CYPLUS

CAPE YORK PENINSULA

LAND USE STRATEGY

NATURAL RESOURCES ANALYSIS PROGRAM
(NRAP)

COASTAL ENVIRONMENT GEOSCIENCE OF CAPE YORK PENINSULA

R.V. Burne and T.L. Graham
Australian Geological Survey Organisation
1995

With contributions by:
J.F. Marshall, P. Michaelsen and B.G. Lees

AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

CYPLUS is a joint initiative of the Queensland and Commonwealth Governments

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Final report on project:

NR14 - COASTAL ENVIRONMENT GEOSCIENCE SURVEY

CAPE YORK PENINSULA LAND USE STRATEGY
STAGE I

PREFACE TO PROJECT REPORTS

Cape York Peninsula Land Use Strategy (CYPLUS) is an initiative to provide a basis for public participation in planning for the ecologically sustainable development of Cape York Peninsula. It is jointly funded by the Queensland and Commonwealth Governments and is being carried out in three stages:

- Stage I - information gathering;
- Stage II - development of principles, policies and processes; and
- Stage III - implementation and review.

The project dealt with in this report is a part of Stage I of CYPLUS. The main components of Stage I of CYPLUS consist of two data collection programs, the development of a Geographic Information System (GIS) and the establishment of processes for public participation.

The data collection and collation work was conducted within two broad programs, the Natural Resources Analysis Program (NRAP) and the Land Use Program (LUP). The project reported on here forms part of one of these programs.

The objectives of NRAP were to collect and interpret base data on the natural resources of Cape York Peninsula to provide input to:

- evaluation of the potential of those resources for a range of activities related to the use and management of land in line with economic, environmental and social values; and
- formulation of the land use policies, principles and processes of CYPLUS.

Projects examining both physical and biological resources were included in NRAP together with Geographic Information System (GIS) projects. NRAP projects are listed in the following Table.

Physical Resource/GIS Projects	Biological Resource Projects
Bedrock geological data - digitising and integration (NR05)	Vegetation mapping (NR01)
Airborne geophysical survey (NR15)	Marine plant (seagrass/mangrove) distribution (NR06)
Coastal environment geoscience survey (NR14)	Insect fauna survey (NR17)
Mineral resource inventory (NR04)	Fish fauna survey (NR10)
Water resource investigation (groundwater) (NR16)	Terrestrial vertebrate fauna survey (NR03)
Regolith terrain mapping (NR12)	Wetland fauna survey (NR09)

Physical Resource/GIS Projects	Biological Resource Projects
Land resource inventory (NR02)	Flora data and modelling (NR18)
Environmental region analysis (NR11)	Fauna distribution modelling (NR19)
CYPLUS data into NRIC database FINDAR (NR20)	Golden-shouldered parrot conservation management (NR21)
Queensland GIS development and maintenance (NR08)*	
GIS creation/maintenance (NR07)*	

* These projects are accumulating and storing all Stage I data that is submitted in GIS compatible formats.

Research priorities for the LUP were set through the public participation process with the objectives of:

- collecting information on a wide range of social, cultural, economic and environmental issues relevant to Cape York Peninsula; and
- highlighting interactions between people, land (resource use) and nature sectors.

Projects were undertaken within these sector areas and are listed in the following Table.

People Projects	Land Projects	Nature Projects
Population	Current land use	Surface water resources
Transport services and infrastructure	Land tenure	Fire
Values, needs and aspirations	Indigenous management of land and sea	Feral and pest animals
Services and infrastructure	Pastoral industry	Weeds
Economic assessment	Primary industries (non-pastoral, non-forestry)	Land degradation and soil erosion
Secondary and tertiary industries	Forest resources	Conservation and natural heritage assessment
Traditional activities	Commercial and non commercial fisheries	Conservation and National Park management
Current administrative structures	Mineral resource potential and mining industry	
	Tourism industry	

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Notes:

Due to the timing of publication, reports on other CYPLUS projects may not be fully cited in the REFERENCES AND BIBLIOGRAPHY section. However, they should be able to be located by author, agency or subject.

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INTRODUCTION

The NR14, Coastal Environment Geoscience Survey project utilises a wide variety of information and techniques to compile the basic coastal geoscientific information necessary for the development of a land use strategy for Cape York Peninsula. The report therefore provides a statement of the methodology employed, together with results of the data analyses undertaken and coastal geoscience GIS coverages completed to date.

The project was undertaken to produce a geoscientific synthesis of the evolution and character of the coastal zone of Cape York Peninsula to include:

- assessment of the oceanographic and meteorological processes affecting the coastal area;
- documentation of the character of coastal environments and the nature of sedimentary deposits within them;
- analysis of Holocene evolution of the coastal zone;
- identification of areas of significant instability; and
- consideration of issues relevant to sustainable use.

METHODOLOGY

The approach adopted takes into account the factors which jointly determine the variation in coastal ecosystems. These include the landforms; processes; materials; and evolutionary history of the geoscientific components of the coastal zone and the relationship between these components, other physical and chemical environmental elements, and the biological communities.

The project examines coastal systems at a high spatial resolution by combining methods of field research with analysis of digital multispectral data obtained from satellite remote sensing. Field surveys of shoreline deposits were undertaken to reconstruct the history of coastal evolution , and to assess vulnerability to erosion or flooding. Offshore, marine geologists examined the seafloor using seismic profiling, bottom sampling, and direct inspection to assess the nature and extent of nearshore sediments, and to unravel their history of accumulation.

The methods employed have yielded six GIS coverages as follows:

1. Bathymetry. The coastal waters of Cape York are incompletely surveyed and poorly charted. No reliable digital coverage of the bathymetry exists. The GIS coverage was compiled by merging all available data from published nautical charts and additional material compiled by Mr Cameron Buchanan of AGSO with the reef location map compiled by GBRMPA. These data were merged and edited by Dr Neil Hamilton of the CSIRO Division of Wildlife and Ecology.

2. Benthic Substrates. This coverage consists of enhanced Landsat Thematic Mapper Data Sets. The depth/substrate unmixing algorithm of Bierwirth et al. (1993) has been applied to shallow water areas to indicate substrate type and bed roughness. In deeper water areas band 1 (blue light) of the Landsat data has been enhanced to provide information on bottom type.

3. Coastal Geoscientific Coverage. This coverage shows the distribution of coastal geoscientific mapping units which reflect both the morphostratigraphy and depositional environments of the coastal deposits. These were derived from interpretation of enhanced Landsat TM imagery and associated aerial photography.

4. Offshore Interpretive Coverage. This interpretation of the variation of offshore depositional environments is based on a review of the variation in seismic characteristics, bedform information, grab samples, core samples and Landsat Imagery.

5. Location of Cruise Tracks, Survey Lines and Sample Sites.

6. Data Files of the Sediment Analyses.

NATURAL AND ANTHROPOGENIC CONSIDERATIONS RELEVANT TO THE SUSTAINABLE USE OF COASTAL ENVIRONMENTS

Coastal erosion

Beach erosion and marine inundation of freshwater bodies near the coast are among the most pressing environmental concerns in coastal areas at the present time. Evidence of this shoreline retreat manifests itself in a number of ways. The most obvious evidence is the widespread occurrence of an erosion scarp at the back of beaches cutting into mature vegetated coastal features. Commonly associated with these scarps are a series of undermined and collapsed mature trees around the coast of Cape York Peninsula. On open sandy coastlines such as the northeastern flank of the Cape this erosion will continue to mobilise a fringe of dune sand behind the beach, which may over time increase to progressively larger transverse dunes. Consideration of both the erosional retreat of the shoreline and this mobile body of dune sand should be incorporated in future land use planning.

Another observed erosional indicator is the exposure of older, formerly buried stratigraphy through the eroding beachface. This was observed on the western side of Princess Charlotte Bay where mudflat facies were emerging through the beachface, and a small coastal dune with immature vegetation testified to the retreat of the coastline. Also, at this Princess Charlotte Bay site erosion had exposed a formerly buried mangrove sequence, while in other locations buried reef sequences are being exposed. Radiocarbon dating of samples from these sequences presently in progress will reveal their age of formation.

More subtle, but no less critical to land use, is the progressive saltwater invasion of water bodies and low lying flats adjacent to the coastline. This encroachment is observed more readily in the low lying areas such as Princess Charlotte Bay where salinity has turned former stands of forest into vast areas of deadwood.

Of significance to grazing in the area is the invasion of waterholes by saltwater. Anecdotal evidence from a local grazier suggests that saltwater invasion of streams has progressed more than a kilometre further inland in his lifetime. Additionally, supratidal invasion of coastal flats will progressively restructure the vegetation toward more salt tolerant species at the disadvantage of grazing.

Many beaches on the west coast of the Cape were observed to be in a generally constructive mode during 1994 survey work, despite the evidence of a substantial erosion scarp at the rear indicating long term erosion. Sections of coastline appear to be building out over bar platforms, and substantial berm development was observed in several locations. It is likely that this construction phase is a relatively temporary phenomena within the longer term trend of net erosion. Observations over a period might indicate that these phases are in fact cycles geared to short term wetter and drier climatic periods.

The interaction of human activities and coastal erosion can be viewed from two perspectives:

i. Humans as agents of change - Localised activities of people in the coastal zone do not generally result in significant coastal erosion. Exceptions to this from other parts of Australia and the world have been where extensive seawalls have been erected, and where substantial quantities of sediment have been trapped by catchments or removed from fluvial channels and the nearshore by mining. Large scale removal of subaqueous deposits results in a lowering of the local base level to which the onshore-offshore profile is attempting to equilibrate, resulting in an increase in the shoreline slope and ultimately to a reduction in sediment on beaches.

Conversely, vegetation removal in stream catchments can lead to an increase in sedimentation to the coast.

By far the most profound influence on coastal erosion initiated by human activity is the more insidious effect of constant sea level rise resulting from global warming. Although difficult to quantify, there is general agreement between the majority of scientists that sea level is rising due to global warming of the atmosphere. This warming increases the volume of oceans both directly and by an increased contribution from melting ice. The general consensus from a meeting of the Intergovernmental Panel on Climate Change (1991) is that global mean sea level will rise between 3-10 centimetres per decade for the next century. Although the complex interaction of oceanic and atmospheric processes is difficult to model it is predicted that a general increase in coastal erosion and flooding will result (and present evidence indicates this is already occurring), while other less predictable changes in oceanic and weather systems such as the incidence of cyclones and changes in currents and winds are likely.

ii. Humans as victims of coastal erosion - Coastal areas have long been a preferred site of human habitation, however, in recent decades the mobility of natural coastal features has increasingly come into conflict with the survival of high cost permanent structures. Remedial measures such as groins and seawalls are expensive and of limited long term effectiveness against continuous sea level rise. Careful consideration of coastal mobility and future increases in near coastal flooding when siting new construction is the most viable hazard mitigation measure on the extensive Australian coastline. Florida (USA) has demarcated a Coastal Construction Control Line seaward of which is declared a zone subject to erosion and regulation.

Population centres, tourist and recreational resources

Properly managed coastal areas can be a very positive tourist and recreational resource, conversely, when poorly managed can lead to accelerated depletion of the primary resource (eg. beaches, stream quality, fringing reefs), and an associated reduction in aesthetic value. Although not exhaustive the following discussion notes some aspects of coastal management that need to be addressed with examples from Cape York Peninsula.

Waste water

In areas of concentrated population such coastal townships and tourist facilities contamination of water bodies with waste water can become a significant problem. Excess nutrients from sewerage and polluted waste from light industry and fuel storage can have a profound effect on the structure of biological communities, particularly coral reefs.

The destruction of coral reef ecosystems by nutrification stemming from sewerage and agricultural runoff is well documented in the Caribbean and Hawaii, and several studies on the effect of nutrients are presently underway in the Great Barrier Reef. The introduction of increased levels of nutrients encourage algal growth at the expense of corals, and increase the susceptibility of corals to other environmental stresses such as disease, coral bleaching and sediment smothering.

Careful attention should be given to waste disposal systems in coastal areas, and in particular where largely untreated waste is directly introduced into nearshore zones or into near coastal water tables (eg. via septic systems).

As discussed previously the central region of estuaries (ie. normally identified by meandering streams and mangrove/mud character) are energy voids in which very fine sediments are deposited. This is significant in the consideration of activities upstream as pollutants (in particular particulates) will tend to be pooled in this estuarine region. Once accumulated in these low energy environments pollutants have the potential to be further concentrated or transformed to more toxic substances by micro-organisms. These toxins may then be further concentrated by biomagnification as they are translated through the food chain.

Coastal structures

The long term erosional trend suggested in section 6.1 and observed on other Australian coastlines needs to be considered in the placement of coastal structures. In unconsolidated coastal sediments a small vertical rise in sea level can translate to a substantial lateral retreat of a shoreline. On open sandy coastlines both the actual landward retreat of the beach and the mobile dune fringe which precedes it can overwhelm near coastal structures, and truncate coastal real estate.

Where the survival of coastal structures is in conflict with the natural progress of coastal erosion the common response is to build a rock wall barrier to the sea. This can generate several undesirable responses:

i. It can generate a reflective wave which in harmonic combination with incident waves can cause deeper scouring of the nearshore, thereby allowing more energy to attack the shore.

ii. As a consequence of *i.* strong rip currents are generated in the immediate area.

iii. It can lead to accelerated erosion of the beach in areas adjacent to the wall.

Groins running perpendicular to the beach are effective in trapping sand locally, but modern engineering systems which increase seashore roughness in the nearshore and energy absorbing seawalls are the most satisfactory response.

Near coastal clearing on steep regolith for road or building construction in tropical areas presents an obvious siltation hazard to nearshore fringing reefs.

Although not a current consideration in Cape York Peninsula, damming of rivers in the future would regulate the discharge of water and sediment to the coast and locally further exacerbate erosion.

Tourist impact

The impact of tourism on coastal areas can be broadly divided into three categories: formal tourist facilities such as resorts and caravan parks, informal onshore activities including vehicles and camping, and offshore activities related to both of the former.

i.. Formal activities - These generally imply concentrations of people and therefore the structural and waste considerations mentioned above apply. Vehicle and walking tracks which intersect the coastal foredune can become areas of accelerated wind and water erosion. In cases where these dunes are substantial large sand `blowouts' which transgress rapidly inland can occur. A simple program of stabilising such tracks with `log and chain' pathways, and restricting access over lightly vegetated dune areas can prevent this.
Associated with areas of concentrated tourist activity are requirements for water supply and garbage disposal. In the case of the former this can lead to unsightly but otherwise generally undamaging pit excavations in back dune areas, but in the latter can lead to poorly controlled dumping of rubbish including petroleum products and unbiodegradable waste.

ii. Informal activities - Four wheel drive vehicle tracks were observed crossing coastal dune areas in a number of locations. Where these areas are heavily trafficked multiple tracks had been established. In general the effect of these tracks is to destabilise and mobilise large quantities of dune sand. This effect is greatest across the crest of dune forms where they create breaches in the vegetated surface, and can be particularly damaging where they intersect the dune to beach interface.

