GREAT BARRIER REEF MARINE PARK AUTHORITY
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SEDIMENTARY FRAMEWORK OF MAINLAND FRINGING REEF DEVELOPMENT, CAPE TRIBULATION AREA

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SUMMARY

Mainland fringing reefs with a diverse coral fauna have developed in the Cape Tribulation area primarily upon coastal sediment bodies such as beach shoals and creek mouth bars. Growth on steep rocky headlands is minor. The reefs have extensive sandy beaches to landward, and an irregular outer margin. Typically there is a raised platform of dead reef along the outer edge of the reef, and dead coral columns lie buried under the reef flat. Live coral growth is restricted to the outer reef slope. Seaward of the reefs is a narrow wedge of muddy, terrigenous sediment, which thins offshore.

Beach, reef and inner shelf sediments all contain 50% terrigenous material, indicating the reefs have always grown under conditions of heavy terrigenous influx. The relatively shallow lower limit of coral growth (ca 6m below AHD) is typical of reef growth in turbid waters, where decreased light levels inhibit coral growth.

Radiocarbon dating of material from surveyed sites confirms the age of the fossil coral columns as 5680-6110 ybp, indicating that they grew during the late post-glacial sea-level high (ca 5500-6500 ybp). The former thriving reef-flat was killed by a post-5500 ybp sea-level fall of ca 1 m.

Although this study has not assessed the community structure of the fringing reefs, nor whether changes are presently occurring, it is clear the corals present today on the fore-reef slope have always lived under heavy terrigenous influence, and that the fossil reef-flat can be explained as due to the mid-Holocene fall in sea-level.

A medium term programme is required to record sediment loading and coral community structure, and to establish the environmental vulnerability of these reefs.

KEYWORDS: Cape Tribulation, fringing reef, siltation, sea-level high

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1. INTRODUCTION

Fringing reefs in the Great Barrier Reef are generally attached to offshore islands, except in the northern region where they are attached to the mainland. The southernmost mainland fringing reefs grow in the Daintree-Mossman area, midway between Cooktown and Cairns (Fig.1). A well-developed series of mainland reefs near Cape Tribulation has a rich coral fauna, containing some 140 species within 50 genera (Veron, *pers. comm.*, **Appendix I**). These reefs occur on an exposed, tropical coastline, close to a major river mouth, and adjacent to a hinterland with heavy, perennial rainfall. Consequently the reefal carbonates are accumulating at Cape Tribulation in an area of high terrigenous influx.

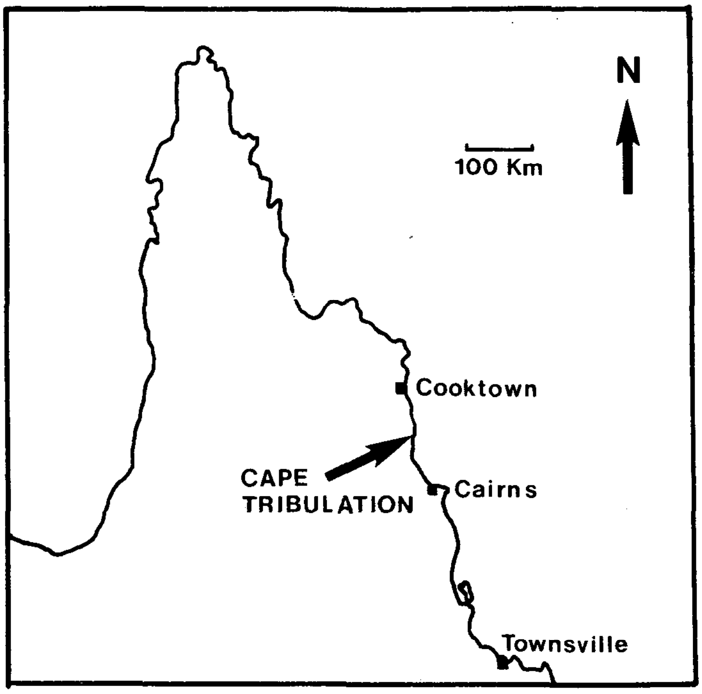

Figure 1. *Location map of the Cape Tribulation area.*

Coral growth is generally inhibited by high turbidity, whether from terrigenous influx or from resuspension of muddy bottom sediment. Turbidity affects corals in several ways (Bak,1978):

- Suspended sediment depresses light levels, lowering symbiotic algal activity and hence calcification rates
- Sediment blankets cause coral suffocation
- Energy used in sediment removal saps polyp vitality
- Suspended sediment has unfavourable effects on plankton food sources
- Suspended and soft sediment cover prevents successful settlement of planulae
- Fresh water associated with riverine sediment influx can cause osmotic problems for coral polyps

The effects of siltation on corals and coral communities are reviewed in **Appendix II**. Individual corals may tolerate intermittent turbidity, but not chronic turbidity, particularly siltation. Increasing sedimentation rates cause progressive disruption and impoverishment of a healthy coral community, marked by :

- Decreased coral cover
- Decreased species richness
- Decreased coral growth rates
- Reduced recruitment and coral death
- Invasion by opportunistic species, and prolific growth of algae.

While there are no data published on the sedimentation rates on the Cape Tribulation reefs, field observations indicate the corals are growing in unusually muddy conditions and thus may require special management considerations. Further any abnormal increase in siltation (Anon,1985) could threaten their survival.

In fact, there are virtually no data on the turbidity tolerances of Australian corals, and most published work refers to Carribean situations. Consequently we do not know whether the coral communities at Cape Tribulation are well within their tolerance limits, or whether only slight increases in turbidity will cause drastic changes to the communities.

This study documents the sedimentologic setting of the Cape Tribulation reefs, and the resulting stratigraphy, and considers the factors controlling development of this reef type.

2. METHODS

The study is based on both offshore and onshore data. A three-day cruise in May 1985 recovered 133 line km of shallow seismic (ORE 3.5Khz profiler) and sidescan sonar records, and nine vibracores (Fig.2). All depths noted on seismic profiles assume a sound velocity in seawater of 1500m/s. A four day land trip allowed mapping of the coastal region, recovery of surface sediment samples and the drilling of six auger holes using a trailer-mounted Jacro drilling rig hired from the Australian Institute of Marine Science. Auger samples were recovered by spiralling the bit into the substrate, and then withdrawing the drill string, so that the sample was not disturbed by travelling up the auger flights. We are confident sample depths are accurate to within 0.5m. All heights are referred to Australian Height Datum (AHD), which approximates mean sea level.

Textural analysis of sediments consisted of wet-sieving through 2mm and 63 micron sieves to separate gravel, sand and mud fractions. The gravel and sand fractions were examined under binocular microsope, and the mud fraction was split. One split was dissolved in 10% HCl to determine acid soluble (i.e. approximate carbonate) content, and the other used for X-ray diffraction analysis to determine clay mineralogy.

The clay fractions were suction-filtered onto Whatman GF/C glass fibre filters which were dried and glued to glass slides. X-ray diffraction analyses were done on a Rigaku D-Max 500 diffractometer using the following settings : Cu Ka target at 40Kv and 20ma with curved crystal graphite monochromator; scan at 0.5 degree/min over 45.0-1.3 degrees 2 Θ, count rate 100/s, time constant 5s, chart speed 5mm/min. Two runs were performed for each sample : air dried and after saturation for 48 hours with ethylene glycol.

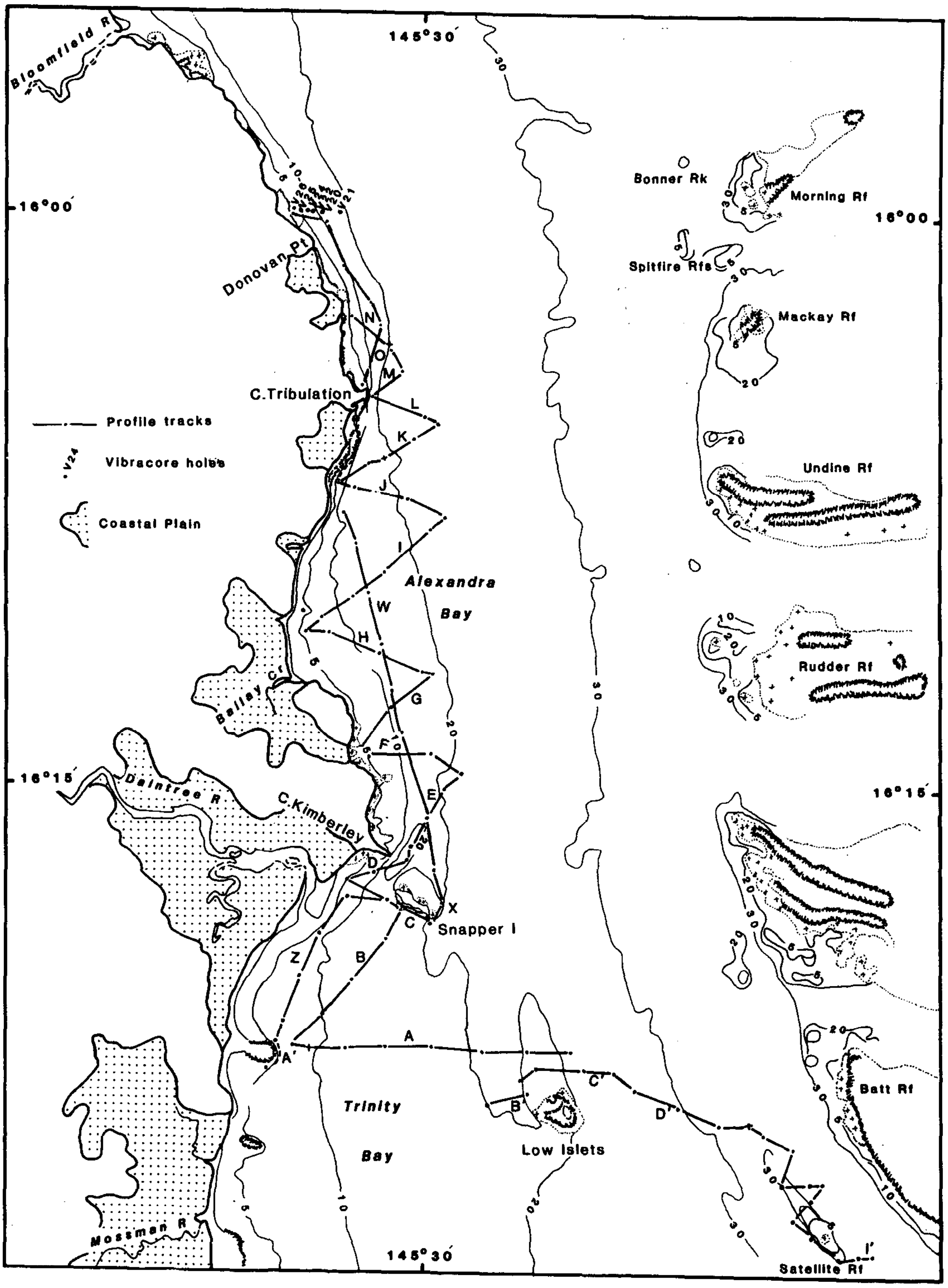

Figure 2. *Map of Cape Tribulation area showing localities mentioned in text, bathymetry and profile tracks.*

