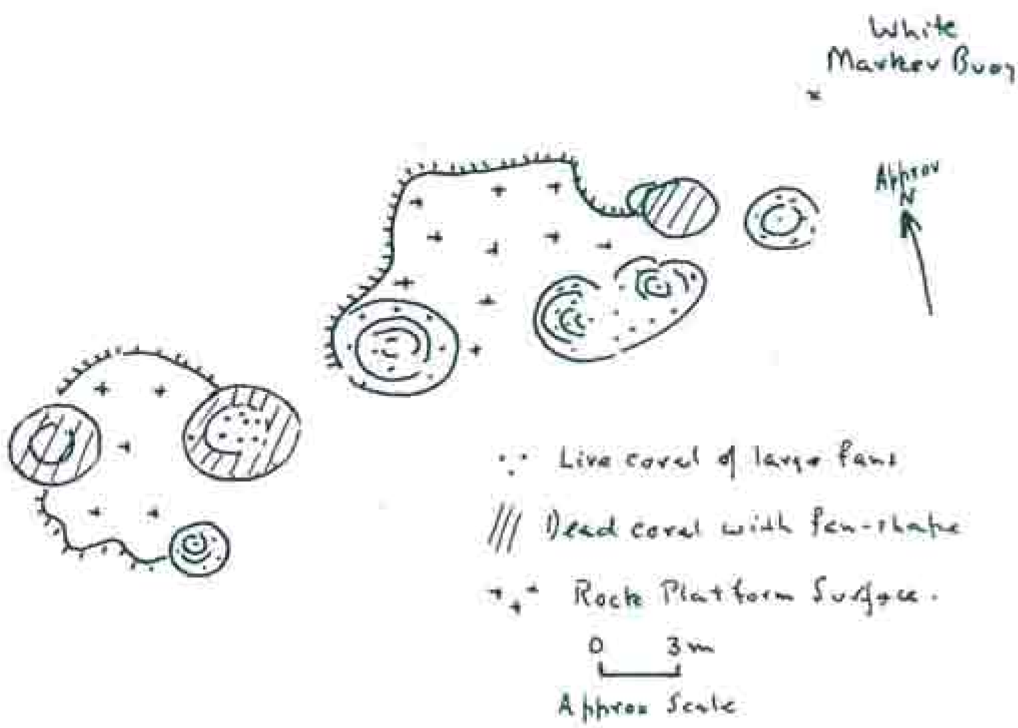
B12 Surface detail of terraced growth form.



B13 Bulbous growth over vertical faces of a narrow fissure.



Appendix Fig. B.14 Profiles of N & S walls at D4 Patch Reef.



Appendix Fig. B.15. Sketch of Patch Reef outline at D5.