In many situations closure of these routes along coastal dunes may not be an ideal solution as they provide the only access to favoured recreational/camping sites at the mouths of major rivers. The alternative here appears to be to upgrade a single access route (ie. by adding sections of 'log and chain' roadway for traction and stability on dune crests and difficult sections), and revegetation on either side of the track.

Unsupervised camping in coastal environments can result in several undesirable practices: accumulations of litter and excrement, destruction of living trees, accidental burning of areas of vegetation, encouragement of feral animals. The installation of garbage bins has been shown to be an unsuccessful response to the litter problem as they commonly become sites of accumulated garbage which are unsightly and attract animals. A successful strategy for managing camping in areas such as this is to introduce a point-of-entry supervision to areas where numbers can be controlled by permit camping, and a public education program on sound camping practices can be implemented. Suitable toilet facilities can be installed (ie. while considering the need not to pollute local water tables), and people should be encouraged to carry their garbage back out of the area. This implies some regular ranger interaction.

iii. Offshore activities - Boating, fishing, investigations of coral reefs, and snorkelling and SCUBA diving are popular coastal activities.

Boating and fishing activities can lead to damage to local fauna and flora by both mechanical damage (ie. by propellers and anchors) and pollution if sewerage is discharged directly or petroleum products are discharged with bilge water. This pollution can become quite significant where larger tourist boats are involved, or numbers of commercial fishing vessels are concentrated in bays. Areas of concentrated boating activity including activities such as paragliding and jetskiing can interrupt breeding and feeding patterns of larger endangered marine fauna such as dugongs and turtles. Commercial fishing nets can disturb vast areas of the inner shelf with associated damage to seagrass beds. Trawling puts fine sediment (and associated nutrients) into suspension, and if conducted close to coastal reefs on a regular basis (eg. when a number of vessels launch nets leaving embayments) can affect growth.

Coral reefs are the most vulnerable coastal environment to tourist impact. Sightseers damage reefs primarily by walking over and touching corals which causes both mechanical breakage, and removes the protective mucus layer that protects coral during low tides. Collection of shells and other reef specimens reduce the diversity of reef biota. Snorkelling and SCUBA diving can sustain considerable mechanical damage to reefs, and deplete them by collection if poorly conducted.

Grazing and agriculture

Grazing

Generally the present levels of grazing observed in Cape York Peninsula do not represent a threat to coasts in terms of erosion or delivery of excess nutrients. In fact, coastal areas may benefit at the expense of catchment areas where the accelerated erosion of soil increases the sediment supply discharged by rivers. There is, however, an associated toll on nearshore coral reefs with the addition of excessive amounts of sediment (ie. and a concomitant increase in nutrients). Nutrient enriched discharge from intensive grazing practices such as feedlots have the potential to seriously impact locally on coastal flora and fauna.

Agriculture

Commercial agriculture is not presently widespread in Cape York Peninsula, but in other tropical climates has been a recognised agent of destruction of coastal fauna and flora. Where fertilisers have been applied, excess nutrients find there way into coastal discharge and can have a profound destructive effect on reefs. Additionally, a severe salinity problem has developed in irrigated coastal soils throughout other tropical regions where intensive agriculture is carried out.

Lowland coastal environments may be underlain by the deposits of former estuaries and mangrove swamps. These may contain sulphide minerals and have the potential to give rise to acid-sulphate soils if exposed by agricultural practices or excavation for building, mining, or irrigation. The precise extent of these buried deposits cannot be mapped at the scale of sampling used in this study, however they are most likely to occur in areas of back-barrier and inter-barrier swamp.

Extractive industries

Exploitable minerals within the coastal regions generally fall into two main types:
i. heavy minerals (eg. ilmenite, zircon, rutile) and
ii. silica.

Bauxite may also become a consideration where it extends to coastal cliffs.

The presence of heavy minerals relies largely on the availability of a parent rock in the catchment area of coastal rivers to provide a source, whereupon coastal processes will then act to concentrate these minerals into beds that can be productively mined. Broad regional surveys in Cape York Peninsula have failed to find exploitable quantities of heavy minerals to date. The common method of mining heavy minerals in coastal areas is by floating dredge which progressively creates its own pond in coastal sediments, with mined areas being rehabilitated in its wake. Rehabilitation programs on both the east and west coast of Australia have generally proved responsible in the faithful rehabilitation of mined areas, however, a degree of loss of diversity, mature forest, and soils formation generally accompanies an operation such as this.

Vast quantities of high grade silica are found in the expansive dunefields of eastern Cape York Peninsula. There are areas of conservation and cultural significance within dunefields, and proposals to mine in these areas need to consider the effect on the quantity and quality of the reservoirs of water contained within these systems. A large silica mining operation has been in progress at Cape Flattery for a number of years and has provided substantial economic benefit. Rehabilitation of the mined area is monitored by state government organisations.

The primary concerns for the coastal environments from such ventures are those discussed earlier relating to concentrations of population and intrusive structures (eg. breakwaters), and the potential impact of pollution from large vessels. The accumulation of old vessels and blasting of headland bedrock in the case of the Cape Flattery has imposed a long term aesthetic toll, however, the attitude of the mine population to local coastal environments appears to be conservationally sound.

Removal of fluvial/alluvial overburden for construction material has the potential to expose former estuarine and mangrove deposits to leaching. As discussed previously in the agriculture section these leached products contaminate waterways and can have a significant impact on aquatic biota.

Coastal sediments do not generally present desirable soils for commercial forestry, however, forest clearing in catchment areas or where regolith extends to the coast provides a potential siltation/nutrient problem affecting nearshore reefs.

Navigation

The ship channel inside the Northern Great Barrier reef is one of Australia's most restricted seaways, and at the same time one of Australia's busiest. There is a real risk of collision or grounding giving rise to significant levels of pollution. Much of the reef outside this channel is still uncharted.

There are three ports in the region. Cooktown is isolated by a bar which prevents the entrance of vessels except those of shallow draught, and then only at favourable states of the tide. The Port of Weipa is accessed by a dredged channel which is prone to siltation. The Port of Thursday Island is difficult to access and is not an ideal harbour. Port facilities formerly existed in current-swept Albany Passage, but are now abandoned.

Port Musgrave provides one of the best natural harbours in Queensland, but the entrance has numerous bars and is only navigable by shallow draft vessels.

1. INTRODUCTION

NR14, Coastal Environment Geoscience Survey. The project utilises a wide variety of information and techniques to compile the basic coastal geoscientific information necessary for the development of a land use strategy for Cape York Peninsula. Circumstances outside the control of the Project and the large amount of data that was accumulated have delayed its completion to early 1995. This report therefore provides a statement of the methodology employed, together with results of the data analyses undertaken and coastal geoscience GIS coverages completed to date. The finalised project results will be published as an AGSO Bulletin at a later date.

1.1. Coastal geoscience

The Coastal Geoscience Project of the Australian Geological Survey Organisation (AGSO) undertakes coastal geoscientific mapping and research to provide the baseline geoscientific data and interpretations necessary for the sustainable development and integrated resource management of Australia's coastal zone.

Traditionally the coast has been regarded as almost synonymous with the "shoreline" or even the "beach." Considerations of coastal regionalisation have been similarly limited, with respected workers differentiating only between "muddy", "sandy", and "mangrove " coasts.

Contemporary perspectives of the coastal zone are much broader and cover not only "that area of the land that is influenced by the sea and that area of the sea that is influenced by the land" (i.e. the area of coastal impact) but also that area in which processes evolve that eventually influence the area of coastal impact (i.e. the area that influences the coast) - commonly defined landwards as the catchment of rivers and seawards as the edge of the continental shelf.

Unlike European and North American coastlines, which are dominated by terrigenous sediment produced by erosion of the land, much of Australia's coast is composed of materials generated as waste products of shelf ecosystems, especially from the activities of carbonate secreting organisms. It is therefore most important to note the interdependence of living and non-living components in determining the geoscientific characteristics of the coastal zone.

New insights of coastal geoscience in the past 20 years, particularly in the topics of regional variation in sea-level history and in the improved understanding of the nature and diversity of processes of coastal sedimentation, have served to emphasise that the coastal zone, itself the product of past environmental change, can provide a predictive understanding of the effects of changes in climate, land-use and sea-level on the functioning and sustainability of coastal This report forms part of the Cape York Peninsula Land Use Strategy (CYPLUS) Project ecosystems.

The parameters that control the evolution and stability of the coastal zone include:- hydrography, oceanography, weather, fetch, temperature, sediment supply, biological productivity, sea level history, and several others. The coastal zone may therefore be seen as a physical manifestation of the complex interaction of many variables in both time and space, though it represents only an incomplete and biased record of these parameters and processes. The actual products of natural variation within one system may vary dramatically with time, while, conversely, the products found in very different systems may be remarkably similar although the controlling parameters may be very different.

A particular coastal region may therefore vary in detail with changing instantaneous combinations of values of various parameters but within ranges expected for the natural occurrences for that region. This is the natural resilience of the system. Major instability and disturbance will be caused by a fundamental change in the values of the limiting parameters, for example, as a result of long term climate change or due to restrictions imposed either intentionally or unintentionally by human activity. These restrictions might be in the form of:

- changed stream sediment load,
- changed water movement patterns, or
- changed coastal vegetation.

1.2. Project objective

The project was undertaken to produce a geoscientific synthesis of the evolution and character of the coastal zone of Cape York Peninsula to include:

- assessment of the oceanographic and meteorological processes affecting the coastal area;
- documentation of the character of coastal environments and the nature of sedimentary deposits within them;
- analysis of Holocene evolution of the coastal zone;
- identification of areas of significant instability; and
- consideration of issues relevant to sustainable use.

2. METHODOLOGY

The approach adopted in this project takes into account the factors which jointly determine the variation in coastal ecosystems. These include the landforms; processes; materials; and evolutionary history of the geoscientific components of the coastal zone and the relationship between these components, other physical and chemical environmental elements, and the biological communities.

The project examines coastal systems at a high spatial resolution by combining methods of field research with analysis of digital multispectral data obtained from satellite remote sensing. Field surveys of shoreline deposits were undertaken to reconstruct the history of coastal evolution , and to assess vulnerability to erosion or flooding. Offshore, marine geologists examined the seafloor using seismic profiling, bottom sampling, and direct inspection to assess the nature and extent of nearshore sediments, and to unravel their history of accumulation.

The innovative combination of enhanced imagery and Geographic Information System (GIS) modelling provides the opportunity for wide spatial coverage and a degree of analysis which has previously been unavailable, and which individually have been shown to have proven capability. Landsat Thematic Mapper datasets are processed by techniques of digital unmixing of spectral responses that have been developed in AGSO to show:

- variation in shallow marine substrates and benthic ecosystems;
- water turbidity; bathymetry and bottom topography;
- coastal vegetation;
- coastal geomorphology; and
- lithology of coastal lands.

The area is divided into coastal facies units which were mapped using a combination of Landsat TM image data, supplemented by 1:80 000 panchromatic aerial photography (1970), 1:50 000 colour aerial photography (1990), and field work carried out over the period 1992-1994 by the Australian Geological Survey Organisation (AGSO), including offshore research cruises in October 1992 and October 1993.

A standard scheme for the categorisation of coastal geoscientific units was devised to enable the presentation of the results of this mapping. The scheme recognised primary associations, secondary groups and individual features, each having a higher resolution. Figure 1 shows the scheme of categorisation used in this project. Figures 2 & 3 show examples of GIS output combining onshore categorisation of the coastal facies with offshore representations of analysed multispectral data. The information obtained in this project is realisable at scales between 1: 100,000 and 1: 1,000,000. It is intended that this analysis, which has been applied initially to a study of the Cape York Peninsula, will eventually cover as much of coastal Australia as possible.

FIGURE 1

MORPHOLOGICAL CATEGORISATION OF COASTAL & SHELFAL ENVIRONS

DEPOSITIONAL SYSTEM	QUALIFIER		DEPOSITIONAL FEATURE	DEPOSITIONAL SUB-FEATURE		CODE	TIDAL ASSOCIATION
HINTERLAND			Bedrock (undifferentiated)			BR	
			Regolith (undifferentiated)			R	
FLUVIAL			Valley			FV	
			Channel			FC	
			Longitudinal bars			FLB	
			Transverse bars			FTB	
			Point bar accretionary deposit			FPB	
			Natural levees			FNL	
				Braided channel		FBC	
ALLUVIAL			Alluvial fan			AF	
			Alluvial plain			AP	
			Braided plain			ABP	
			Meander plain			AMP	
DUNEFIELD			Sand sheet/Sand stringer/Dome			DUSH/DUST/DUDO	
			Barchan dune/Barchanoid ridge dune			DUBA/DUBR	
			Transverse ridge dune			DUTR	
			Blowout dune/Parabolic dune			DUBL/DUPA	
			Reversing dune/Linear (Long'l, Seif) dune			DURE/DULI	
			Star dune			DUSR	
			Lake			DULK	
			Swamp			DUSW	
HARD COASTLINE	BEDROCK *(UNDIFFERENTIATED)*	BR	Cliffed coastline			H*C	
			Shore platform			H*SP	
	REGOLITH	R	Non-cliffed coastline			H*NC	
STRAND-PLAIN	BARRIER		Beach-ridge		#	SBBR#	
			Separated beach-ridge	Dune-capped	d	SBSBR#	
			Chenier	Lunette-capped	l	SBCH#	
			Barrier-island			SBIS	
			Barrier-tombolo			SBTO	
	INTRABARRIER/ BACKBARRIER		Flat			SIFL	TIDAL ASSOCIATION
			Lake			SILK	
			Swamp			SISW	
			Lagoon			SILG	SUPRATIDAL
				Washover-fan		SIWF	
	COASTAL FLAT		Mudflat (hypersaline)			SCMU	
			Marsh (hypersaline)			SCMA	
			Coastal dune			SCDU	
ESTUARY			Bay-mouth barrier			EBMB	SUPRATIDAL
			Ebb-tide delta			EETD	INTERTIDAL
			Flood-tide Delta			EFTD	
			Wash-over			EWO	
			Bay-head delta			EBHD	
			Mangrove			EM	
			Tidal Sandbar			ETSB	
			Tidal mudbar			ETMB	
			Central basin			ECB	SUBTIDAL
DELTA						DE*	SUPRATIDAL
	Birdsfoot/ Lobate	B	Deltaic plain			DE*P	
			Deltaic marsh			DE*M	
	Cuspate/ Arcuate	C	Subaerial levee			DE*SL	
			Distributary channel			DE*DC	INTERTIDAL
	Estuarine	E	Tidal channel			DE*TC	
			Mangrove			DE*MV	
			Subaqueous levee			DE*QL	SUBTIDAL
			Distributary mouth bar			DE*MB	
			Distributary mouth sand sheet			DE*MS	
			Channel mouth bar			DE*CM	
			Pro-delta deposit			DE*PD	