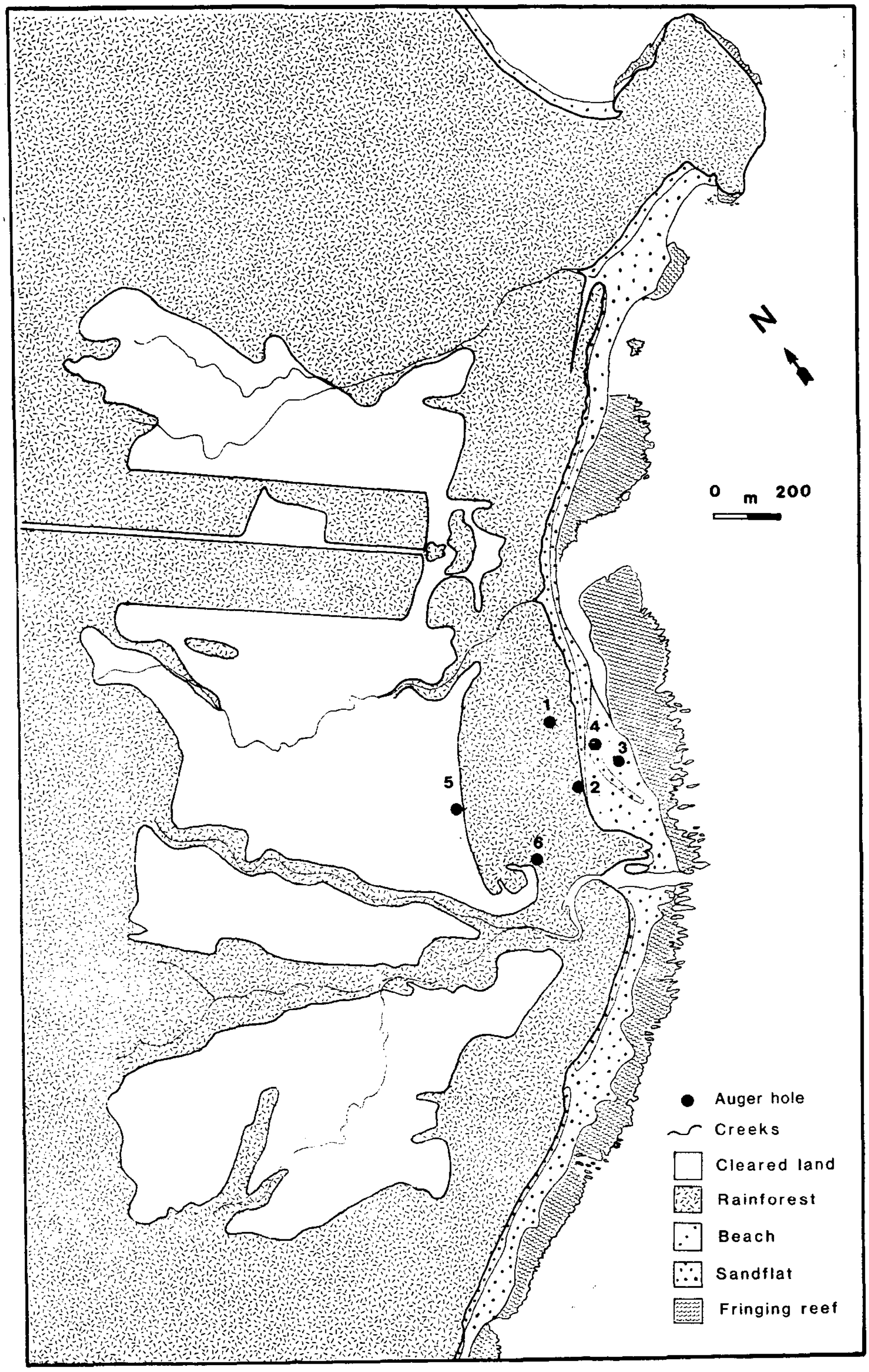

Figure 3. *Map of coastal area south of Cape Tribulation, showing extent of mainland fringing reefs and location of onshore Jacro auger sites.*

3. DESCRIPTION OF THE AREA

Fringing reefs occur intermittently along the mainland coast north of Cairns, but are best developed north of Mossman. This study concentrates on the area from the mouth of the Daintree River to Donovan Point (Figs.2,3) where the coastline consists of a series of rocky headlands separating sandy beaches. There are two main bays : Trinity Bay which is bordered by an extensive coastal plain constructed by the Daintree and Mossman Rivers, and further north, Alexandra Bay which has only a narrow coastal plain deposited by local creeks. Rocky headlands extend eastwards for 1 km from the trend of the coast, and represent high energy situations compared to the bays.

The coastal hinterland is composed of deformed Silurian-Devonian lithic sandstones intruded by Permian granites, and the coastal ranges rise up to 1374m in height (Bureau of Mineral Resources,1962). The land is covered with dense tropical rainforest which extends down to high tide level. Apart from cleared farmland on the Daintree floodplain, and minor cleared holdings inland of Alexandra Bay, the region is in a natural state.

The offshore area can be divided into an inner shelf (to 20m water depth), a flatter middle shelf (20-40m water depth) and a mid-shelf reef tract some 15km offshore. There are two small bedrock islands in the southern part of the area, Snapper Island and the Low Islets.

The climate is wet tropical. The following data are taken from the summary by the Bureau of Meteorology (1971). Average annual rainfall exceeds 3750 mm at Cape Tribulation, and decreases to the north and south, being only 2000 mm at Port Douglas. Average annual rainfall of 2000-3750 mm is typical for the Daintree River catchment, and rainfall is well distributed throughout the year. Average annual evaporation is of the order of 1250 mm. The mean annual temperature is 24° C, the average maximum 28° C and the average minimum 21° C.

Regional oceanographic conditions are described by Pickard and others (1977). Prevailing winds along the coast are northeasterly to southeasterly. "*In autumn the frequency and constancy of the southeasterlies gradually increase until by May; they blow on more than 80% of days with an average speed of 12 to 15 knots*" (Bureau of Meteorology, 1971, p.57). Despite a relatively continuous tract of midshelf reefs, the prevailing SE weather blows obliquely up the inner-mid shelf, causing the common formation of waves 1-2m high. Consequently the coastline is subjected to relatively high-energy conditions.

Fringing Reefs

Mainland fringing reefs in the area occur in three different situations : steep, rocky shores, distributary mouth bars and beach shoals (Fig.3). The reefs along rocky shores are narrow and of limited extent. However, reefs developed on coastal sediment bodies such as distributary mouth bars and beaches are up to 300m wide and extend for 1-3km along the shoreline. Typically these shorelines comprise an inner sandy beach and an outer reefal area (Fig.4). The inner beach is a swash zone backed by a beach ridge supporting thick rainforest. To seaward is a sandflat, commonly with mobile intertidal bars up to 0.5m high which extend several tens of metres along the shore. Scattered dead coral microatolls and heads are common on the sandflat, either exposed or shallowly buried.

At Myall Beach the fringing reef lies seaward of the sandflat and consists of three parts: 1) a dead, emergent reef top, 2) a living reef crest and upper slope, and 3) a sediment covered lower slope which passes onto the inner shelf (Fig.4). The emergent reef forms an irregular, raised, wave resistant pavement at approximately -0.5 to -1.0m (AHD), incised by gutters up to 1m deep. This subfossil reef consists of branching and head corals heavily encrusted and cemented together by coralline

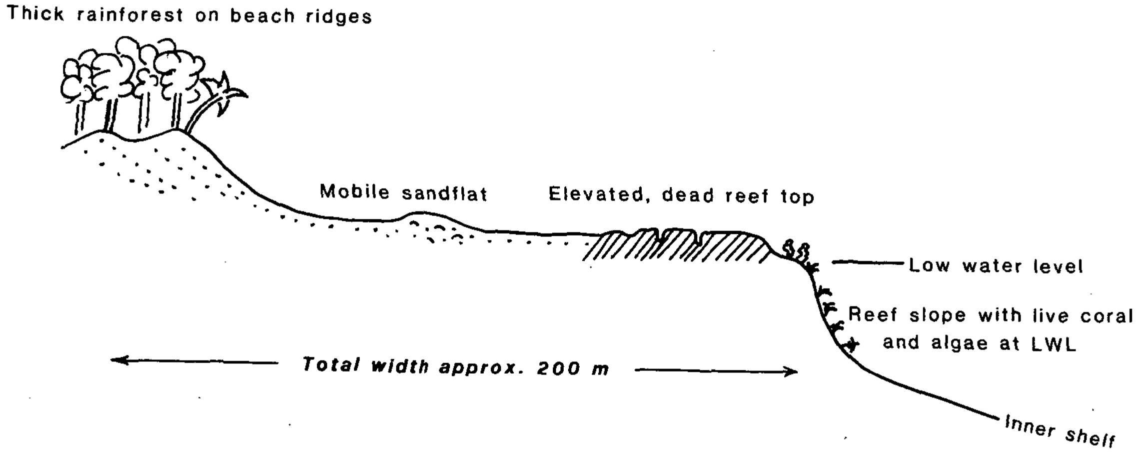

Figure 4. *Schematic profile across a typical fringing reef.*

algae, barnacles and oysters. Living corals only occur seaward and below the dead reef top, along a steep, indented outer margin approximately 3m high, with deep gutters between patch reefs and individual coral columns. The upper limit of live coral growth has been levelled at ca -1.40m (AHD). SCUBA observations (N.M.Mockett, *pers. comm.*) show the lower slope, seaward of this cliff, consists of sandy substrate with scattered coral heads up to 0.5m high, coral rubble, seagrasses and taller columns close to the reef margin. Coral growth extends about 50m seaward of the reef edge, down to ca 6m below AHD at Cape Tribulation, and up to ca 10m elsewhere along the coast. This depth range is shallow compared to the mid-shelf reefs only 15km offshore, where coral growth extends down to 30-40m (J.E.N. Veron, *pers.comm.*). Sediments of the lower slope become increasingly muddy seawards where they merge with those of the inner shelf.

The waters over the reef and seaward of the reef margin are commonly very brown due to suspended muddy sediment. Even following the prevailing light to moderate winds, SCUBA divers report difficulty seeing more than 10m underwater in depths less than 10m. These observations, and the shallow depth limit of coral growth (ca 6m), indicate that corals are growing in perennially turbid water on both the reef flat and reef slope.