FIGURE 1 cont

BEACH					BE	
			Spit		BESP	SUPRATIDAL
				Foredune	BEFD	
				Berm	BEBM	
				Beach scarp	BESC	
				Tidal mudflat	BETM	INTERTIDAL
				Beachface	BEFC	
				Beachrock	BERX	
NEARSHORE			Sand bay infill		NESBI	SUBTIDAL
			Mud bay infill		NEMBI	
			Minor delta		NEMD	
				Longshore Trough	NELT	
				Longshore bar	NELB	
			Bar platform		NEBP	
NERITIC	UNDIFFERENTIATED				NU	
	INNER		Coastal sand wedge		NCSW	
			Coastal mud wedge		NCMW	
			Palimpsest sand body		NPSB	
			Sand wave		NSWV	
			Linear banks		NCLB	
			Barchan banks		NCBB	
			Passages		NCP	
			Spit banks		NSB	
BIOHERM					B	
	CORAL REEF				BC*	
		*	Fore-reef slope		BC*FR	
		Fringing F	Reef front		BC*RF	
		Atoll A		Spur & groove	BC*SG	
		Shoal SH	Reef crest		BC*CT	
		Patch PA		Coralgal rim	BC*CR	
		Crescentic C				
		Lagoonal L	Reef flat		BC*FL	
		Planar PL		Shingle rampart	BC*SR	
				Boulder tract	BC*BT	
			Back reef		BC*B	
				Aligned coral tract	BC*AC	
				Sediment apron	BC*SA	
			Lagoon		BC*L	
			Lagoon patch reef		BC*LP	
			Lagoonal basin		BC*LB	
			Lagoonal channel		BC*LC	
			Cay		BC*CY	
			Vegetated		BC*CV	
			Non-vegetated		BC*CN	
			Intra-reef passages (HOA)		BC*IP	
			Leeward fan		BC*LF	
	STROMATOLITE				BST	
	BANKS		Halimeda		BBH	
			Seagrass		BBS	

PREFIXES: H - Holocene, pH - pre-Holocene

SUFFIXES: du - dune-capped, lu - lunette, t - transgressive, d - degraded, r - relict

FIGURE 2

WEIPA AREA, CAPE YORK PENINSULA, QLD.
IMAGE PROCESSING COMBINED WITH
MORPHOLOGICAL CATEGORISATION OF COASTAL ENVIRONS

0 10 20 30 km

Scale 1:600 000 UTM Projection, Zone 54

Morphology by Trevor Graham, 1994, Coastal Geoscience, AGSO Image Processing by Matti Peljo, AGSO

FIGURE 3

CAPE FLATTERY, CAPE YORK PENINSULA, QLD.
IMAGE PROCESSING COMBINED WITH
MORPHOLOGICAL CATEGORISATION OF COASTAL ENVIRONS

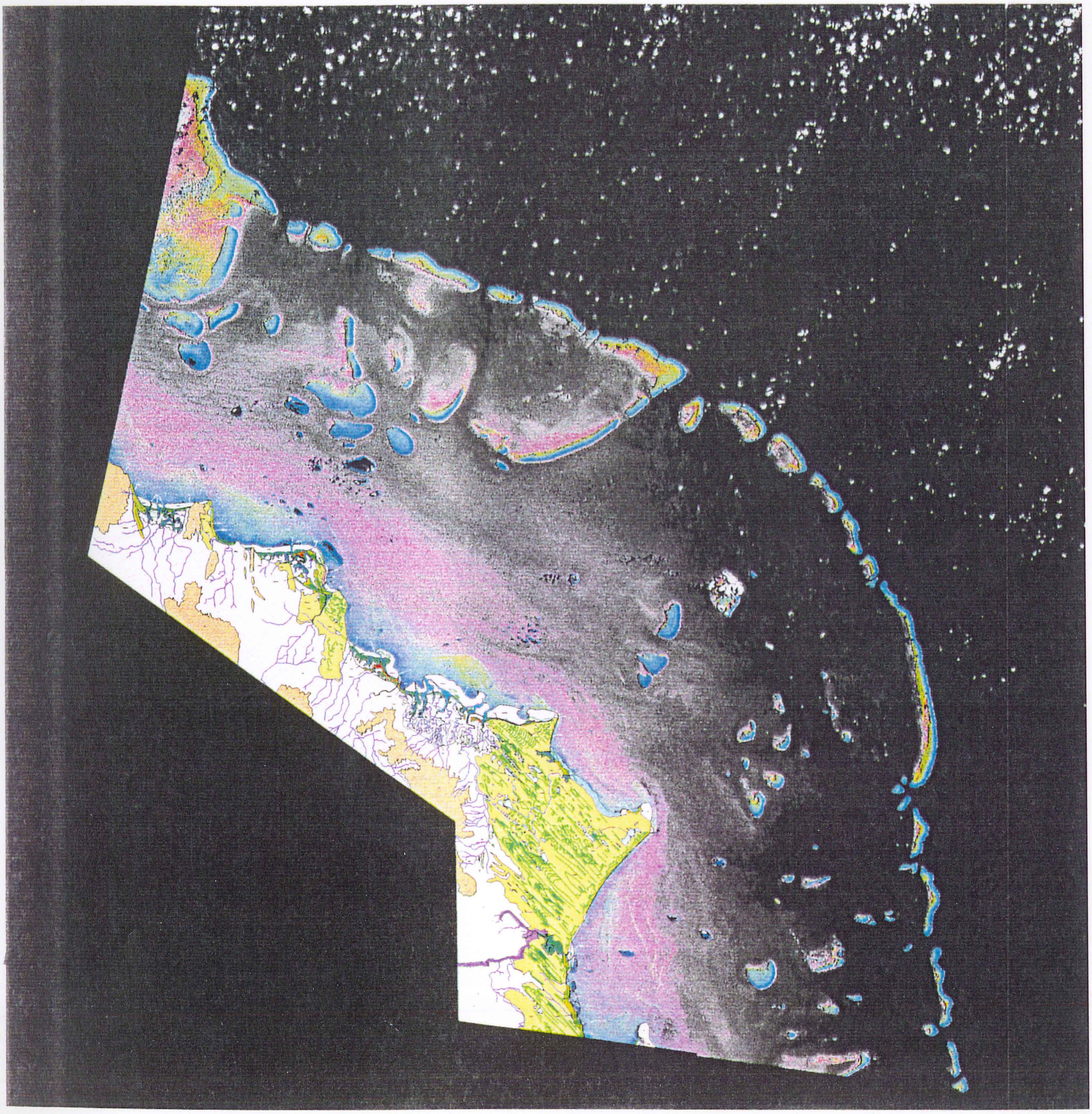
0 10 20 30 km

Scale 1:800 000

UTM Projection, Zone 55

Morphology by Matt Haynes, 1994, Coastal Geoscience, AGSO

Image Processing by Heather Rennie, using algorithm by P. Bierwirth, AGSO



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3. DESCRIPTION OF GIS DATASETS

Six GIS coverages will be constructed for this project:

1. Bathymetry. The coastal waters of Cape York are incompletely surveyed and poorly charted. No reliable digital coverage of the bathymetry exists. The GIS coverage was compiled by merging all available data from published nautical charts and additional material compiled by Mr Cameron Buchanan of AGSO with the reef location map compiled by GBRMPA. These data were merged and edited by Dr Neil Hamilton of the CSIRO Division of Wildlife and Ecology.

2. Benthic Substrates. This coverage consists of enhanced Landsat Thematic Mapper Data Sets. The depth/substrate unmixing algorithm of Bierwirth et al. (1993) has been applied to shallow water areas to indicate substrate type and bed roughness. In deeper water areas band 1 (blue light) of the Landsat data has been enhanced to provide information on bottom type.

3. Coastal Geoscientific Coverage. This coverage shows the distribution of coastal geoscientific mapping units (figure 1) which reflect both the morphostratigraphy and depositional environments of the coastal deposits. These were derived from interpretation of enhanced Landsat TM imagery and associated aerial photography.

4. Offshore Interpretive Coverage. This interpretation of the variation of offshore depositional environments is based on a review of the variation in seismic characteristics, bedform information, grab samples, core samples and Landsat Imagery.

5. Location of Cruise Tracks, Survey Lines and Sample Sites.

6. Data Files of the Sediment Analyses.

4. LATE QUATERNARY SEA LEVEL VARIATION AND COASTAL DEVELOPMENT

Fundamental to understanding of the evolution of the coastline of Cape York Peninsula is an appreciation of how coasts respond to changes in sea level. Within geological timeframes sea level has been shown to have fluctuated quite dramatically in response to water from the worlds oceans becoming locked into large bodies of land-based ice during ice ages ('glacial' periods).

The last major sea level lowstand occurred around 18,000-20,000 years ago, and evidence indicates that sea levels in northeastern Australia were lowered by more than 130m below present level (Veeh and Veevers, 1970; Chappell, 1974). Of course as sea level receded to this level the shoreline followed it, and conversely as sea level again rose to present levels the shoreline migrated back across the continental shelf.

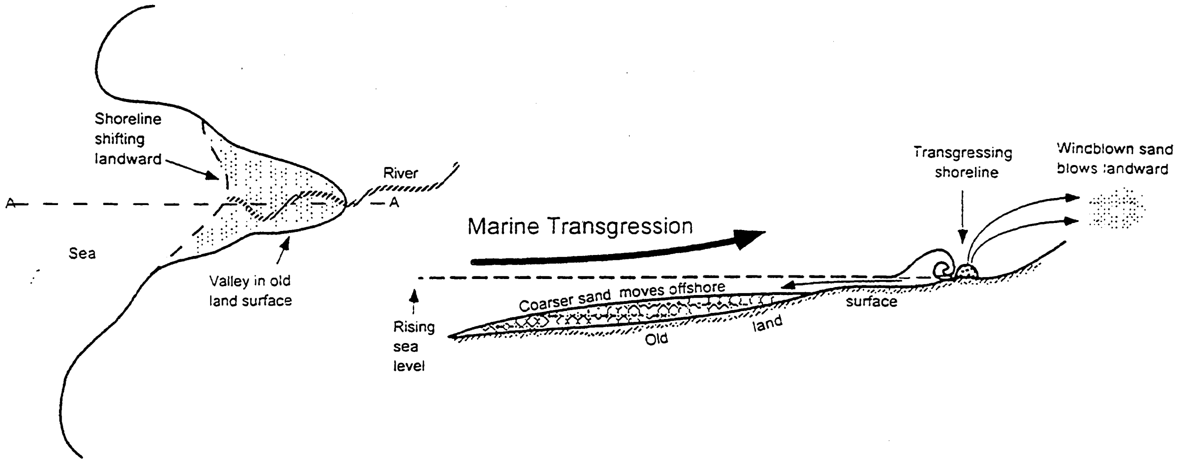
Sea level has been determined to have stabilised around its present level some 6,500 years ago, and at this time had flooded into a series of embayments formed by valleys in the old land surface. This encroachment of the sea onto the land surface as sea level rises is termed a *marine transgression*. Most of the last major rise in sea level has taken place in the Holocene epoch on the geological time scale (ie. the period from 10,000 yrs ago to present), and both the marine transgression and resulting depositional features are commonly referred to by their Holocene association.

As a general principle marine transgression of areas of poorly consolidated material will proceed slower in steeper landscapes resulting in greater erosion of the land surface and the redistribution of sediments offshore. Across low lying landscapes flooding of the land surface progresses faster, and therefore less erosion occurs. Commonly, finer sand is blown landward from the shore to accumulate as dunes inland (Fig. 4 A).

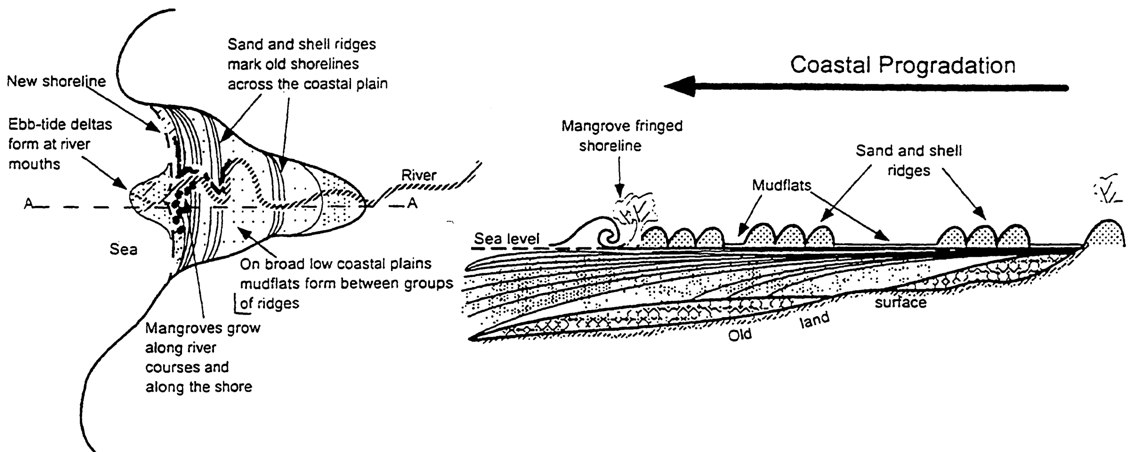
As a consequence of sea level rise slowing to a halt, the sea ceases to encroach on the land surface and the shoreline stabilises in one position. At this time the sediment brought to the coast by rivers and currents will begin to fill the space created offshore by the rising sea level. The period commencing when sea level stopped rising and stabilised around the present level is referred to as the *stillstand* (Fig. 4 B).

In time sediments from both rivers and stores of sediment on the shelf fill the nearshore zone and the beach begins to step out seaward over this foundation. This is referred to as *coastal progradation*. This process will generally continue until an embayment is filled to an approximate arc between headlands (ie. the 'bayline'- refer Fig. 4 C).

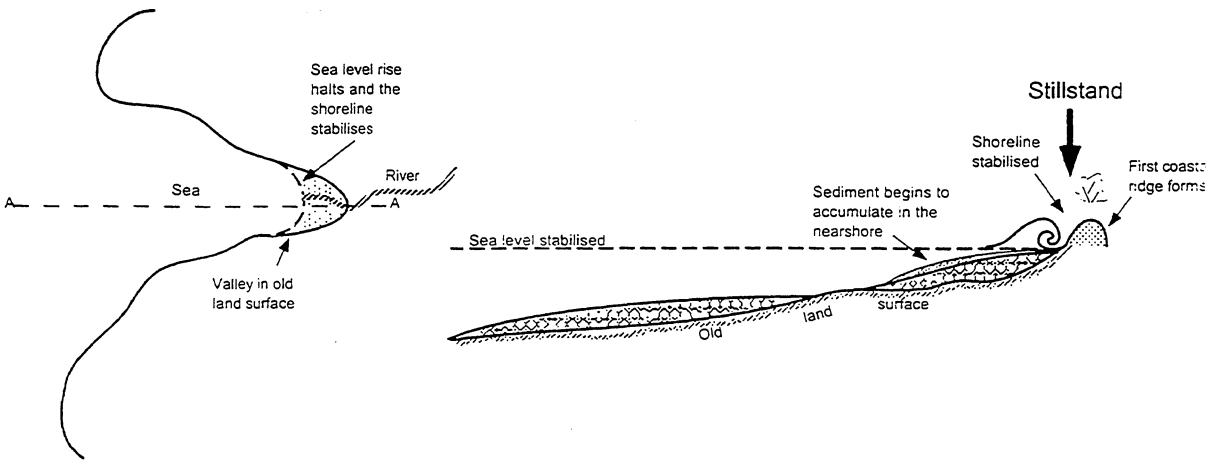
The main determining factors influencing progradation are: sediment availability, the shape and seafloor topography of the embayment, and energy. These in turn can be influenced by a number of other factors, for example: orientation to prevailing weather/sea conditions, frequency of high energy (storm events), the degree of variability in the annual climatic cycle, proximity of the embayment to large rivers and its location in relation to the direction of the longshore drift of sediments from these rivers.



A. Transgressive phase - sea level rise causes the sea to encroach on the land surface via valleys and low plains



C. Progradational phase - the coast builds out as the embayment fills with sediment discharged from rivers



B. Stillstand phase - sea level rise slows to a halt and correspondingly the sea ceases transgressing the land surface.

Figure 4 Generalised model for coastal development in response to sea level rise and stabilisation

Low gradient coasts - where the offshore seafloor has a low gradient and there is high sediment discharge (eg. the southern Gulf of Carpentaria), extensive mudflats will tends to form as the system becomes overloaded with sediment and there is insufficient wave energy to remove it. Climatic cycles of the order of hundreds to thousands of years have affected the nature of embayment fill in Cape York Peninsula, resulting in progradation being episodic and distinctly different types of deposit being layed down. When wetter periods occurred higher river discharge resulted in rapid progradation of mudflats, while during drier periods when there was less sediment delivered to the nearshore, wave processes were able to winnow finer sediment from the nearshore leaving a coarse residue of sand and shells. This material was then moved onshore during higher energy events to form groups of shell and sand ridges (Rhodes, 1980).

Changes in the position of major river mouths has also profoundly effected the evolution of coastal plains in low lying landscapes.

Steeper gradient shores - on steeper coastal profiles wave processes are more effective, and fine sediment is removed some distance offshore leaving sand and gravel to be worked onshore into a more continuous series of ridges. As a result of this steeper profile embayments are less laterally extensive and the deeper nearshore takes longer to develop a suitable platform for progradation. This has generally resulted in the formation of more compressed sequences.

Prior to the present high stand of sea level the last such high level toward the end of the Pleistocene epoch on the geological time scale, during the last 'interglacial' period approximately 122,000 years ago. This sea level is generally recognised as having been around 5m higher than present sea level, resulting in the sea having transgressed further inland. Consequently, initial coastal deposits at the commencement of progradation associated with this high sea level were deposited beyond the reach of present marine conditions, and can still be recognised in many places preserved inland of the deposits from the most recent phase of progradation. These deposits have undergone significant erosion during this time and much of the shell material has been leached from them leaving a series of generally degraded sandy/clay bodies still recognisable in aerial photographs by their elongated shore parallel form.

5. CATEGORISATION OF THE COAST OF CAPE YORK PENINSULA

5.1. Introduction

The coast is composed of a complex association of individual features. To facilitate the discussion of the coast of Cape York Peninsula (and to assist in the application of general land use strategies) the coast has been divided into broad categories based on similar combinations of features. However, the allocation of sections of coastline into rigid categories is not straightforward. In many cases the same elements may exist across a number of categories, or in some cases they identify a stage of maturity toward a different final identity (eg. estuaries are an intermediate stage before becoming a major deltaic coast on achievement of depositional equilibrium with respect to accommodation available and the prevailing energy environment). In some cases the coastal areas within a category may fall within a recognisable geographical region and therefore bear that association in its name, while other categories can be found distributed around the entire Cape.

5.2. Onshore

5.2.1 Southeastern Gulf of Carpentaria expansive plain coasts

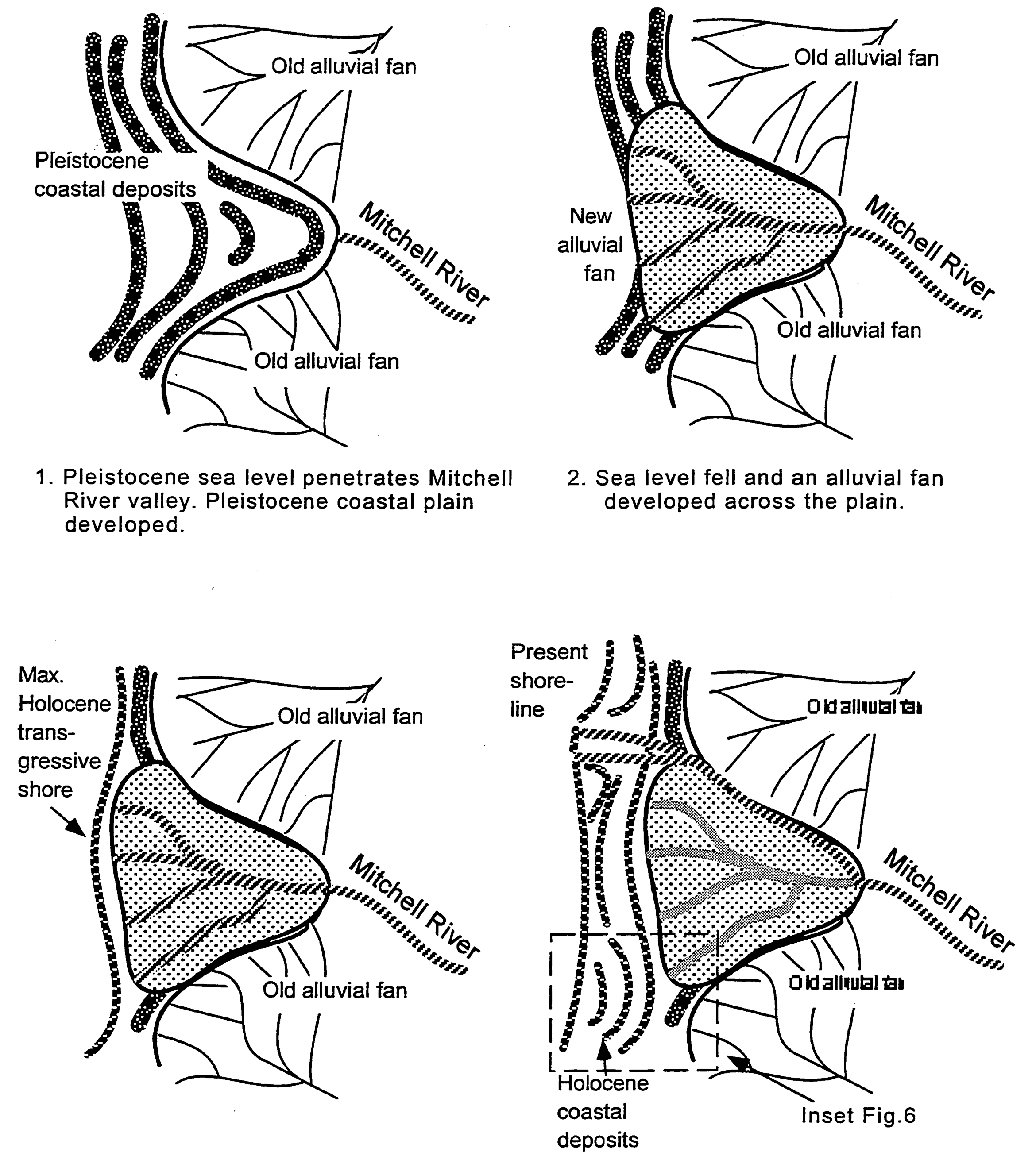
Geography of the coastal plain

The lower western Cape York Peninsula coast bordering the southern Gulf of Carpentaria is characterised by broad, low-lying coastal plains. Within the study area these extend from the southern Nassau River boundary north to the Archer River estuary. At the Nassau River these plains are transitional between extensive chenier plains around Karumba in the southern Gulf and dominantly beach-ridge plains around Pormporaaw and extending north around Cape Keer Weer. Within the study area the coastal plain becomes confined to a minimum width of approximately 3km around the foreslope of the Mitchell River alluvial fan, broadening to a maximum width of ~27km immediately north of the Mitchell River.

Regional Quaternary geology

The distribution of Quaternary coastal deposits in this region is strongly influenced by the distribution of large alluvial fans of varying ages. The deflection of the Pleistocene barriers on the Rutland Plains north of the Nassau River indicate that the ~122,000yrs BP high sea level penetrated a wide embayment which has since been occupied by an extensive alluvial fan of the Mitchell River. Grimes and Doutch (1978) identified five major stages of fan development associated with the Gilbert and Mitchell Rivers, of which the final two stages postdate this late Pleistocene sea level transgression. The alignment of the first Holocene ridges indicates that the coast at the time of the last maximum transgression (ca.5,900yrs BP) wrapped around the arcuate shape of this Mitchell River fan (Fig. 5).

Between the Mitchell River and Archer River a continuos lineation of degraded Pleistocene coastal deposits lies along the fore lobes of vast older alluvial fans. This testifies to there being no major fan development extending into the present coastal plain after the ~122,000yrs BP sea level highstand for this section of coastline.



1. Pleistocene sea level penetrates Mitchell River valley. Pleistocene coastal plain developed.

2. Sea level fell and an alluvial fan developed across the plain.

3. Sea level rose in the Holocene and the shoreline at the transgressive maximum wrapped around the foreslope of the fan.

4. The Holocene coastal plain developed. Some relict Pleistocene ridges are preserved.

Figure. 5 Model for the Quaternary development of coastal plain between Nassau River and Mitchell River.

Site investigations

Valentine (1961) described the coastal plain between Archer River estuary and the Mitchell River largely from aerial reconnaissance.

Whitehouse (1963) had described the beach ridges on this coast. Doutch et al. (1972) discussed the development of beach ridges between latitudes 15°-17°, and Grimes (1974) described beach-ridge sequences on the southwestern coast of the Gulf of Carpentaria. Smart (1973,1976) investigated the development of the coastal plain on Cape Keer Weer in a total of 20 auger-drillholes ranging to a maximum depth of 17.4m.

A very comprehensive study of coastal environments and stratigraphy in the southern Gulf region was conducted by Rhodes (1980). He investigated the extensive chenier plains between the Leichhardt and Norman Rivers to the south of the present study area, and beach-ridge plain development around Edward River and Christmas Creek within the area. A total of 31 auger-drillholes were placed along two transects at Pormporaaw and Christmas Creek to investigate the development of the coastal plain in the stratigraphic record. This is the most thorough investigation of coastal development in far north Queensland and will be quoted extensively throughout the course of the following discussion.

During the present study the stratigraphy of the Rutland Plains was investigated in 10 mechanically-augered drillholes (to a max. depth of 17.4m). The location of these drillholes is shown in figure 6.

Nature of Quaternary coastal deposition

The southern portion of the study (ie. around Nassau River) is broadly transitional between the chenier plains of the southern Gulf and the predominantly beach-ridge plains around Pormporaaw and Cape Keer Weer further north. Within the area beach-ridges alternate with chenier development. In a number of places beach-ridge sequences are observed to fan out into muddy plains to become cheniers in a laterally continuous fashion. The alternating distribution of beach-ridge sequences and cheniers is largely governed by the structural template created as the transgressing sea encountered the extensive alluvial fans that form the hinterland of the southwestern coast of Cape York Peninsula.

Progradation would have proceeded rapidly in the broad embayments with low angle nearshore profiles located on either side of Mitchell River fan, leading to the development of extensive mudflats. Additionally, these embayments would have represented low energy nodes relative to the more prominent foreslope of the fan favouring them as depocentres of sediments redistributed alongshore. Conversely, the steeper foreslope of the seaward lobe of the fan has resulted in groups of more compressed beach ridges. This suggests that the grade of the offshore at the time of deposition is probably the main factor determining where beach ridges or cheniers form.

The Rutland Plains drilling transects investigated during the present study reveal a cross-section through one of these peripheral former embayments (Fig. 7). Drillholes were located along two transects in order to:

i. intersect the stratigraphy between the Pleistocene and rearward Holocene barriers and,
ii. transect the Holocene coastal sequence in approximately the direction of progradation.