Inner Shelf

The inner shelf can be considered in two parts (Fig.5). South of Noah Head, there is a wide sandy platform with its outer edge at 8-10m water depth. The platform widens southward and, except where it is incised by the Penguin channel, merges with the shallow fill of Trinity Bay. North of Noah Head the inner shelf slope is steeper, the sand platform is narrow and forms the toe of the fringing reefs. Side-scan sonar surveys show the substrate is even, without obvious bedforms and with promontories of the irregular reef edge jutting seawards. Seaward of the inner shelf lies the mid-shelf, a relatively flat plain surfaced by relict sediments.

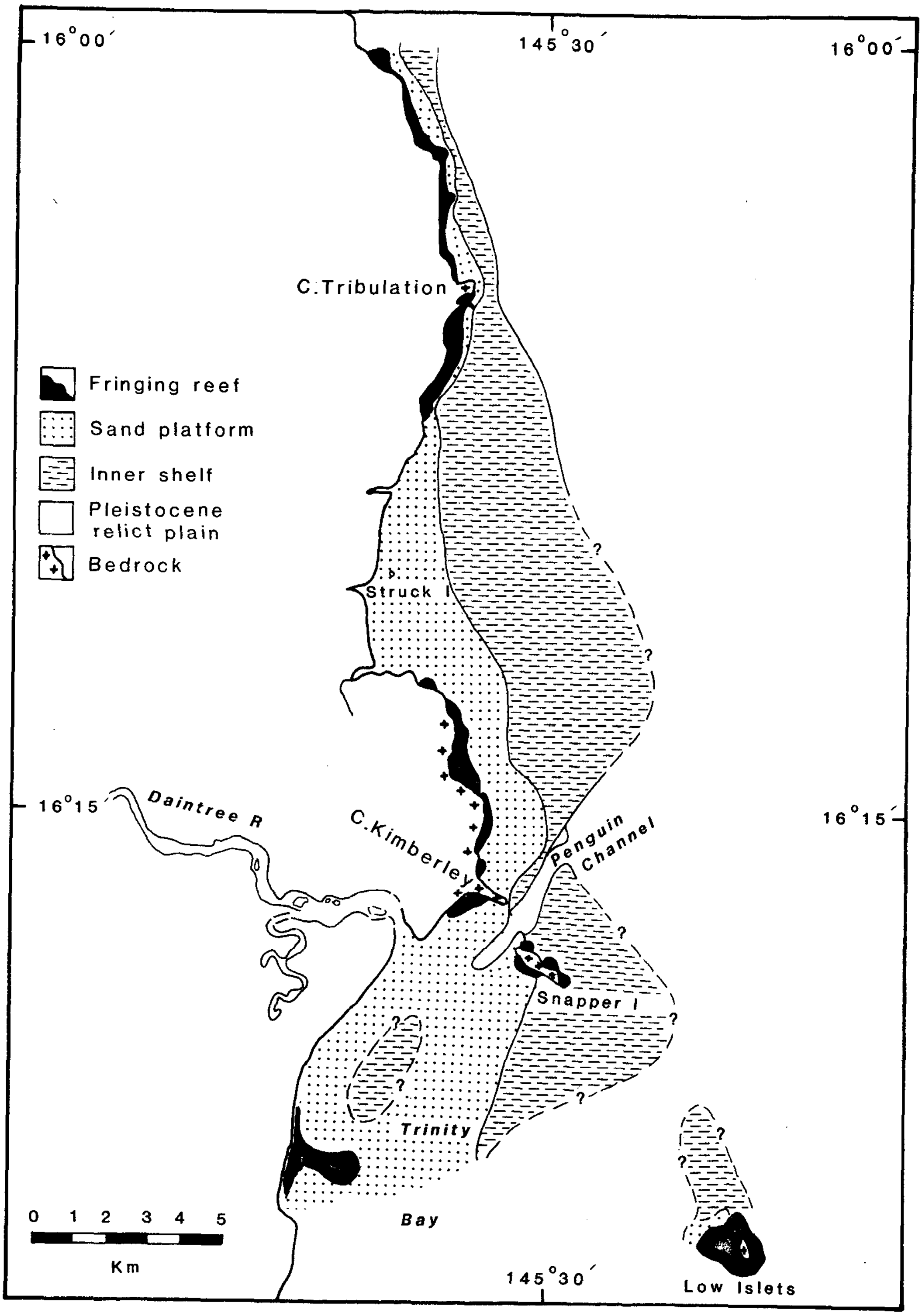

Figure 5. *Offshore physiography and sedimentary facies.*

4. SEDIMENTARY UNITS

Seismic Stratigraphy

The thickness of post-glacial deposits was determined from shallow seismic profiles, supported by vibracore data (Fig.6). The deposits are 10m thick near the coast and thin seawards. In northern Trinity Bay off the Daintree River mouth this wedge extends at least 11km offshore where it surrounds the Low Islets. The wedge narrows to the north, and is only 2-3km wide north of Cape Kimberley. Thus the major locus of modern terrigenous deposition in the region is in Trinity and Alexandra Bays.

Figure 6 also shows the location of buried channels incised into the Pleistocene surface and now overlain by post-glacial deposits. The palaeo-Daintree River trends onto the shelf from the present river mouth and there is a smaller tributary west of the Low Islets. Thalweg elevations suggest that west of Low Islets a smaller channel flowed northward, probably marking the course of the palaeo-Mossman River rather than a branch of the palaeo-Daintree. There is also a wide system of small channels emanating from the Table-Bailay drainage area.

Three seismic sequences (P,T,R) separated by two persistent reflectors (A, B) can be recognised on the 3.5kHz profiles (Fig.7). The lower reflector is very uneven, outlines channels up to 18m deep and several hundred metres across, appears as a dark, shaded zone on the profiles, and generally forms acoustic basement (Fig. 7A,B,C.). We correlate this reflector with Reflector A of Orme and others (1978) and Johnson and Searle (1984). We interpret Reflector A as the eroded Pleistocene land surface which developed during the last sea-level low. The upper reflector, B, is planar and dips gently seaward (Fig. 7B,C,D).

Seismic sequence P is acoustically opaque to the 3.5kHz system (Fig. 7A,B,C), and its upper surface is marked by Reflector A. Sequence P lies at or just below the seabed on the mid-shelf, and is also exposed in the Penguin Channel west of Snapper Island, where strong tidal currents cause scour between the mainland and the Island. In general, sequence P appears to represent the incised Pleistocene alluvium. However on line 854C D there is a prominent peak of sequence P, which lies directly off Cape Kimberley and is probably bedrock. Further work deploying a boomer seismic profiler and vibracorer is needed to confirm the nature of sequence P.

Seismic sequence T is of very irregular distribution and thickness, bounded at the base by Reflector A and at the top by Reflector B. Internal reflections vary from finely layered and laterally continuous (Fig. 7A) to irregular (Fig. 7C). These internal reflections commonly lap out beneath or are truncated by Reflector B. Sequence T tends to fill channels and depressions, and is interpreted as fluvial and estuarine sediment backfilled in landscape depressions during the post-glacial transgression.

Seismic sequence R is a laterally extensive, lenticular to wedge-shaped body, with a maximum thickness of 10m, occurring 0.5-2.0km offshore, thinning landwards, onto the mid-shelf, and also to the north (compare Figs. 7B,C,D with 7E and F). Sequence R is bounded at the base by Reflector B and at the top by the sea-bed (Fig. 7C,D,E,F). Typically the sequence comprises a shoreward part which has seaward dipping reflectors, and a seaward part which is transparent. These two parts correspond to the sublittoral sand platform, and the inner shelf mud-belt, the two major zones of modern terrigenous deposition.

Hard bottom evidenced by dark seabed reflectors in the northern seismic profiles (Fig. 7E,F) may represent remnant highs in the Pleistocene landscape (i.e. sequence P), or they may be carbonate reefs developed at slightly lower sea level, perhaps the -9m shoreline of Carter and Johnson (1986).

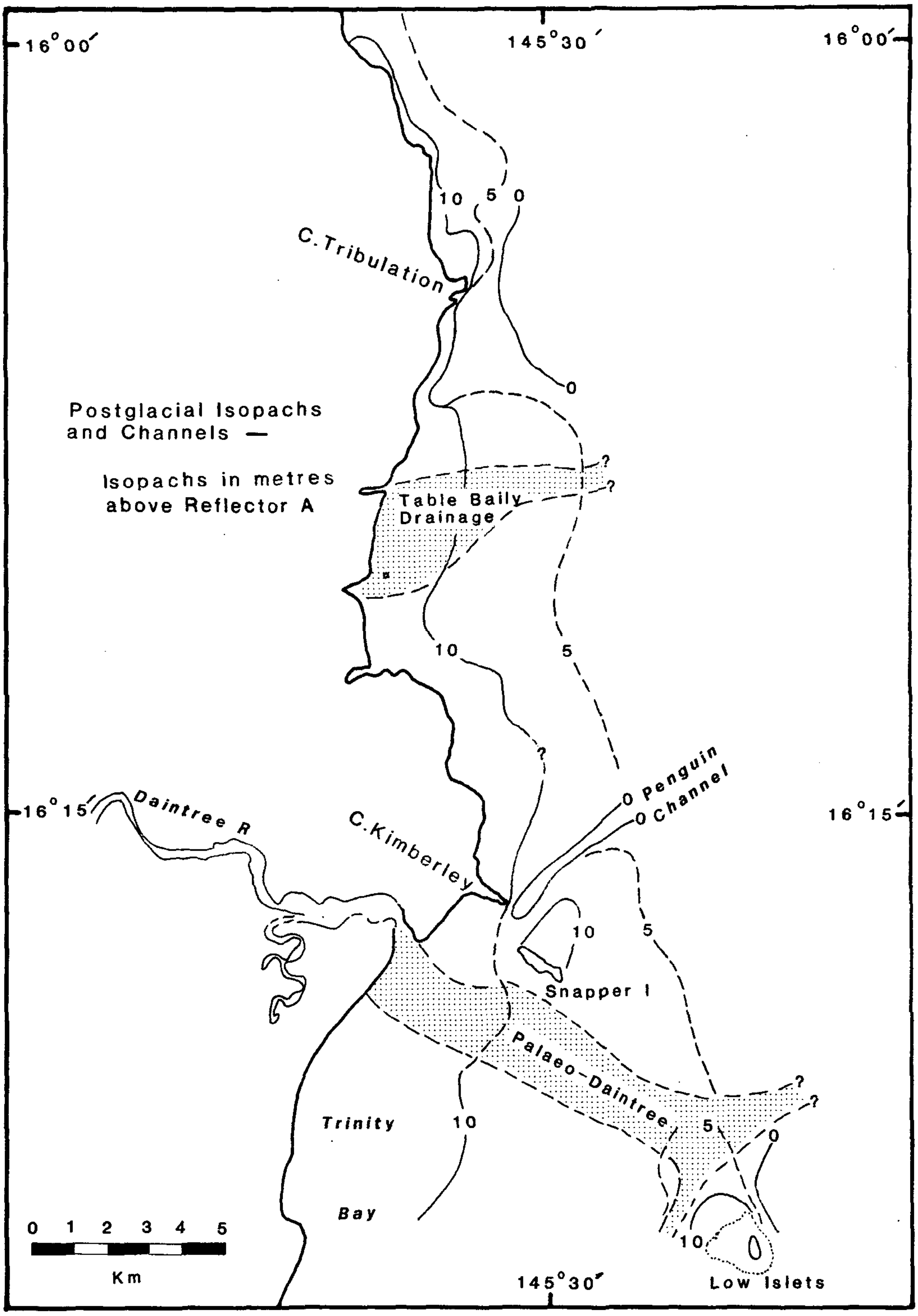

Figure 6. *Isopach map of post-glacial sediment overlying Reflector A, and location of buried palaeo-channels.*

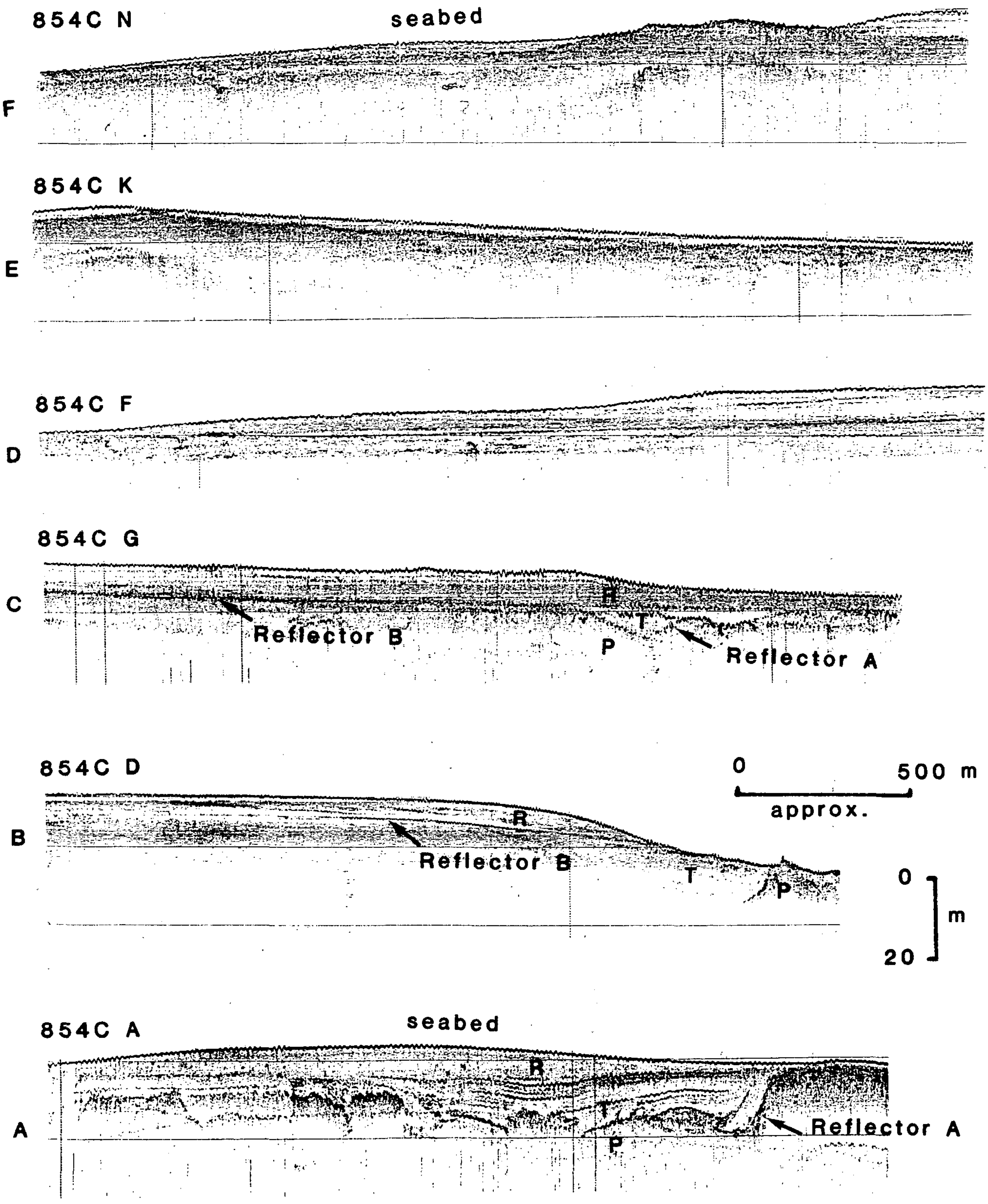

Figure 7. *Representative shallow seismic profiles, positioned from south to north. Profile A crosses the channel of the palaeo-Daintree River.*

All profiles stopped just seaward of the shallow water fringing reefs which would constitute a cap on sequence R. Thus sequence R is interpreted as deposition, at essentially stable sea level, of both terrigenous influx and subsidiary carbonates derived from the fringing reefs.

Sedimentary Units and Age Structure

Five stratigraphic units were intersected by the drilling (Figs.8,9) :

- Modern alluvium
- Beach-beach ridge sand
- Reef top unit
- Inner shelf unit
- Pleistocene unit

Textural data for the sediments are shown in Figure 10. Apart from the alluvial units, the major units are lithologically distinct. Both modern and Pleistocene alluvium samples are designated by the same symbol and show a wide range of compositions.

The **modern alluvium** is poorly-sorted, red-brown, commonly mottled, muddy sand with up to 50% gravel. The gravel fraction is granule to pebble sized lithoclasts of schist or Fe-oxide cemented fine sediment, probably reworked laterite. The sand fraction is consistently fine to medium sand-size, mainly clear/grey angular quartz, with minor Fe oxide cemented grains. Felspars are rare.

The **beach-beach ridge** sands are grey, well sorted, fine to medium, quartzose (80%) sand. Skeletal carbonate composes 5-15% of the samples and is mainly comminuted bivalve and coral debris. Gravel and mud fractions total less than 25% of the sample. Mica forms up to 5% of the sample in some layers, especially towards the base of the unit. An organic rich soil layer up to 0.5m thick with common pumice clasts is generally developed landward of high tide levels.

The **reef top unit** contains massive head corals and columns, surrounded by poorly sorted matrix. Drillhole 4 penetrated a Porites column 5m thick, and similar columns were encountered in other drilling in nearby reefs (B. Partain, *pers. comm.*). The matrix is composed of poorly sorted gravelly sands and sandy gravels, generally with less than 15% mud (one sample has 40% mud). The gravel fraction is composed of abraded coral fragments up to 50mm in size, with finer bivalve, gastropod, bryozoan and coral debris. Rare lithoclasts and plant material also occur. The sand fraction contains 50-90%, poorly sorted, angular, grey, very fine to coarse grained quartz. The skeletal carbonate comprises broken, but commonly fresh grains of foraminifera, bivalves, gastropods and echinoid spines.

The **inner shelf unit** is composed of muddy sand and sandy mud with less than 8% gravel. Two units are recognised in the cores, an upper unit (A), and a lower unit (B). Unit A contains 25-71% mud, and generally forms the seabed. The gravel is skeletal debris, mainly fresh bivalve, echinoid and crustacean material with minor plant detritus. The sand fraction is dominantly (85- 95%) clear, angular, fine quartz with minor micromolluscs, benthic foraminifera, echinoid fragments. Unit B contains 52-87% mud. The gravel is a variable mixture of skeletal debris (molluscs, echinoids, corals, bryozoans) and yellow quartz grains. The sand fraction contains 50-95% clear, angular quartz, with minor mica and plant detritus. The skeletal grains are foraminifera, echinoids and bryozoans. Towards the base, unit B has medium to coarse quartz and Fe-oxide cemented grains, which have been reworked from the underlying Pleistocene alluvium.

The **Pleistocene alluvium** is composed of gravelly and sandy mud with 85% mud. The sediment is generally mottled red brown/ochre/grey with gravel sized discoloured quartz clasts and Fe-oxide cemented fine sediments (?laterite). Poorly sorted, very fine to coarse quartz grains, Fe-oxide grains and minor mica are present, but no skeletal carbonate.

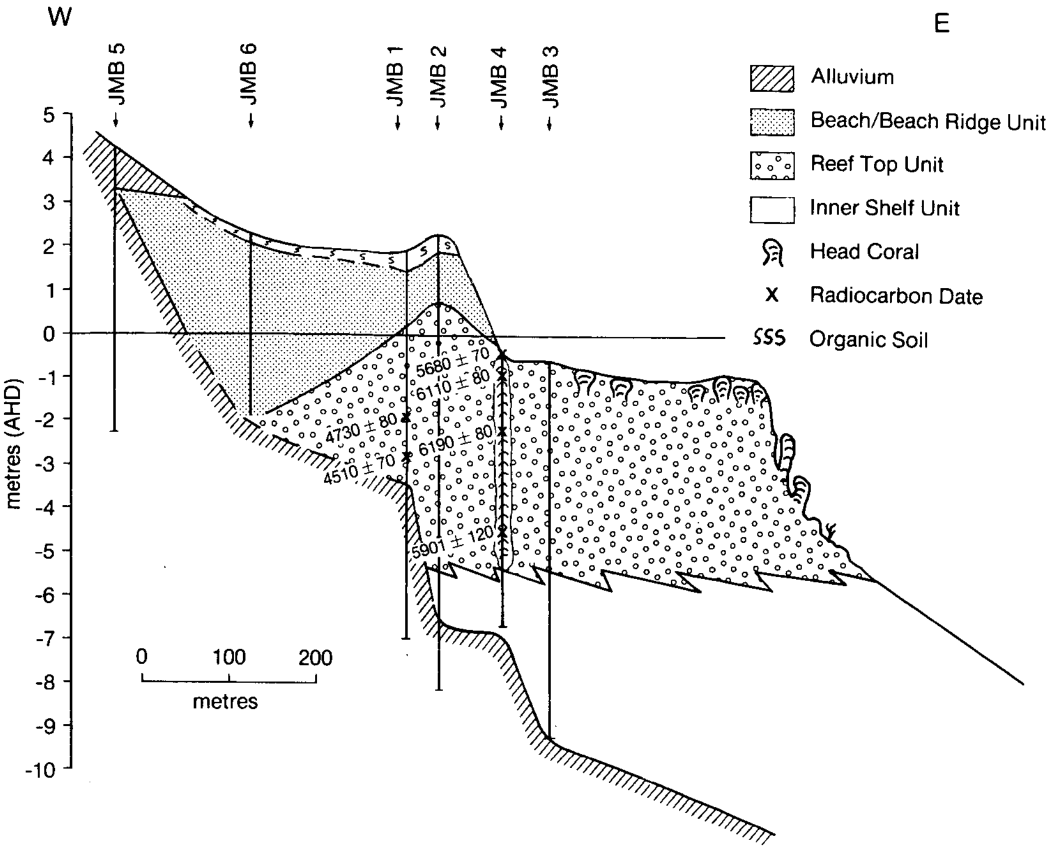

Figure 8. *Stratigraphy of coastal fringe as determined by augur drilling. Drillhole locations are shown in Figure 3.*