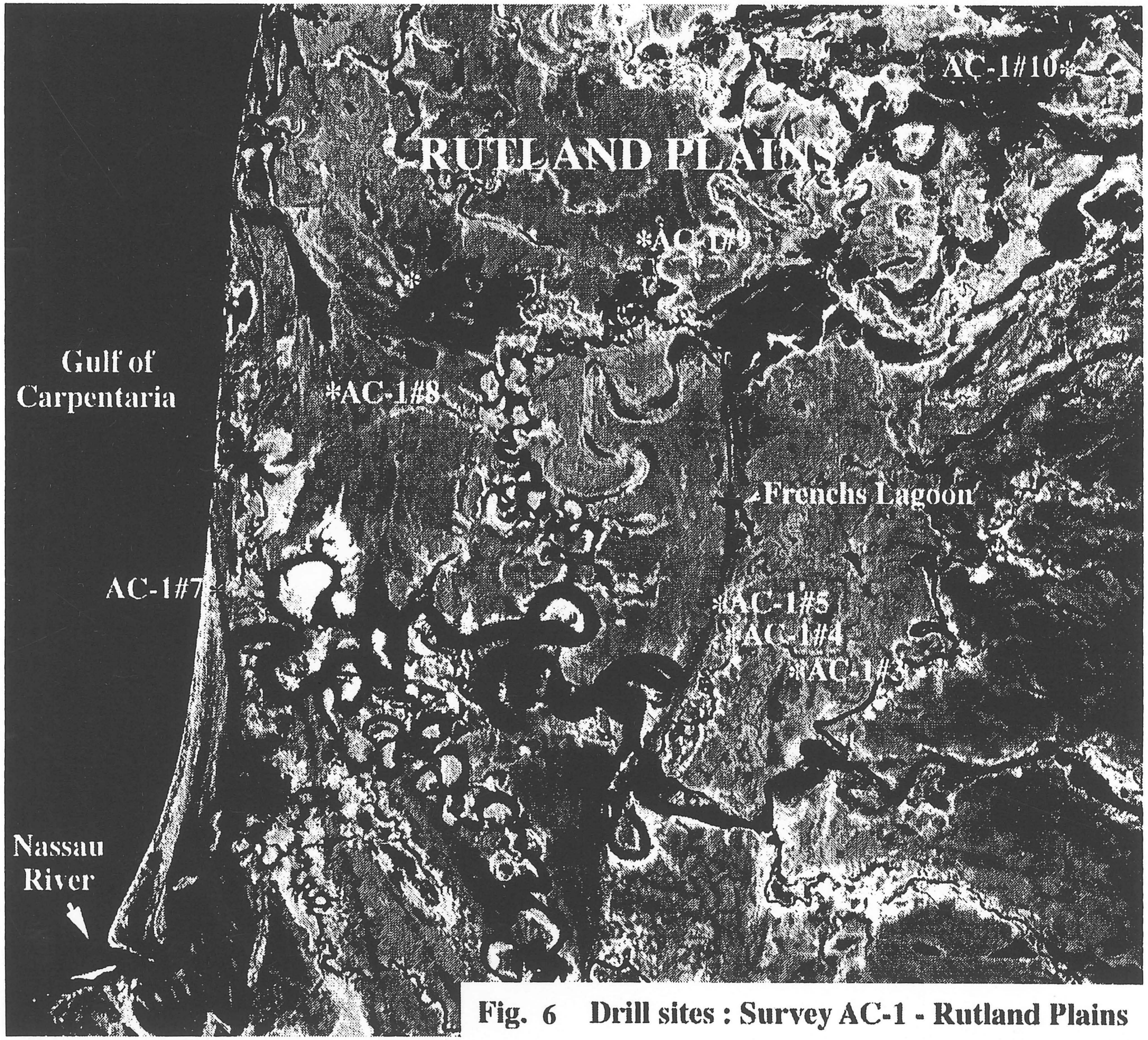


Fig. 6 Drill sites : Survey AC-1 - Rutland Plains

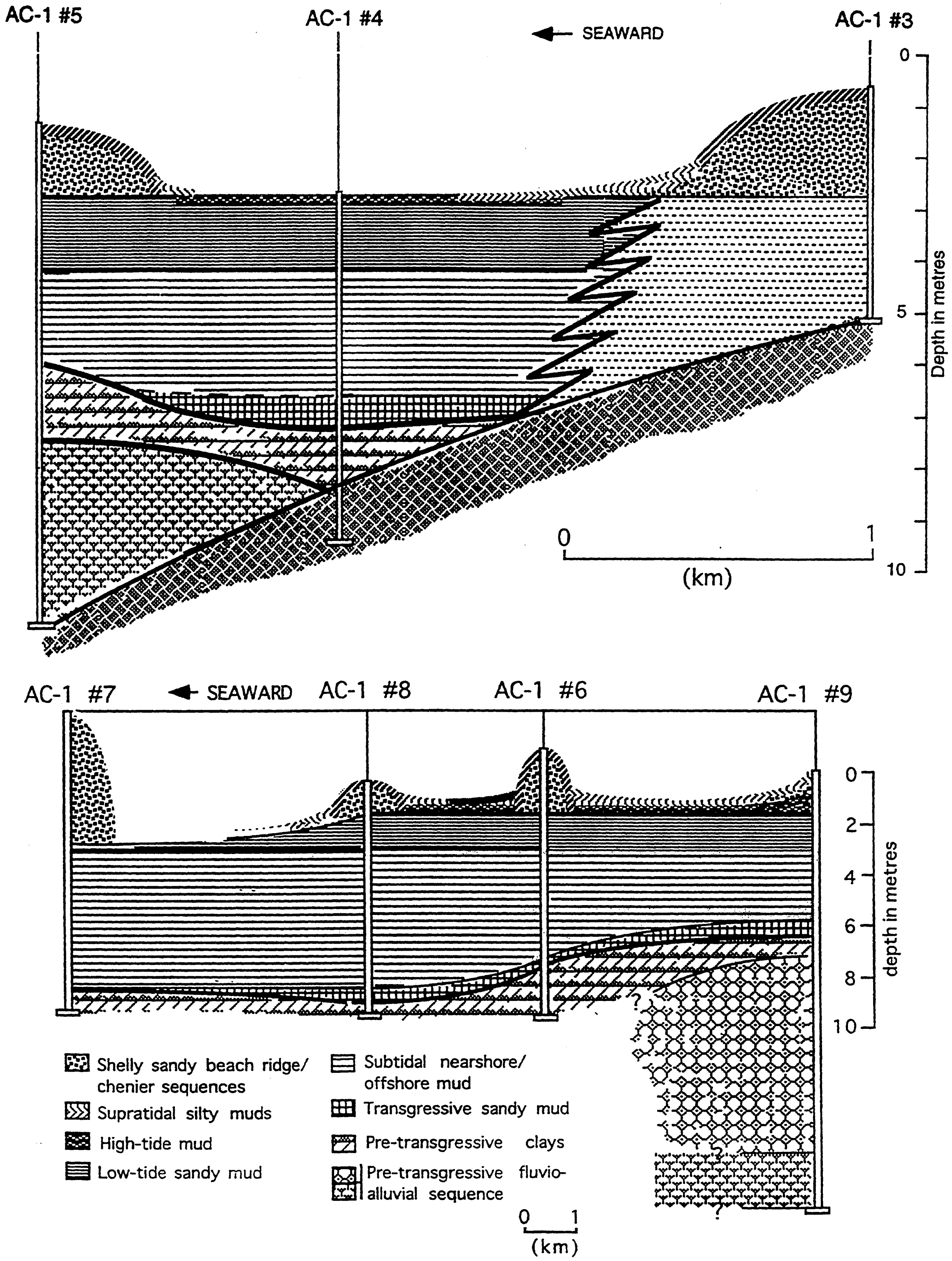


Figure 7 Stratigraphic sections from drilling transects on Rutland Plains, Cape York Peninsula

Although these transects are spaced a considerable distance apart holes AC-1 #5 and AC-1 #9 would have been formed approximately coevally (ie. along the same shoreline). The age at which these ridges formed, and the general progress of the transgression and subsequent coastal progradation in this area will be resolved by radiocarbon dating of material presently in progress.

The lowest (and therefore oldest) stratigraphy intersected in the drillholes is revealed at the base of holes AC-1 #3, #4 and #5. Drilling at the base of these holes encountered a shallow depth of stiff, pale white/yellow clay with an abundance of calcitic pebbles overlying a indurated layer, and is likely to represent the surface of an older alluvial fan deposit flanking the Mitchell fan. In hole AC-1 #3 (on a degraded landward ridge) this older material is overlain by deposits related to the Pleistocene inundation. Progressing up through the stratigraphy clays with a component of fine/very fine sands give way to more sandy facies.

The pre-Holocene age of these sediments is indicated by an absence of organic or carbonate material and the general maturity of the soil profile developed in the upper section. Additionally, accessories such as abundant iron/manganese nodules and soft calcitic material (the product of leaching) support an older age for these sediments.

Progressing seaward from this Pleistocene barrier the topography falls to an unvegetated mudflat (the site of hole AC-1/#4), and rises abruptly onto an isolated elongated ridge dissecting the plain (the site of hole AC-1/#5). As illustrated in the cross-sectional representation (Fig.7), the lower stratigraphy in these holes reveals a younger alluvial fan deposit overlain by a Holocene marine sequence. At the base of this Holocene section olive clays with intercalated sandy lenses indicate the development of estuaries behind the transgressing coast. This in turn is overlain by a blue/grey plastic mud developed representing the first pulse of progradation as fine sediments were discharged into the nearshore. Toward the top of this facies pockets of micaceous sand and mud are intercalated marking the approach of the prograding nearshore. Finally a chenier ridge was deposited (ie. site AC-1/#5), with an initial shallow, gravelly coarse sand deposit of only 0.5m, on top of which a further 0.5m of dune cap has developed.

The stratigraphy in these three holes effectively captures the critical intersection of the older alluvial surface and the younger Mitchell River fan, as well as the Holocene marine incursion which, consistent with expectation, has terminated seaward of its Pleistocene counterpart. The extensive muddy plain and chenier configuration extending seaward from this location suggests that rapid progradation of the coastline occurred after this Holocene transgression.

The transect of drillholes from AC-1/#9 on a barely discernible ridge in grassland 10km from the coast to AC-1/#7 in the near coastal ridge series capture a similar pattern of rapid progradation and widely spaced chenier development. Drillhole AC-1/#9 intersects 7m of Holocene marine stratigraphy overlying the alternating gravel and sand beds in the distal reaches of the Mitchell River fan. These in turn overlie a clay surface at a depth of 15m.

Stemming from the more compressed beach ridge sequences on the foreslope of the Mitchell River fan these cheniers fan out across the mud filled embayment. As this prograding shoreline achieved a bayline between the mouth of the Nassau River and the front of the Mitchell fan the rate of progradation slowed, and beach ridges were deposited.

As revealed in erosional exposures on the bank of the Nassau River and in hole AC-1/#7 this forward series of beach ridges is substantially cemented into layers of beachrock several metres thick. This beachrock has resulted from the interaction of a substantial freshwater table supported by the river behind with seawater at the beachface. This mixing induces chemical changes which causes calcium carbonate to be precipitated, cementing available sediments.

On the southern side of the mouth the inflection in the coast and the river discharge have trapped longshore transported sediments prolonging chenier development. Sediments in these cemented ridges as with the modern beach have a very high proportion of carbonate (ie. mainly shells), which would be derived from high energy events winnowing offshore sediments. An excavation in the modern beach revealed that the apex of berms have been translated landward by large overwash deposits composed entirely 6-10cm *Turritella* sp. shells sourced in this manner.

Remote sensed imagery of the coastline between the Nassau and Mitchell rivers shows that the pattern of previously deposited ridges has been truncated, indicating that the shoreline has experienced a period of erosional retreat. However, the present beach configuration at Rutland Plains indicates to the contrary that a recent period of constructive development has taken place. A berm has been isolated on the upper beach by progradation and a new active berm has replaced it further seaward. A substantial bar and runnel platform which partially emerges at low tide has developed on the lower shoreface, providing a foundation for further growth. The upper (isolated) berm on this beach has the form of an incipient beach ridge and as such was investigated by a 20m long, and up to 2m deep, excavation. The internal bedding revealed in this excavation supports the Bird (1984) model for beach ridge development where, the apex of a berm is translated landward by storm truncation, and given sufficient sedimentary input to the nearshore a new berm will form seaward. The isolated berm will then become colonised by coastal vegetation and a dune cap will develop.

The excavated berm revealed that it had developed primarily as a berm with numerous seaward sloping laminae, and subsequently had been truncated by a high energy event which had translated the apex landward and dumped a large gravel overwash deposit behind. It is difficult to estimate whether such phases are cyclical and over what period they may operate and, if so, whether such cycles may be operating within the framework of a longer period erosional trend associated with more permanent climatic adjustments. Only long term monitoring can make a valid assessment of these changes.

5.2.2 Northwestern river-dissected, linearly-barriered coast

Geography and Geology

This section of coastline extends from Duifken Point near Weipa to Vrylia Point and is characterised by a relatively narrow (2.5-5km), lineated coastal plain (Fig. 2). The coastal geometry displayed along this sector is the product of the relatively continuous and steeper residual landscape surface which has met transgressing seas. In general the regolith surface forming the framework of this section of coastline is bauxitic laterite (commonly pisolitic) with shallow aeolian deposits in patches. Between Duifken Point and Cullen Point this substrate has been stepped seaward by a structural lineations in an underlying late Cretaceous early Tertiary formation.

Coastal landforms

In contrast to the expansive plains to the south, the overall steeper sloping land surface of this area has allowed less marine penetration inland and a more compressed coastal sedimentary sequence characterised by beach ridge rather than chenier development. The common configuration for this section is:

- a degraded Pleistocene barrier abutted against the land surface at the rear (with some back barrier swamp areas created where fluvial depressions have been truncated),
- a forward Holocene barrier which has prograded some distance to the present shoreline, and
- an intervening swamp area where many coastal rivers have been redirected to run shore parallel by the Holocene sedimentary obstruction.

These rivers experience a sudden reduction in grade as they encounter this area behind the Holocene barrier causing a concomitant reduction in flow energy, and an increasing tendency to be redirected and meander. This leads to the deposition of fine sediments among tidal mangroves.

The point at which these streams finally break through the Holocene barrier and discharge to the sea is often determined by the confluence of two or more streams adding impetus at a particular location. At the mouth of these rivers arcuate deltas commonly form characterised by longshore directed bars. This indicates that longshore current and transport processes dominate over the fluvial outflow processes. Fringing coral reefs are observed along the coast between Duifken Point and Cullen Point as a result of colonisation of available shallow lateritic rock substrates such as the one exposed at Cullen Point.

At some locations, such as adjacent to the mouth of the Jackson River, relict embayments were formed where the transgressed landscape was indented. Progradation in these embayments has been relatively rapid (particularly during the Pleistocene), and consequently the shoreline has stepped out chenier fashion as a series of longshore spits recurving to the river mouth resulting in a splayed pattern of ridges.

Characteristically a sparsely vegetated coastal dune platform occupies the area immediately landward of the beach, and over lengthy stretches of coastline these platforms terminate landward in small fields of transgressive dunes.

Barriers in the relatively compressed coastal sequence south of Pennefather River are capped by phases of transgressive dune deposition from early Holocene to present. Lees et al. (1993) believe that these phases are likely to be related to climatic episodes. These extensive dune sheets are not evident in the coastal sequence investigated near Skardon River where the entire Holocene sequence is characterised by a distinct ridge topography. However, this Holocene sequence has clearly also developed in episodes, and a number of more prominent dune capped ridge are present.

Site investigations within this category

Little previous research has been conducted on this portion of coastline. Lees et al. (1993) have carried out a hand auger investigation of a transect across the barriers south of the Pennefather River, and have processed thermoluminescence ages for this formation.

During the present survey a transect of six holes running parallel to those of Lees et al. (1993) (but closer to Pennefather River) was investigated by mechanical auger (figure 8). A second transect of seven holes were sited across the late Quaternary sedimentary plain south of Skardon River (figure 9).

Nature of Quaternary coastal deposition

The transect investigated at Pennefather River has similar surficial elements as described by Lees et al. (1993), however, the presence of an underlying coral reef covered substrate at this location has supported additional progradation leading to a more expanded coastal sequence than that investigated by those authors. Surface morphology and stratigraphic elements in the late Holocene section of this barrier are shown in figure 10. A low tide platform precedes the present 4° slope high tide beach which terminates landward in a 3.2m high 17° scarp. Behind the beach a sparsely vegetated dune area extends some 200m landward culminating in a substantial vegetated coastal dune with 6.5m relief over a swale to its rear. This marks the extent of the more recent mobile dune fringe which is comparable with unit A of Lees et al. (1993), and interpreted by those authors as enveloping earlier Holocene deposits.