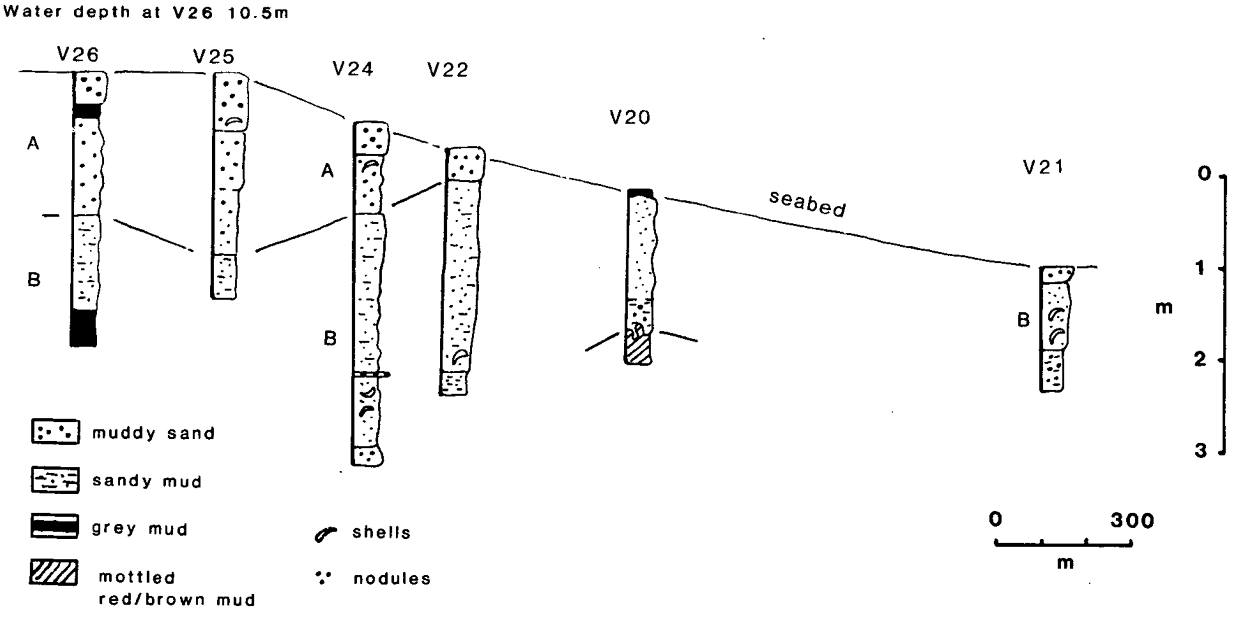

Figure 9. *Inner shelf stratigraphy determined from vibracores. Core locations are shown in Figure 2.*

The onshore drilling shows the reef top unit is overlain to landward by the beach-beach ridge sands, which are in turn overlain by a wedge of modern alluvium (Fig.8). This sequence unconformably overlies Pleistocene alluvium. Unfortunately the layers immediately overlying the unconformity were sandy and water-saturated, and could not be recovered, so the nature of this stratigraphic level is not known as well onshore as it is offshore.

The offshore vibracores show that the inner shelf unit thins seawards, and that it consists of unit A developed mainly nearshore, and unit B developed further seaward. Unit B is generally muddier, as would be expected of the more seaward deposit, but it also contains sandy sediment admixed from a basal transgressive sand sheet, itself derived from reworking of Pleistocene alluvium.

Radiocarbon dating of samples from the inner part of the fringing reef section (Fig.8, **Appendix III**) shows the reef top unit commenced accumulating at least 6000 yr BP, and that the coral column in drillhole 4 grew upward and was later encased in the matrix sediment. The top of the column and several surrounding microatolls at the same level on the sandflat have planar tops at -0.6m (AHD). This level is approximately 0.8m higher than modern coral growth, and coincides with data of Chappell and others (1983) from further south in the central Great Barrier Reef which showed a late post-glacial sea-level high of +1m around 6000 yr BP. The raised, dead coral platform at the outer margin of the fringing reef is also higher than modern coral growth, indicating growth at a slightly higher sea-level.

Nature of the Clay Fraction

The high terrigenous content of all the sedimentary units indicates that the Cape Tribulation fringing reefs have developed in an environment of consistent terrigenous influx. Fine to medium quartz sand constitutes 50% of the sand fraction in all units.

The mud is also dominantly non-carbonate (Fig.10, **Appendix IV**). Most samples contain % acid-soluble material, and those with 20-50% come from the reef top unit and the beach-beach ridge sand. X-ray diffraction analyses show the clay-size carbonate is a mixture of calcite, magnesian calcite and probably aragonite. The calcite may be derived from bioerosion of oysters, reworking of soil carbonate from Pleistocene alluvium, or contemporary input.

The mineralogy of the terrigenous clays was investigated by X-Ray diffraction to test whether such a technique could be used to trace modern inputs (**Appendix V**). The terrigenous clays are a mixed assemblage.

Preliminary sampling of the contemporary input indicates two assemblages. The first is composed of abundant kaolinite and illite/illite-smectite mixed layer clays, and rare smectite. The second is characterized by abundant hydromica/vermiculite and vermiculite-mixed layer clays, with common kaolinite and illite, and lacking smectite. In summary, contemporary input appears to be dominated by kaolinite, hydromica/vermiculite, subsidiary mixed layer I-S clays, and only rare smectite.

Modern marine beach/beach-ridge, nearshore and inner shelf clays are characterized by common to abundant smectite, smectite/illite mixed layer clays and large d-spacing material. Kaolinite is common to abundant and illite common. This marine clay mineral assemblage contains minimal amounts of smectite, and is distinctly different to that being discharged to the sea by coastal creeks in the area, and by the Daintree River. However, in the beach/beach-ridge sediments onshore there is also a mixed-layer smectite/vermiculite, from which develops a discrete vermiculite phase down the hole.

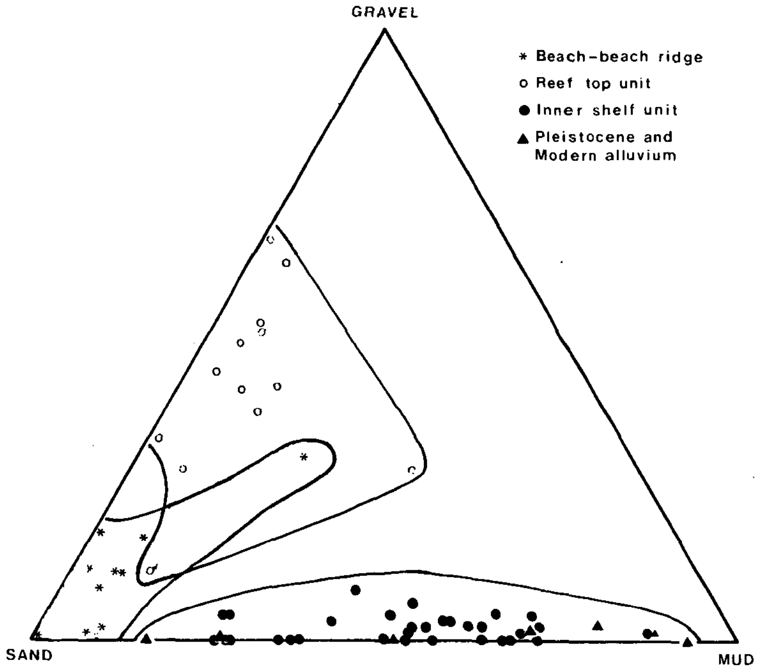

Figure 10. *Ternary diagram showing gravel, sand and mud contents of sediments from auger and vibracore samples. Shading delimits samples from the same environments.*

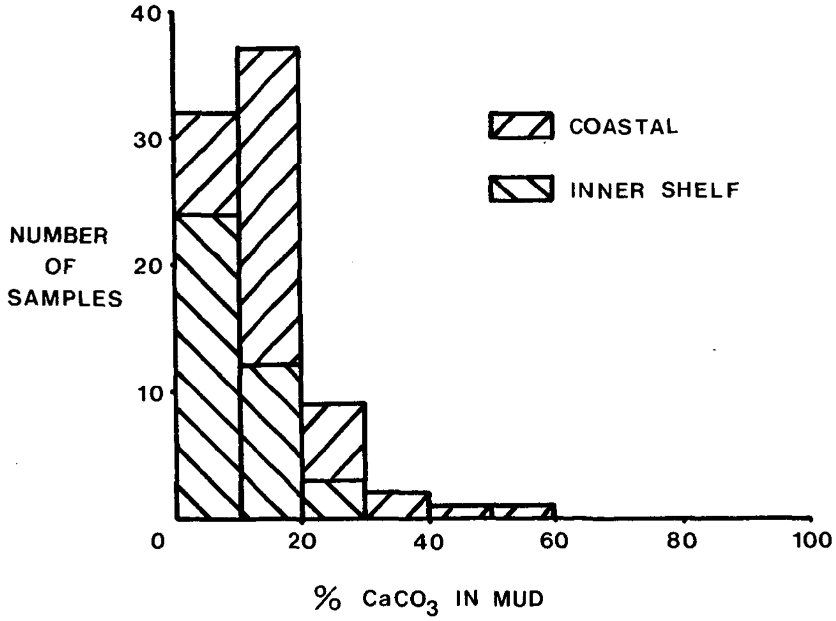

Figure 11. *Acid soluble (calcium carbonate) percentages of muds.*

The mottled muddy sediment underlying the inner shelf unit is dominated by kaolinite and illite, with hydromica and beidellite-kaolinite mixed layer clays. Smectite and smectite- mixed layer clays are rare. This assemblage is also typical of the Pleistocene unit recovered by auger drilling under the shoreward edge of the present coastal plain. However, onshore, kaolinite is even more dominant over illite. This clay mineral assemblage is more like the contemporary input and its composition suggests formation in a weathered kaolinite-rich soil horizon. Thus it seems clay minerals cannot be used to trace the discharge of individual drainage systems in this area.

In summary both the modern terrigenous inputs and the mottled muds are dominated by kaolinite/illite assemblages, while the modern marine sediments are dominated by smectite and illite- smectite mixed layer clays. It is unlikely the modern clays are being selectively transported away from the immediate offshore area. The different assemblages are probably due to rapid diagenesis of the clays when they are immersed in the marine environment.

5. DEVELOPMENT OF THE CAPE TRIBULATION AREA FRINGING REEFS

The Cape Tribulation area fringing reefs are developed mainly on coastal sediment bodies. The reef appears to grow as an irregular, indented wall which builds seawards, and is later encased in detrital material. The present reef margin has a deeply-incised spur and groove morphology with isolated coral colonies growing seaward of the reef edge. The drillhole data show the subfossil reef-flat also contains coral columns surrounded by detrital sediment, supporting this interpretation. Modern coral growth is generally in water depths shallower than ca 6m below AHD. Such a limited depth range of coral growth is consistent with other data from the literature amd with the turbid waters commonly observed during fieldwork. Thus the reef-top unit has a potential thickness of ca 7m and is prograding seawards over muddy deposits of the inner shelf unit.

Reef accumulation is very similar to other fringing reefs from the Great Barrier Reef region described previously by Hopley and others (1983) and Johnson and Risk (1986). Carbonate-rich reefal deposits are prograding seawards over finer grained, terrigenous sediments which are accumulating on the inner shelf seaward of the fringing reef. Sandy beach and beach ridge sediments are being deposited to landward by shoreward transport of skeletal carbonate across the reef flat, and by longshore transport of terrigenous sediment from river and creek mouths.

The reefs have grown throughout their history in an environment of heavy terrigenous influx. Sediments of all units have terrigenous contents greater than 50%, and in many cases greater than 80%. Data from continuous cores through the inner shelf unit show the carbonate content of the mud is highest (17- 26%) in the surficial sediments at the deeper water edge of the inner shelf unit. The carbonate content of the mud is generally constant, in the range 1-11% throughout most of the unit, indicating there has been little change in terrigenous influx during accumulation.

We interpret the dead columns and microatolls on the reef-flat, and the dead raised reef-margin, as representing corals stranded by the mid- Holocene fall in sea-level. Similar emergent, subfossil reefs also occur further south (Chappell and others,1983; Johnson and Risk,1986). The Cape Tribulation "fringing reefs" in fact lack live coral on the reef-flat and crest, and contemporary coral growth is restricted to the fore-reef slope.

6. CONCLUSIONS

1. The mainland fringing reefs of the Cape Tribulation area are primarily developed on coastal sediment bodies, not against steep rocky headlands.

2. The reefs consist of a fossil, coral-rich, reef-flat with a seaward fringe of living coral. Further seawards, the reef abuts, and probably overlies, a muddy inner shelf unit. To landward, beach-beach ridge sands overlie the fossil reef-flat unit.

3. All sediments associated with the reef have high terrigenous contents (>50%), indicating the reefs have always grown under heavy terrigenous influx. However, the rapid diagenesis of clays in the marine environment in this area precludes their use as tracers of discharge from individual drainage systems.

4. Radiocarbon dating of levelled dead microatolls and coral columns shows that they grew at a higher sea-level, indicating that the fossil reef-flat was produced by the mid-late Holocene sea-level fall.

5. There are virtually no data on the turbidity tolerances of Great Barrier Reef fringing reef corals and coral communities, nor on the variations experienced by these communities. Thus management authorities cannot assess accurately whether corals such as those at Cape Tribulation are growing well within their turbidity tolerances, or whether their existence would be threatened by even a small increase in turbidity.

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ERRATUM

The two following references were inadvertently omitted from the main reference list :

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APPENDIX I

CORAL SPECIES LIST FOR THE CAPE TRIBULATION AREA

BY

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SOURCE : Veron, J.E.N., 1986. Checklist of corals from the Daintree Reefs.Fringing Reef Workshop - Science, Industry and Management. Great Barrier Reef Marine Park Authority, Workshop Series No. 9, p.99-103.

Checklist of corals from the Daintree Reefs

J.E.N. Veron

Australian Institute of Marine Science

Summary

141 species of scleractinian corals, belonging to more than 50 genera, were recorded from the Daintree reefs during a 3 day study in November, 1985. Of these species, *Alveopora gigas, A.marionensis* and *Psammocora sp.* have not previously been recorded from the Great Barrier Reef. The absence of any previous record of *Alveopora gigas* from any eastern Australian community except the Daintree reefs is extraordinary since the species forms conspicuous colonies with large and very distinctive polyps.

Species List

Acanthastrea echinata	rare, recorded from Ayling alone
Acropora aculeus	rare
Acropora anthocercis	rare, difficult to recognize
Acropora brueggemanni	very common and widespread
Acropora cerealis	uncommon
Acropora cytherea	patchy
Acropora danai	in one area only
Acropora divaricata	common, most colonies purple
Acropora donei	patchy
Acropora elseyi	patchy, abundant at one site
Acropora formosa	patchy
Acropora grandis	rare or very patchy
Acropora humilis	uncommon
Acropora hyacinthus	uncommon
Acropora kirstyae	rare
Acropora latistella	patchy
Acropora microclados	uncommon
Acropora microphythalma	very common in some area
Acropora millepora	uncommon; distinct salmon pink
Acropora nasuta	patchy
Acropora palifera	very common
Acropora paniculata	rare
Acropora samoensis	common
Acropora selago	patchy or uncommon
Acropora subulata	very common
Acropora tenuis	common, very distinct
Acropora sp.	very common, widespread
Acropora valida	very common in shallow water
Acropora vaughani	patchy
Acropora willisae	common in shallow water
Alveropora gigas	common, not previously recorded ineastern Australia
Alveopora marionensis	common, not previously known from GBR

Astreopora myriophythalma	rare
Barabattoia amicorum	uncommon, similar to *Favia*
Blastomussa wellsi	rare
Caulastrea furcata	rare
Coeloseris mayeri	identified by Ayling
Coscinareae columna	very common, widespread
Cyphastrea microphthalma	common, big knobby colonies
Cyphastrea serailia	common
Duncanopssamia axifuga	uncommon
Echinophyllia aspera	very common, widespread
Echinophora gemmacea	common
Echinopora horrida	rare, identified by Ayling
Echinopora lamellosa	very common, widespread
Euphyllia ancora	uncommon, very distinctive
Euphyllia alabrescens	uncommon, very distinctive
Favia favus	common
Favia lizardensis	uncommon, large colonies
Favia pallida	common
Favia speciosa	rare
Favia veroni	uncommon, distinctive
Favites abdita	uncommon
Favites complanata	uncommon or patchy
Favites flexuosa	rare
Favites halicora	uncommon
Favites pentagona	very common
Favites russelli	rare
Fungia fungites	very common
Fungia paumotensis	common
Fungia repanda	very common
Fungia simplex	uncommon
Fungia valida	common
Galaxea astreata	common
Galaxea fascicularis	common
Goniastrea australensis	very common, very large colonies
Goniastrea favulus	uncommon
Goniastrea palauensis	common
Goniastrea pectinata	uncommon
Goniastrea retiformis	common
Goniopora columna	common; large oral cones
Goniopora djiboutensis	common; flat sheets
Goniopora lobata	common
Goniopora minor	patchy
Goniopora stokesi	rare, identified by Ayling
Goniopora stutchburyi	uncommon
Goniopora tenuidens	common as large colonies
Heliofaugia actiniformis	rare
Herpolitha limas	common in some areas
Hydnophora exesa	very common
Hydnophora pilosa	rare
Leptastrea pruinosa	common
Leptastrea purpurea	common
Leptoria phrygia	rare
Leptoseris mycetoseoides	patchy
Lobophyllia hemprichii	common or patchy

Merulina ampliata	very common
Montastrea curta	uncommon
Montastrea magnistellata	rare
Montipora aequituberculata	common, small colonies
Montipora crassituberculata	uncommon
Montipora foliosa	uncommon, small colonies
Montipora grisea	probably rare
Montipora hispida	very common
Montipora hoffmeisteri	uncommon, cryptic
Montipora informis	rare
Montipora nodosa	common
Montipora spumosa	uncommon
Montipora stellata	very common, widespread
Montipora undata	uncommon
Montipora verrucosa	uncommon
Moseleya latistellata	
Mycedium elephantotus	identified by Ayling
Oulophyllia crispa	identified by Ayling
Oxypora lacera	very common
Pachyseris rugosa	common at one site only
Pachyseris speciosa	very common
Pavona cactus	rare, Ayling identified
Pavonia varians	uncommon
Pavona venosa	very common
Pectinia lactuca	very common, widespread
Platygyra daedalea	common
Platygyra lamellina	uncommon
Platygyra pini	common
Platygyra sinensis	common
Platygyra verweyi	uncertain identification; rare
Plerogyra sinuosa	rare
Pocillopora damicornis	common
Podobacia crustacea	common
Polyphyllia talpina	common
Porites annae	common
Porites lichen	common, lacks distinct coloration
Porites lutea	very common; large colonies
Porites mayeri	common; colonies become columnar
Psammocora contigua	patchy
Psammocora profundacella	uncommon
Psammocora superficialis	patchy; unusually large colonies
Psammocora sp.	common; upright flattened branches
Psuedosiderastrea tayamai	uncommon, distinctive
Sandalolitha robusta	uncommon
Seriatopora hystrix	common in isolated patches
Stylocoeniella guentheri	uncommon, cryptic
Stylophora pistillata	common; forms unusually fine branches
Symphyllia agaricia	rare
Turbinaria bifrons	uncommon
Turbinaria conspicua	
Turbinaria mesenterina	the most common *Turbinaria*
Turbinaria patula	rare
Turbinaria peltata	patchy
Turbinaria reniformis	common

APPENDIX II

REVIEW OF THE EFFECTS OF SILTATION ON CORALS AND CORAL COMMUNITIES

BY

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Effects of Siltation on Corals and Coral Communities

D.P. Johnson

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Introduction

Any analysis of the effects of siltation on coral reefs necessarily revolves around the siltation tolerances of corals. Corals are the basic constructional organisms of the reef, and are central to the integrity of the reef community. Changes in coral reef communities depend on the responses to siltation of the individual component species. Johannes (1975) has pointed out that selective mortality of corals results in the migration or death of other fauna. In other words, the environmental tolerances of the reef community cannot exceed those of the component corals. This is not to say that other organisms may not have narrower tolerances or are not integral parts of the community. However the corals are so important ecologically and visually that their needs at least must be met.

Coral reef ecosystems are very sensitive to ecological change for three reasons (Pastorok and Bilyard, 1985):

- corals have narrow physiological tolerances,
- key species interactions are susceptible to pollutant stresses, and
- effects of toxic materials may be greater at highwater temperatures.

This review concentrates on the effects of particulate materials, rather than nutrient or toxic pollution. Firstly the effects on individual species are summarised, secondly the consequent changes in coral communities are noted, and finally a qualitative summary of the effects of siltation is given with observations on the research which needs to be done.

Deleterious Effects of Siltation on Reefs

Although healthy coral communities have been observed growing in generally turbid waters (e.g. Marshall and Orr,1931; Roy and Smith,1971), it is also clear that many reefs have been extensively damaged or destroyed by excessive siltation. Johannes (1975) summarised several studies, particularly those which ocurred in response to man's activities, such as increased sediment yields due to poor land management, dredging spoil, mill waste and sewage pollution. Pastorok and Bilyard (1985) have reviewed the effects of sewage pollution, including the detrimental effects of increased levels of nutrients, sediments and toxic substances.