Behind this coastal dune sequence the main body of late Holocene progradational sediments extend from a further 600m inland. This barrier, which is interpreted as having formed since the transgressive maximum, is composed of three distinct sub-environments. At the rear of the sequence is a steep 5.5m high, isolated dune body running shore parallel for several kilometres. The results of drilling on the crest of this dune show that approximately 7m of well-sorted, white quartzitic dune sand overlie an older surface indicated by an abrupt colour boundary to dark brown, more poorly sorted sand. This abrupt boundary was also encountered at the same level in a drillhole immediately behind this dune body (AC-1/#11 in figure 10), and is consistent with the sediment character observed in older facies encountered in drillholes further inland.

Progressing seaward of this rearward body of dunes is a low drainage area where depressions between poorly developed ridges are populated by water tolerant species of trees. This area has developed as an intra-barrier swamp behind a series of ridges which in turn extend seaward to the deep swale behind the mobile coastal dune fringe. There are five distinct ridges in this series with individual relief of the order of 1-2.5m, and the stratigraphy identified in drillhole AC-1/#15 reveals that the main body of this progradational series has formed as beach ridges. The surface topography is due to dune capping above the beach facies. Although this dune sand could have been emplaced after progradation, this arrangement of several closely spaced, shore-parallel ridges suggests that they are likely to have tracked the shoreline as it progressed seaward.

Downhole stratigraphy revealed in drillhole AC-1/#15 is consistent with the expected progradational stacking of environments, but with the addition of coral reef facies on the basal substrate. Age dating presently in progress will confirm the age of this reef, which may have developed during the transgression and/or the period after sea level stabilised when this was

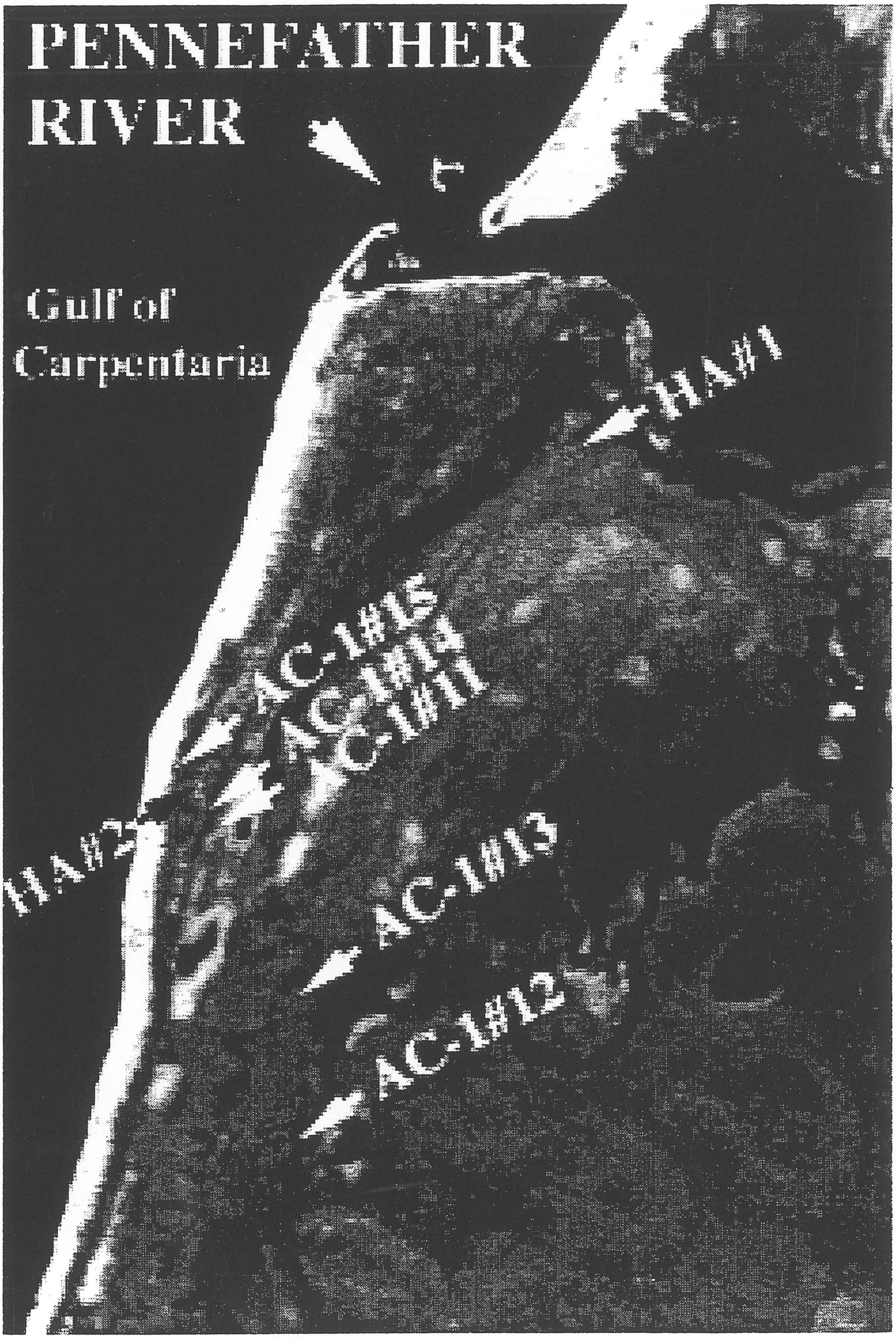


Figure 8 Mechanical auger and hand auger sites near Pennefather River.

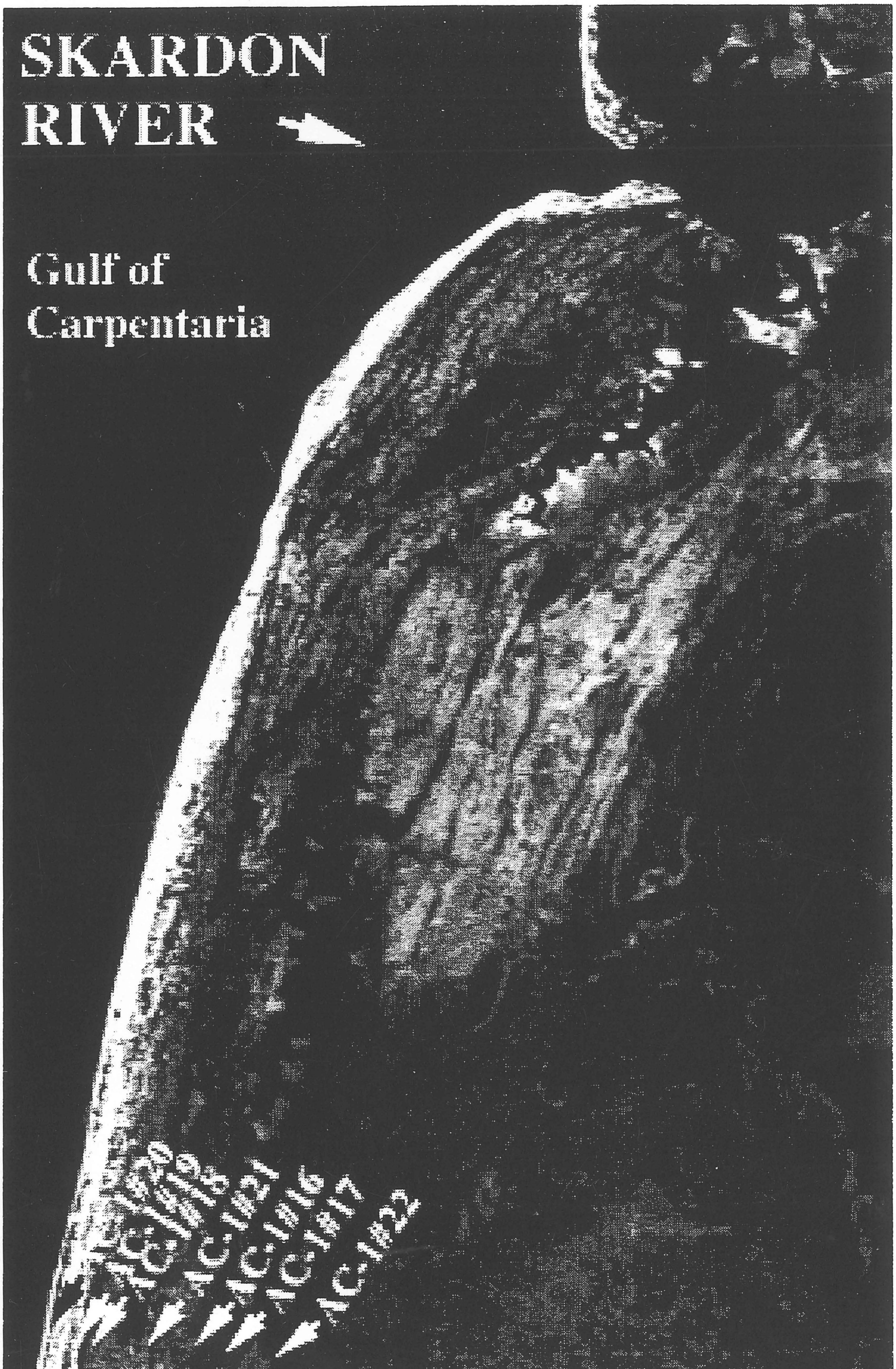


Figure 9 Mechanical auger sites near Skardon River.

an offshore environment. Moving up the section from the reef facies is a grey fine to very fine sandy offshore mud facies coarsening as the shoreline approached. The migration to lower beach facies is identified by both a general coarsening and colour change to brownish- yellow sand, and the introduction of beachrock and laterite pebbles such as observed on modern beaches.

The swale that separates this group of ridges from the currently transgressing mobile dunes is a substantial permanent feature which experiences periodic flooding and probably identifies the end of a discrete episode of progradation. Aerial survey of this section of coastline revealed this pattern of isolated longshore parallel dune ridges and groups of beach ridges separated by long 'gutters' of intra-barrier swamps and lakes to be a common arrangement.

This complete late Holocene barrier of rearward dunes, intra-barrier swamp and forward ridges is equivalent to the more compressed sequence identified by Lees et al. (1993) as a single dune ridge forming unit B. These authors dated the initial dune development at 5,200-5,300 yrs which is shortly after sea level stabilised. The morpho-stratigraphic arrangement across this barrier indicates that the transgressing Holocene coastline probably halted in the vicinity of the intra-barrier swamp, landward of which the large body of dune sand established. A larger dune commonly marks the final transgressing shoreline position. This may be a function of the shoreline pausing at this turnaround while waiting for the nearshore to fill and provide a platform for progradation, or a substantial body of dune sand may migrate with the transgressing shoreline as it continued to erode and rework sediments, or both. The reef bearing substrate offshore has provided a platform for progradation that has resulted in the extension of the coastal sedimentary plain between this location and the Pennefather River.

Moving inland, this entire Holocene progradational series is divided from an older broad low-relief barrier (unit C of Lees et al., 1993) by a substantial back-barrier swamp. This older barrier extends further inland to where another drainage line demarcates the boundary to the general bauxitic/lateritic regional regolith surface.

Two holes were drilled in this rearward dune series (unit C); one toward the rear and one centrally within the barrier. The latter exhibits similar near surface sedimentary character (ie. bright brown medium to fine sand) to that found beneath the dune sand at the rear of the late Holocene barrier, and to that described by Lees et al. They provided a thermoluminescence age of 8,300yrs ± 1,100 yrs BP for the emplacement of this sand. These authors interpret this as a transgressive phase of dune building resulting from a "Cooper-Thom" event. During these events, which occur during rising sea level, storms destroy vegetation stabilised coastal dune deposits and mobilise sand which in suitable climatic conditions (ie. strong onshore winds and drier climate) forms large transgressive sand sheets. During more moist climatic phases these transgressive dune deposits become stabilised by increased vegetative growth. The results of drilling in the present survey identified this dune cap as extending to a depth of ~2.8m under which a predominantly medium-ranging to coarse, leached sand facies is identified, which coarsens to a gravelly base at 6.95m. A distinct boundary at this depth marks the transition to a fine to very fine sandy clay facies. These facies which unconformably overlie a stiff red clay surface are interpreted as a Pleistocene beach and nearshore sequence. The rearward hole in this unit C barrier revealed similar but compressed stratigraphy without the early Holocene dune cap.

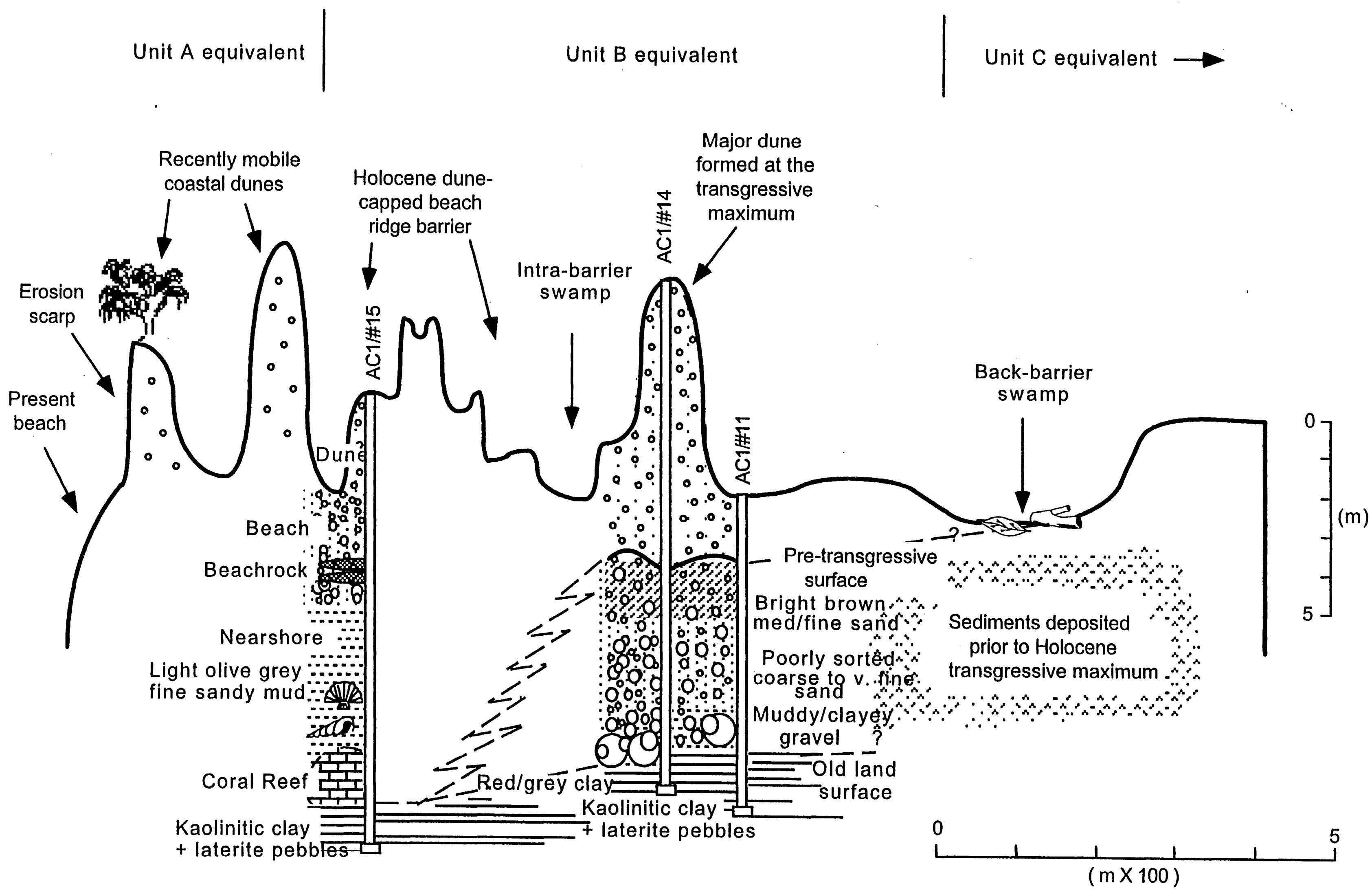


Figure 10 Surface morphology and stratigraphic detail of Holocene section - Pennefather River transect.