Dodge and Vaisnys (1977) compared both living and dead corals from two areas in Bermuda : 1) undisturbed reefs and 2) reefs in a harbour where dredging had occurred 35 years previously. The dredged area showed a lower density of living specimens, a lower proportion of live/dead corals, and altered relative species abundances. Two species of brain coral, *Diploria strigosa* and *D.labyrinthiformis* are equally represented on undisturbed reefs and in dead coral populations from the dredged harbour. However *D. labyrinthiformis*, a species demonstrably more capable of sediment rejection, is the dominant living form inside the harbour. Analysis of the growth patterns of the dead harbour corals showed an abrupt decrease in growth rate, lasting up to nine years before death. In summary, the dredging and subsequent sedimentation in the harbour produced mass coral mortality, although the effects varied from species to species, and it appears the effects of the dredging lasted several years after the event. Unfortunately there are no data on the amount of turbidity induced at the time, nor the pattern over time of its dispersal.

The immediate effects of suspended sediment were recorded by Bak (1978) during the dredging of a bay channel in Curacao. For two days the suspended sediment cloud reduced light levels at 12-13m water depth from the normal 30% to less than 1% of surface illumination. For two more days light levels were less than 6% surface levels. The dredge continued working for a further 14 days during which light levels were less drastically depressed due to currents sweeping the sediment in other directions. On the fifth day of dredging, the reef was covered by 10mm of sediment, apart from the corals which had removed the sediment from their colonies. One coral, platey *Porites astreoides*, appeared unable to dislodge the sediment, became covered and wholly or partly died. All measured corals showed an abrupt decrease in coral calcification rates (up to 33%), and rates remained depressed for more than one month.

A fringing reef near Cahuita, Costa Rica is under siltation stress due to increased sediment influx following regional deforestation of the catchment (Cortes and Risk, 1985). Suspended particulate matter analyses for waters over the reef were in the range 0.2-54.0 ppm. Sediment resuspension rates were much higher than reported for other Caribbean reefs. The study showed that the depths at which corals occurred were shallower in these turbid waters than for the same species in clear waters in the Caribbean, and that coral growth rates were inversely proportional to sediment resuspension rates.

Not all major sediment influxes have disastrous effects. For instance, Dollar and Grigg (1981) reported minimal damage to a reef 14 days after a major spill of kaolin from a grounded freighter. The minimal effects could be due to the fine grained and inert nature of the kaolin, but is probably mainly due to the off-reef transport of the material (see their Figure 5).

In situations where suspended sediment is due to terrestrial influx, the deleterious effect of the sediment is compounded and in some cases outweighed by the osmotic problems resulting from immersion of the corals in low salinity waters (e.g. Rainford, 1925; Goreau, 1964; Banner, 1968). Following Hurricane Flora in 1964, Goreau (1964) reported immense influxes of sediment and fresh water to the sea off Jamaica. Two days of heavy rain resulted in offshore river plumes which lowered nearshore salinities to 3 ppt for two days and to 30 ppt for five weeks. Massive bleaching and expulsion of zooxanthellae from the reef corals occurred. That these effects were due primarily to the fresh water is indicated by three facts : 1) the bleaching and expulsion was confined to a horizontal zone about 3m deep cutting across the topography, 2) the depth of bleaching was greater closer to the source of freshwater influx, and 3) the restriction of bleaching to the surface layers whereas sediment shading should affect deeper zones more than shallow ones.

Laboratory studies to quantify the effects of suspended sediment on corals have been conducted by Bak and Elgershuizen (1976), and Dodge (1982). Bak and Elgerhuizen (1976) compared the rejection behaviours of 19 Caribbean hermatypic corals to sand, oil-sand mixtures and carborundum powder. Rejection of oil-sand particles and of clean sand show similar patterns, with some species showing greater efficiency for carborundum compared to sand, and some species the reverse. Rejection times are generally less than 10 hours and commonly less than 4 hours. The rejection times were longer for larger sand placements on the coral, being typically less than four hours for 0.75g sand but 5-15 hours for 3.0g of sand.

In contrast to the direct addition of sediment to the corals by Bak and Elgerhuizen (1976), a study by Dodge (1982) evaluated the effects on a coral of chronic (6 weeks) exposure to suspended (100 ppm) commercial drilling mud. The coral studied was the common and ecologically important Caribbean species *Montastrea annularis*. Upward, linear growth rate was significantly depressed and there was increased mortality. Szmant-Froelich et al. (1981) working on the same corals, found calcification rates were only 47% after four weeks and 16% after six weeks. Corals exposed to 1 and 10 ppm suspended sediment levels showed none of these adverse effects.

These studies have established the deleterious effect of substantial siltation on corals. It is clear that species vary in their tolerance of siltation, and particularly that intermittent siltation can be tolerated where chronic sedimentation cannot. However, there are very few data on how frequently siltation episodes can be tolerated, or what are the critical levels of suspended sediment before corals are adversely affected. The following points can be made :

1) Corals can thrive in ambient light levels 30% of surface illumination and grow in zones of <5% surface illumination. Data of Motoda (1939) show light levels in clear water are 5% of surface at 20m depth.

2) Suspended sediments attenuate the light levels and therefore can be expected to affect increasingly the corals growing in deeper waters. In areas of chronic turbidity this may impose a shallower than normal limit for coral growth.

3) Laboratory experiments indicate severe effects on coral in shallow water due to 100ppm suspended sediment, but no effects due to 10ppm. Field data of Motoda (1939) confirm vigorous coral growth at 10m water depth with 25ppm suspended material. Field data of Cortes and Risk (1985) indicate 5ppm suspended particulate matter can inhibit coral growth where there are high rates of sediment resuspension. The sensitivity of some common coral species to sedimentation has been summarised by Pastorok and Bilyard (1985). However most of these data are for Atlantic corals.

4) Despite the known dependence of calcification rates on light levels (Goreau, 1959), the relationship is not simple. For instance, not all coral species show a direct correlation between calcification and sun hours (Bak,1974), some coral species calcify more slowly in shallower rather than deeper water (Barnes and Taylor, 1973; Bak, 1976), and decreased calcification rates continue well after light levels have returned to normal following dredging operations, presumably due to metabolic shock (Dodge and Vaisnys, 1977; Bak, 1978).

5) The deleterious effects of a major influx of suspended sediment may outlast the immediate environmental problem by a period of months to years. This long term damage may be due to continued resuspension of introduced sediment or to poorly known effects of metabolic shock.

6) Fringing coral reefs do grow in areas of chronic sediment resuspension (e.g. Marshall and Orr (1931), where the amount of suspended sediment is controlled by local winds and perhaps tidal conditions. Continued coral growth requires constant water flushing to prevent sediment blanketing the corals. Data on the daily and weekly variations in turbidity, and the relation to coral communities have not been published.

7) The deleterious consequences of suspended sediments on corals could be due to six effects (Bak, 1978; Lasker, 1980; Cortes and Risk, 1985):

- Suspended sediment causes lower light levels which depress calcification rates.
- Sediment blankets the coral causing suffocation.
- Energy used in removing the sediment saps the vitality of the polyp.
- Suspended sediment has unfavourable effects on the plankton food sources for the corals.
- Suspended sediment and soft sediment cover on the substrate may prevent successful settlement of planulae.

In cases where the suspended sediment is due to terrestrial runoff, the associated fresh waters may cause major osmotic problems for the polyps.

Mechanisms of Sediment Rejection by Corals

Most hermatypic corals are efficient sediment rejectors compared to other benthic organisms, considering the observation of Bak (1978) that only the corals were clean following sediment influx, while the rest of the reef had a 10mm coating of sediment. Corals employ four mechanims of sediment rejection (Hubbard and Pocock, 1972) :

Distension of the body mass by water intake to cause sediment to slough off. Since there appears to be no coordinated effort across the colony, larger corals would be particularly disadvantaged. Mucus secretion and the entangling of sediment followed by removal of the mass by ciliary action. Removal of particles by tentacles. Ciliary beat producing currents to sweep particles off the polyp.

The different strategies vary between species (Hubbard and Pocock,1972), and seemingly under different conditions for the same species, since the same species performed differently in the studies of Hubbard and Pocock (1972) and of Bak and Elgerhuizen (1976).

Bak and Elgershuizen (1976) note that the inital polyp response to sediment rain is contraction followed by expansion, and the clearing of the surface by ciliary currents and movement of tentacles. Mucus trapping tends to delay clearing of detritus from the polyp surface. Even the one coral may use different strategies to cope with different sediment sizes. For instance, *Montastrea cavernosa* was observed to remove large oil-sand aggregates (30mm) by tentacular action and polyp distension, but smaller particles by ciliary action. However silt-size (to 63 micron) sediment is the coarsest material normally removed easily by corals (Hubbard and Pocock,1972).

In general it seems individual polyp behaviour is more important than other features such as colony form and calyx density for efficient sediment rejection. However, Lasker (1980) argues that both colony form and species behaviour are important, contributing to separate passive and active phases of sediment removal. Passive removal is promoted by convex colonies and tall polyps, while active removal involves action by the polyp. The success of continued sediment removal and continued coral growth will depend on the coral morphology and habitat. It has been observed that a single species has separate morphologies (displays different ecomorphs) in clear versus turbid waters (Laborel, 1969; Loya, 1972). Branched corals through which suspended mud can easily pass are clearly more adapted to turbid situations than platey forms. For instance Rogers (1979) found Rogers (1979) found *Acropora cervicornis* colonies were not affected by applied sediments even though they were killed by shading. Vigorous water movement can help remove particles so that an individual coral is not blanketed for extensive periods.

Responses of Coral Communities to Shading and Turbid Waters

Coral communities growing in turbid waters differ from those in clear waters, in three main ways : lesser coral cover, lower growth rates, lower diversity and different species composition. Dying coral and prolific algal growth are a common response especially where nutrient and sediment influx occur together (e.g. Weiss and Goddard,1977).