In the Skardon River transect (figure 11) the interface between the Quaternary coastal sedimentary plain and the regional regolith surface south of Skardon River is marked by a drainage line approximately 4.5km inland from the coast. A low relief dune body occupies the area for a further ~1.2km seaward before a swamp area demarcates the rearward extent of the Holocene progradational sequence which covers a further distance of ~3.1m to the present shoreline.

A drillhole in the rearward dune body found it to be a shallow veneer of 1.8m of dune sand over a regolith surface of highly pisolitic bauxitic gravel with a red/grey clay matrix. This dune sand has developed a soil profile with a light brown, organic, fine/medium sand A-horizon to 0.6m, changing to a friable clayey sand B-horizon with bright red iron concretions. The maturity of this soil development suggest a likely Pleistocene age for deposition.

Drillhole AC-1/#17 (figures 9 & 11) was placed in a minor grassed interfluve in the swamp between the Pleistocene and Holocene sequences. This hole again penetrated the old land surface at a very shallow depth (2.3m), but captured the thin end of the Holocene depositional wedge. Immediately overlying the old land surface a shelly, gravelly sand deposit marks the intrusion of the Holocene sea, and this deposit grades up the section to a poorly coherent sandy mud. The top 1m of sediment is dark olive and yellow sandy clay which has aggraded *in situ* from fine stream derived sediments and aeolian sand.

Immediately seaward of this swamp a distinct ridge marks the commencement of the Holocene barrier. The stratigraphy revealed in drillhole AC-1/#16 shows this to be a beach ridge with an aeolian cap of ~1-1.25m, based on a relict land surface of stiff kaolinitic clays with large laterite pebbles at a depth of 5.7m. Again the sediments overlying this land surface are very coarse and shelly, with pebbles to 50mm diameter. and are likely to have been deposited as a transgressive lag. Moving up the section a coarse gravelly and shelly sand nearshore facies continues until 3.5m depth where a intercalated bed of grey, shelly, sandy mud intervenes. This latter facies is similar to that found in the low tide barred platforms on modern beaches in the area. Overlying this mud facies another gravelly, shelly facies marks the transition to the lower beachface which grades to progressively finer upper beach sands and finally to the aeolian surface sand.

Moving seaward in the Holocene ridge series the stratigraphy exposed in three further drillholes is consistent with a conventional progradational model. Varying depths of coarse transgressive deposits are preserved above the relict land surface, over which the initial offshore mud facies lie unconformably. Progressing up the section these muds give way to alternating coarser and finer beds indicate the translation through a low tide bar and runnel environment, progressing into the tidal beachface where beachrock is preserved in some locations, and finally into upper beachface and dune deposits.

As mentioned previously the aerial distribution of Holocene ridges south of Skardon River suggests that barrier development has been episodic, and approaching the river mouth subsequent phases of progradation appear to have truncated earlier deposits. A recent series of sparsely vegetated ridges are observed to have developed near the mouth after such an erosional phase.

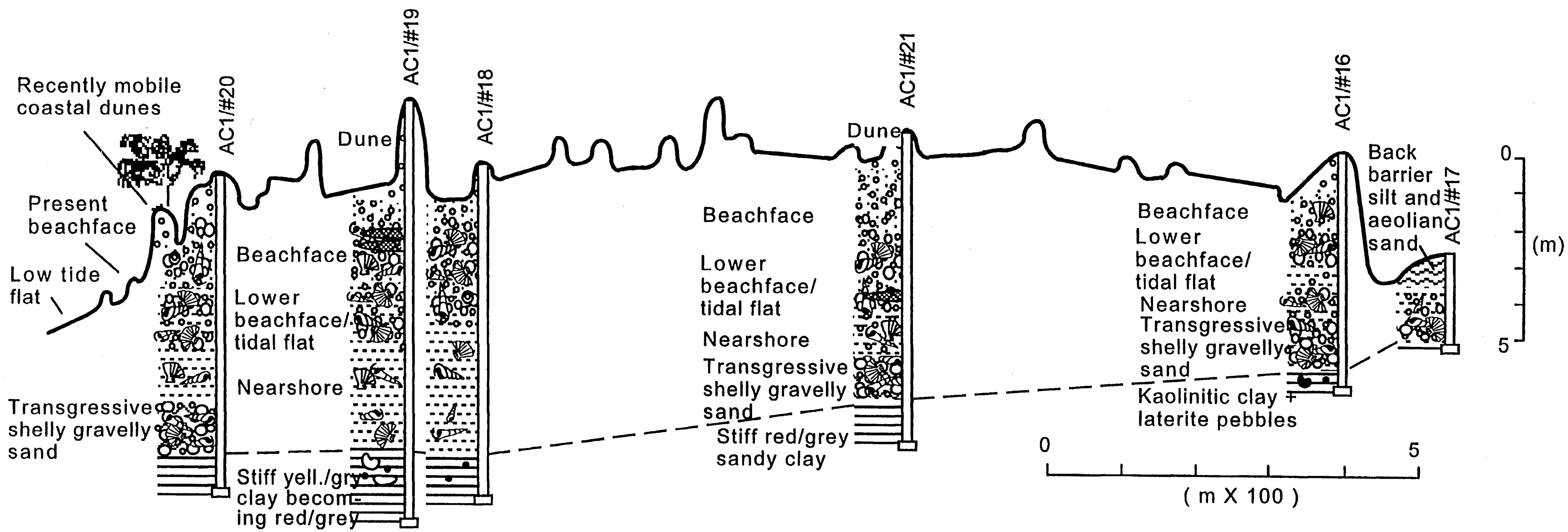


Figure 11 Surface morphology and stratigraphic detail of the Holocene barrier - Skardon River transect

The overall Holocene ridge pattern indicates that the stream established its present orientation quite early, and therefore migrations of its mouth cannot be seen as a major factor in this episodic development. An inflection in the shoreline is observed in the ridge pattern, which consistently migrates in a northwesterly direction and persists through several generations of progradation. This inflection may have developed by interaction between longshore currents and stream discharge, or may be due to shallow substrate offshore in that direction, however, once again cannot be seen as to have initiated a phase of development by its introduction. The most likely agent affecting coastal progradation therefore are periodic shifts in climate.

Summary

The development of coastal landforms along this linearly barriered coast can be interpreted primarily as a response to the interaction of sea level rise and the incumbent coastal physiography. The steeper, more continuous landscape has restricted the width of the coastal plain, and led to a more compressed coastal sequence than observed on the vast southwestern Cape York plains. Progradation has been influenced in a number of locations by the presence of shallow offshore platforms, which sometimes support reef growth.

Similar to coastal sequences on the southwestern coastline of the Cape, progradation in this area has advanced in episodes with erosional or non-depositional hiatuses in between. Lees et al. (1993) concluded that major climatic shifts were responsible for periods of transgressive dune formation at Pennefather River in the early Holocene, and Rhodes (1980) has invoked a similar explanation in explaining the correlation between non-depositional hiatuses in beach ridges near Edward River with chenier emplacement on the southern Gulf of Carpentaria coastline. Further detailed drilling and aging of sequences such as at Skardon River will assist in further refining the history of climatic change on Cape York Peninsula during the Holocene.

5.2.3 Major estuaries of Cape York Peninsula

A simple geomorphological definition of an estuary is "...a funnel shaped opening of a river in the sea" (Reinick and Singh, 1980). Other definitions include criteria such as being tidally effected and dilution of marine and fresh water. A generally accepted definition is that of Pritchard (1967) who describes an estuary as "...a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."

A more recent geologically orientated definition by Dalrymple, Zaitlin and Boyd (1992) has recognised that estuaries form by the drowning of river valleys as sea level rises, and recognise the limits of an estuary by sedimentary criteria. They define an estuary as "...the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth." (p.1132)

Many coastal rivers and streams fit this definition to an extent, however, as Dalrymple et al. point out, estuaries are geologically ephemeral and in time after sea level rise has slowed or halted become filled and cease to exist. As a general principle estuaries during their life will be depositional centres because they are vessels in which energy declines from both a landward and seaward direction. The fluvial energy flux decreases into the estuary because of the drop of hydraulic gradient while wave and tidal energy decreases into the estuary because of depositional barriers at the mouth and frictional damping, leading in both situations to deposition of sediment. At the time that sediment fills the accomodation it ceases to be an estuary and the site becomes a delta, "... if the sediment is supplied directly by the river, or a straight prograding coast (beach-ridge or strandplain; open coast tidal flats), if the sediment is delivered to the area by marine processes (waves or tides, respectively)."(Dalrymple et al. 1992, p.1132). This progressive shift through time and relationship of final environment to wave, tide or river dominance is illustrated in figure 12 from the same authors.

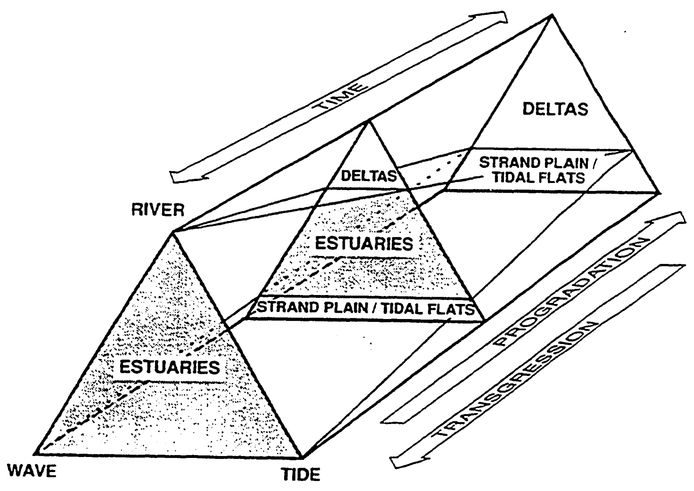


Figure 12 Evolutionary classification of coastal environments. The long axis of the three-dimensional prism represents relative time with reference to changes in relative sea level and sediment supply (i.e., transgression and progradation). The three edges of the prism correspond to conditions dominated by fluvial, wave and tidal processes. Deltas occupy the uppermost area; the intermediate, wedge-shaped space contains all estuaries; and the bottom wedge represents non-deltaic, prograding coasts. Transgressive, barrier-lagoon systems which form along coasts without incised valleys occupy part of the estuary field. During a sea-level cycle, a coastal area will track forward and backward through the prism at a rate, and by an amount, determined by the rate of sea-level change, the sedimentation rate and basin size.

(Dalrymple et al., 1992)

In sections of the Cape York coastline the physiography of the residual landscape has formed a template within which large river valley networks are drowned when sea level rose. The main systems identified on the west coast include the estuary of the Archer River near Arukun, the Mission River at Weipa, and Wenlock, Ducie and Dulhunty Rivers at Port Musgrave. The late Cretaceous - early Tertiary structural lineament between Duifken Point and Cullen Point has been responsible for creating the physiographic framework for these latter two estuaries. Generally branches of these estuaries penetrate a number of river valleys finally narrowing at the headward end, with the exception of the Hey River which becomes unconfined at its headward end as it breaks into the broad low plain created by the early Cretaceous Rolling Downs formation.

On the east coast a major estuaries occupy Newcastle Bay between Jacky Jacky Creek and the Escape River, Temple Bay through which the Kangaroo River discharges, and Lloyd Bay through which the Lockhart River outlets. On the east coast these major estuaries have developed in extensive north facing bays where they gain protection from prevailing southeast wave energy.

Holocene estuarine development

Some of these systems have approached their final depositional equilibrium with regard to river and tidal energy and therefore by strict definition have progressed beyond an estuary classification, however, it is useful to consider them as such when describing them as many of their characteristics prescribe to their estuarine genesis.

Estuaries can be classified into two main categories: wave dominated and tidally dominated. The estuaries identified above are primarily tidally dominated and show certain characteristics accordingly. A generalised model of a tidally dominated estuary is shown in figure 13. As examples, the Weipa and Port Musgrave estuaries exhibit similar features to those identified in this figure. The domination of tidal current energy over wave energy at the mouth of these estuaries has resulted in elongate (transverse) sand bars. As the flood tide is funnelled into the estuary, currents gain speed for a distance due to the confinement before friction finally dissipates the energy. This results in a relatively straight braided channel with a number of transverse mid-channel and bank-attached bars, with tidal mudflats along the lower energy flanks.

Landward of this zone the declining tidal energy meets the declining fluvial energy from the other direction to effectively negating each other and creating a low energy zone. Because of the low energy fine sediments are deposited in this zone, and the stream which is unconfined by hard substrate characteristically develops a meandering pattern. This is the environment seen to be dominated by mudflats and mangroves in the Cape York examples.

Moving toward the head of the estuary the increase in grade produces a concomitant increase in fluvial energy. This results in a reduction in stream channel sinuosity, before finally reaching the boundary beyond which all tidal influence is lost and the true fluvial system takes over. The landward extent of mangroves is also controlled by this loss of salinity, since they have a distinctive growth zone covering the tidal range (ie. from just below mean low water spring tide to just above mean high water spring tide).

As mentioned previously, large estuaries such as Newcastle Bay are at a very mature stage and may be also considered in terms of delta nomenclature. The main body of stream and mangrove dissected sediment in the bay exhibits this maturity. This environment would have evolved from an initial dendritic drainage pattern developed in bare intertidal mudflats, which were progressively colonised by mangroves. The roots of mangrove species assist with deposition by baffling the energy and stabilising deposits. As the surface accreted above a height normally visited by high tide, halophytic grasses would have established leading to the development of the supratidal meadows observed currently over much of the area.

This pattern of development identifies a predominantly tidally dominated genesis, however, a series of cheniers toward the forward margin of this large mud island occupying the bay shows that the final progradational advance has moved into a wave dominated realm. These cheniers characteristically develop immediately behind mangroves throughout the Cape, where they accumulate the products of high energy (ie. storm) events beyond the reach of high tide. They are commonly the site of large accumulations of flotsam and jetsam. In Newcastle Bay this wave affected zone appears to mark the advance of sedimentation beyond the protection of Sharp Point and Turtle Head Island. Having advanced into the wave dominated environment the prodelta deposits could be expected to transform from shore-normal tidal bars to shore-parallel sand bars in the immediate offshore.