The deleterious effects of high sedimentation rates (Fig.A1) on coral communities has been documented in Guam by Randall and Birkeland (1978). Pastorok and Bilyard (1985) summarised the study *"Based on their data, Randall and Birkeland (1978) would expect a 'depauperate coral community of less than 10 species covering less than 2% of the substrate' where the average sediment loads are about 160 to 220 mg/sq.cm/day. A 'rich coral community of over 100 species covering over 12% of the solid substrate' is expected where average sedimentation rates are about 5 to 32 mg/sq.cm/day."*

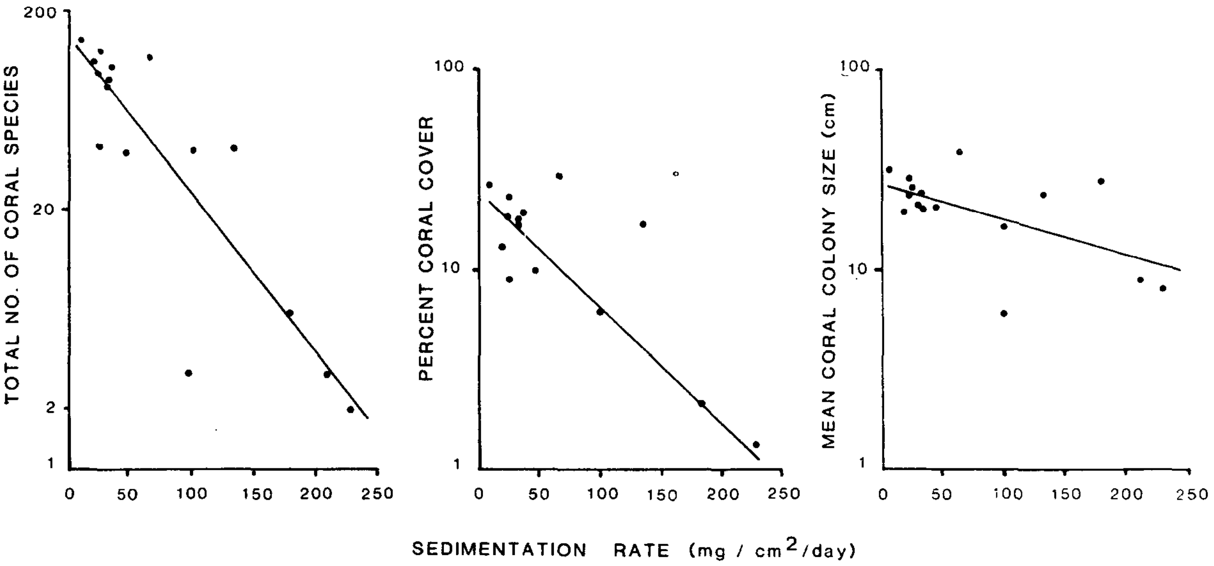

Figure A1. *Coral species richness, percent cover, and colony size as a function of sedimentation rate, Guam (from Pastorok and Bilyard, 1985, based on data from Randall and Birkeland, 1978)*

SEDIMENTATION RATE mg/cm^2/day	DEGREE OF IMPACT
1 - 10	**Slight to moderate** Decreaseed abundance Altered growth forms Decreased growth rates Possible reductions in recruitment Possible reductions in numbers of species
10 - 50	**Moderate to severe** Greatly decreased abundance Greatly decreased growth rates Predominance of altered growth forms Reduced recruitment Decreased numbers of species Possible invasions of opportunistic species
> 50	**Severe to catastrophic** Severely decreased abundance Severe degradation of communities Most species excluded Many colonies die Recruitment severely reduced Regeneration slowed or stopped Invasion by opportunistic species

Table 1. *Estimated degree of impact of various sedimentation rates on coral communities (from Pastorak & Bilyard, 1985).*

Similarly coral cover in clear waters averages 60-80% and extends to depths exceeding 15m, but averages only 30% in turbid areas where it is present only to 9m water depth (e.g. in the Fanning Lagoon; Roy and Smith,1979). Lower coral growth rates in turbid areas have also been documented by Aller and Dodge (1974) and Cortes and Risk (1985). Lower species diversity is found in areas of higher sediment resuspension (Aller and Dodge,1974) and sediment settling (Loya,1972,1976). Similarly, Bull (1982) found coral growth on a fringing reef in the Great Barrier Reef, where there was higher deposition of finer sediment, displayed lower species diversity, lower coral cover and a shallower limit to coral growth.

It is well established that reefs with high rates of sedimentation and resuspension have characteristic faunas, and that corals which dominate such reefs are subordinate or absent on clear water reefs (Lewis, 1960; Roy and Smith, 1971; Loya, 1976; Bull, 1982; Done, 1982). Some of these dominant species have been demonstrated to be efficient sediment rejectors in laboratory experiments (Bak and Elgershuizen, 1976).

A corollary to these observations is that increased sedimentation and resuspension rates should alter the community structure of a reef. Several studies confirm this expectation. For instance Dodge and Vaisnys (1977) demonstrated the change in community structure which followed siltation due to harbour dredging.

Summary

The response of a coral reef to increased siltation, either greater influx of turbid waters or greater resuspension, will vary according to the species present and the degree, type and duration of the siltation. Quantification of the threshold levels for individual species or communities is almost impossible with present data. Pastorok and Bilyard (1985) summarised the available data as a qualitative impact scale (Table 1). Most present data on coral and coral community responses to siltation have been derived from Atlantic species. In general it seems that sewage and other toxic substances have little impact in well flushed environments, such as exist in coastal and offshore situations in the Great Barrier Reef, particularly where there is so little pollution. However, increased sedimentation is a more likely problem, especially in near coastal situations, yet there are virtually no data on the effects of increased sedimentation in Indo-Pacific corals. Medium to long term studies are needed on Great Barrier Reef coral community responses to increased sedimentation.

APPENDIX III

RADIOCARBON AGE DATA

Radiocarbon age data provided by the Waikato University Radiocarbon Dating Laboratory, Director Dr. A.G. Hogg.

Wk	Coll.No	^{13}C (%)	$D^{14}C$ ± SE (%)	Conv Age (yrs BP)	True Age (yrs BP)
853	JMB1 3.9m	0.5E	-436.0 ± 4.4	4600 ± 80	4730 ± 80
854	JMB1 4.8-4.	0.5E	-420.1 ± 3.9	4380 ± 70	4510 ± 70
855	JMB4 0.5m	0.5E	-522.5 ± 4.1	5940 ± 80	6110 ± 80
856	JMB4 1.5-2.	0.5E	-527.2 ± 4.0	6020 ± 80	6190 ± 80
857	JMB4 4.0m	-3.7	-510.2 ± 6.9	5730 ± 120	5901 ± 120
858	JMB4 (A)	-1.1	-497.0 ± 3.8	5520 ± 60	5680 ± 70

* Sample diluted 37% s

Radio-carbon age determinations, University of Waikato laboratory, Hamilton; New Zealand.

APPENDIX IV

TEXTURAL AND ACID-SOLUBLE DATA

Laboratory analyses performed by Neil Mockett, Geology Department, James Cook University.

Depth (m)	**Gravel** %	**Sand** %	**Mud** %	**Mud** (Acid Soluble %)
		JMB 1		
0.1-0.2	30	66	3	10
0.2-0.3	Tr	99	1	19
1.0	9	86	6	22
2.0	1	92	7	5
3.0	43	52	5	18
4.5	28	65	8	10
5.5	28	32	40	3
8.8	43	27	30	
		JMB 2		
0.0	18	81	1	9
0.5	2	89	9	57
1.0	1	91	9	31
2.0	11	83	6	44
3.0	17	76	8	35
4.0	33	64	3	14
5.0	65	33	2	8
6.0	49	46	6	23
6.5	42	44	14	9
7.0	50	37	13	27
7.5	38	49	13	22
9.0	31	39	30	24
10.4	45	29	26	18
		JMB 5		
0.0	Tr	84	16	18
0.5	Tr	73	27	17
1.0	Tr	49	51	16
1.5	2	28	70	12
2.0	3	18	79	10
		JMB 6		
0.0	13	81	6	14
0.5	11	86	3	13
1.0	12	77	11	9
1.25	40	50	10	11
1.75	12	77	11	9
3.0	62	33	5	16
4.0	52	41	7	9
		V20		
0.03	Tr	36	64	22
0.40	2	43	55	26
0.88	3	40	57	26
1.04	8	50	42	13
1.47	1	28	72	11
1.60	0	7	93	4
1.75	1	11	88	3

V21				
0.04	3	37	61	18
0.45	7	41	53	17
0.85	1	30	69	14
1.03	1	12	87	3
V22				
0.05	Tr	43	57	15
0.65	2	43	55	13
1.03	1	32	68	8
1.78	2	36	61	5
2.10	4	47	50	3
2.55	7	30	63	1
V23/3				
0.15	Tr	74	26	13
0.17	1	49	50	6
0.80	3	72	25	8
1.25	4	70	26	10
1.90	2	56	41	5
V24				
0.15	Tr	47	53	7
0.75	Tr	44	56	6
1.40	Tr	33	67	3
1.75	2	45	53	9
2.40	1	33	67	7
2.75	4	32	64	7
3.30	1	28	72	7
V25				
0.11	0	65	35	7
1.06	Tr	73	27	7
1.79	1	62	38	5
2.13	Tr	42	58	4
V26				
0.15	Tr	72	28	11
0.75	1	63	37	11
1.30	1	43	57	11
1.85	3	39	58	9
2.30	6	43	51	7
2.85	4	27	69	3

Note : 1) Some totals for gravel + sand + mud may not be 100 due to rounding.
2) Tr < =1%

APPENDIX V

SUMMARY TABLE OF X-RAY DIFFRACTION DATA FOR TERRIGENOUS CLAYS

Laboratory analyses performed by Neil Mockett, Geology Department, James Cook University.

TABLE 1
CLAY MINERALS IN STREAM SAMPLES

	KAOLINITE	ILLITE	ILLITE I/S MIXED LAYERS	HYDROMICA VERMICULITE & V MIXED LAYERS	SMECTITE
TACHALBADGA CK. (NMRS 1)	***	-	***	-	*
EMMAGEN CK. (NMRS 2)	**	**	-	***	-
MYALL CK. (NMRS 3)	**	**	-	***	-
OLIVER CK. (NMRS 4)	**	**	-	***	-
NOAH CK. (NMRS 5)	**	**	-	***	-
COOPER CK. (NMRS 6)	**	**	-	***	-
DAINTREE RIVER	***	-	***	-	*

TABLE 2
CLAY MINERALS IN NEARSHORE SURFACE SAMPLES

	KAOLINITE	ILLITE	SMECTITE, S/I MIXED LAYERS & LARGE D-SPACING MATERIAL
V26	***	**	**
V25	***	**	**
V23/3	**	**	***
V24	**	**	***
V22	**	**	***
V20	**	*	***
V21	**	**	***
V27	**	**	***
V28	**	**	***

Note :

abundant	***
common	**
rare	*
absent	-

TABLE 3
CLAY MINERALS IN V20

DEPTH (M)	KAOLINITE	ILLITE	SMECTITE S/I MIXED LAYERS	BEIDELLITE/ KAOLINITE MIXED LAYERS
0.00	**	*	***	-
0.95	**	*	***	-
1.49	***	**	**	-
Pre - Holocene surface				
1.62	***	***	-	*
1.79	**	***	-	*
		(Mica/illite)		

TABLE 4
CLAY MINERALS IN V28

DEPTH (M)	KAOLINITE	ILLITE	SMECTITE S/I MIXED LAYERS	BEIDELLITE/ KAOLINITE MIXED LAYERS
0.00	**	**	***	-
0.47	**	*	***	-
0.63	**	*	***	-
0.82	**	**	***	-
Pre - Holocene surface				
1.03	***	*	-	***

Note :	abundant	***
	common	**
	rare	*
	absent	-