Both Pleistocene and Holocene barriers and dunefields are identified on the west to northwestern coast of Newcastle Bay. The Pleistocene barrier at the rear of the bay has effectively choked the valleys behind leading to the development of back-barrier swamps. These low lying areas have been subsequently invaded by dune sand which has adopted a 'stringer' pattern over this wetland base.

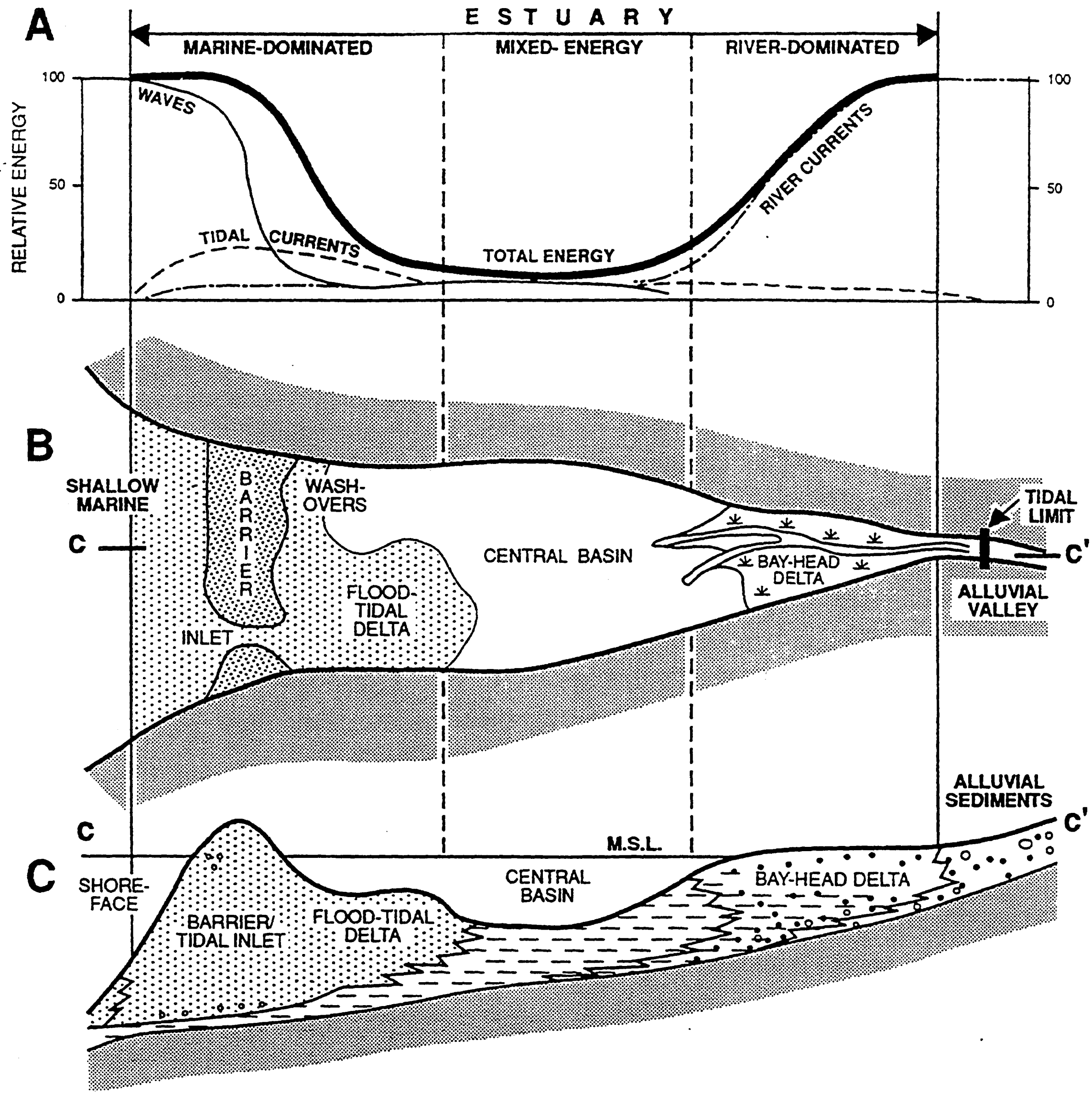


Figure 13 - Distribution of **A)** energy types, **B)** morphological components in plan view, and **C)** sedimentary facies in longitudinal section within an idealized wave-dominated estuary. Note that the shape of the estuary is schematic. The barrier/sand plug is shown here as headland attached, but on low-gradient coasts it may not be connected to the local interfluves and is separated from the mainland by a lagoon. The section in **C** represents the onset of estuary filling following a period of transgression. (Reproduced from Dalrymple, Zaitlin and Boyd, 1992).

One of these dunes was investigated in a pit exposure and in hand auger samples, and found to be composed of 3.5m of dune sand unconformably overlying swamp sediments. Both the Pleistocene and Holocene barriers would have developed in the period after their respective transgressions, but before central Newcastle Bay had become congested with prograding sediments. In this open embayment this section of coast would have been exposed to wave energy. The rear ridges of the Holocene barrier are anchored to the steep basement protrusion to their eastern end and have developed thick dune caps resulting in relief of the order of 10m. The more seaward ridges have prograded with low relief over a residual landscape shelf. Similar slightly emerged platforms are observed presently adjacent to headlands to the east. A series of drillholes through these seaward ridges revealed between 2.9 and 5.0 metres of Holocene section overlying coarse gravelly red/brown pre-transgressive regolith. The lower Holocene progradational sequence is composed of grey, shelly, fine to very fine sandy nearshore mud, which is overlain by fine to medium beach sand, terminating in a well sorted fine dune sand at the surface. The present shoreline is mangrove lined with the characteristic chenier developed immediately behind, and an extensive low tide flat extending seaward into the bay.

The estuarine sequences of both Temple and Lloyd Bays are curtailed at a bayline but exhibit a fragmented seaward margin of elongated bars suggesting tidal dominance.

5.2.4 The Jardine River coastal plain

Geography and Geology

The Jardine River occupies an enormous catchment etched into the mainland Jurassic sandstone geology of northern-central Cape York Peninsula. It travels from headwaters some 60km inland to cross a vast plain before discharging on the west coast. This expansive plain extends some 20km inland from the present shoreline, and is characterised by web of stream channels dissecting residual aeolian deposits. The plain occupies a gap of approximately 40km from Vrylia Point, marking the northern termination of the older aluminous laterite regolith that controls the coastal configuration south to Weipa, and Mutee Head where the basement geology controlling the geology of the far northern section of Cape York commences.

Site investigations in this category

During this study helicopter based reconnaissance was carried out across the Jardine River coastal plain and Crab Island, including surface sampling of pre-Holocene barriers. A drilling transect was placed across the relict delta facies and Holocene barrier coastal sequence south of Mutee Head during a later land survey.

Nature of Quaternary coastal deposition

The coastal plain to the south of the Jardine River features a complex of pre-Holocene and Holocene barriers extending from approximately 8km inland from the present shoreline. Behind the most landward barrier a complex network of stream channels have degraded an aeolian sand sheet to form a series of low, lightly vegetated mounded features.

Moving seaward three major pre-Holocene (Pleistocene?) barriers can be identified, which although degraded, still exhibit distinct elongate ridge morphology. These white sandy ridges support a low scrub vegetation while the intervening broad swale areas support a heath-like vegetation. Their isolation from each other and strandline form suggest that they formed initially in a chenier fashion, and subsequently became the loci for dune formation. The pattern of recurving suggests longshore migrations of palaeostream mouths and associated spits, similar to the modern analogues seen in a number of Holocene barriers along this coast.

Amid the crowded drainage network crossing the alluvial plain more substantial palaeochannels can be identified which correspond to these migrating barriers. It is likely that the Jardine River has adopted these more southerly courses in the past. A large area immediately south of the present river course exhibits a stringer dune type pattern, suggesting that sand has blown across low wet areas. This lower drainage area is interpreted as a former delta. A residual sand body within this area was investigated and, in contrast to the other barriers has more substantial soil development and coarser (ie. not aeolian) sand.

A substantial swamp area divides the Holocene barrier from its earlier counterparts, which is occupied by active streams and mangroves near Vrylia Point, and changes to marsh and heathlands further north. As seen in other locations the Holocene barrier has developed in episodes with apparent non-depositional and erosional hiatuses, however, the abundant supply of sediment has continued to extend the progradational plain at this location.

The prominent shoreline at Slade Point and development of the adjacent offshore sand island (Crab Island) has likely developed at a depositional node formed where wind driven longshore drift moving north up the coast has intersected and negated the current driven longshore distribution of Jardine River sediment moving south. Much of the variation in the morphology of the Holocene barrier may relate to changes in the relative strength of these competing forces through time.

The Jardine River delta presently occupies a central position within the range of its Holocene migrations, which in the past have extended from Mutee Head to the north to a more southerly directed position. The delta has the form of a 'birdsfoot-lobate' style, the characteristic form of a river dominated delta where river discharged sediments are continuing to prograde the delta front into the offshore water body. A number of distributary channels are formed through the delta sediments and delta front bars have formed in interaction with prevailing currents.

A drilling transect of four holes was placed through relict delta and Holocene barrier environments south of Mutee Head. The delta facies intersected alternated between organic rich silt/clay deposits and very coarse sand to gravel facies representative of laterally migrating stream channel and alluvial deposits. Detailed sedimentary processing is presently being conducted to further resolve this complex stratigraphic history. The permanent Holocene barrier extending south from the basement rock outcrop at Mutee Head is compressed into ~400m laterally, and rises abruptly ~4m from the deltaic plain behind.

Drilling on a rearward ridge in the barrier revealed approximately 3m of beach and dune sand overlying a weakly formed palaeosol marking the transition to deltaic facies extending to a depth of 11.4m. These deltaic facies were not evident in a drillhole in the most seaward permanent Holocene ridge where 4.3m of beachface and dune facies overlies 1.35m of shelly nearshore facies resting abruptly on a brown sandy mud with abundant lateritic gravel. Drilling was terminated at 6m on an impenetrable surface, most probably related to the ferruginous laterites forming the regional geologic structure. A shallow lateritic shelf was observed emerging ~1m at low tide in the immediate offshore, and it is apparent that these rock substrates have provided the foundation structure for the development of this compact coastal barrier.

Again there appears to be evidence of recent erosion along this shoreline with mature trees being undermined, and at the mouth of the Jardine River substantial dieback and erosion of a former mangrove community was observed, (although in this latter case natural migrations of the river mouth may cause localised erosion).

5.2.5 Dune coasts

Several very extensive dune fields occur on the eastern coast of Cape York. These are almost exclusively siliceous unlike similar deposits on the eastern coast of Arnhem Land and Groote Eylandt where there are minor deposits of calcareous material within the larger siliceous dunes.

The largest of the dune fields (ca 750 sq km) extends northwards from the mouth of the Olive River almost to Cape York with only minor breaks. The greatest concentrations of aeolian material lie immediately to the north of the Olive River between Temple and Shelburne Bays. A similarly extensive dune field (ca 600 sq km) extends north from the Endeavour River to Lookout Point, north of Cape Flattery.

The origin of these extensive dune fields appears to be the reworking and north-westwards transport of fluvio-deltaic deposits exposed on the shallow shelf during periods of low sea level Lees and Lu Yanchou, 1992). The emplacement of the bulk of the material in all the dune fields dates to this time (ca 18,000 yrs BP). Reworking of these sediments by rising sea level (ca 8500yrs BP and ca 5500yrs BP), and late Holocene variations in climate has led to the emplacement of younger units. Older units in the Cape Flattery dune field (ca 170,000yrs BP and older) date to times of earlier low sea level.

There is no simple pattern of onlapping dune sequences as at Cooloola or Fraser Island.

In the Cape Bedford - Cape Flattery dune field the migration and diversion of river channels as a result of dune movement has resulted in large sections of dune stratigraphy being reworked. A drainage line which flowed north-east from near Hope Vale mission to join a prior course of the McIvor River exiting to the south of Beor Reef has been blocked by migrating dunes and now forms the right branch of the Endeavour River. Another drainage line to the south of this, with a mouth close to Grey Hill, has also been diverted. North of the present course of the McIvor River, the dune field stratigraphy has been preserved and a deep sequence of palaeosols can be identified.

In the Cape Grenville dune field, between Temple and Shelburne Bays, the transgression of elongate parabolic dunes in the central and western parts of the dune field has been responsible for most of the reworking. Here exposed areas of the deeply weathered sands have been deflated to the watertable during successive dry seasons by strong, persistent, and almost uni-directional south-east trades. In this part of the dunefield perched watertables are common and for much of the year the landscape is waterlogged.

The sediment dynamics of this unusual environment are such that the long, very shallow lakes which result from the transgression of elongate parabolic dunes are progressively sub-divided into chains of lake-lunette complexes. This is one of the few places where one can observe today the processes which led to the formation of the western NSW and northern Victoria palaeolake-lunette landscapes. The eastern part of the dune field is higher, less waterlogged and formed of older, surviving dune units. Here the vegetation cover is more complete and areas of current aeolian activity are rare.

The vegetation in the dune fields responds quite dramatically to small changes in mineralogy and weathering. In the Cape Bedford - Cape Flattery dune field the lower McIvor River marks not only a boundary between older dune deposits to the north, and younger, reworked, deposits to the south, but also a marked vegetation boundary. To the south are extensive and varied heath communities, and to the north some significant areas of Auricaria forest growing on deep, old dune podsols. A remarkably high density of stone tools in blow-outs in this forest suggest past intensive use of this resource.

The vegetation patterning in the Cape Grenville dune field, between Temple and Shelburne Bays is also highly correlated with soil age and levels of inundation. Both support highly diverse and poorly understood ecosystems. They differ markedly with the other coastal dune fields of northern Australia where frequent aboriginal burning has had a significant and deleterious effect.

There are some important areas of vegetation for conservation in these dune fields. The tropical heath communities of eastern Cape York are considerably more diverse than those which occur on the other northern Australian dune fields. The 'Thryptomene Closed Scrub', described from Lizard Island, and also for the coastal dune fields, is characterised by an abundance of epiphytic orchids and ant plants and occupies some of the drier areas of white sand. The best example of this unusual community so far recorded lies to the immediate north-east of Conical Hill in the Cape Grenville dune field. In general, the 'wet heath' of these dune fields is poorly represented in reserves, and the complex and spectacular patchwork of monsoon vine forest, tall closed heath and low wet heath which covers much of the dune fields has not been extensively investigated. Similarly, the few investigations of aquatic fauna that have been carried out in the dune lakes indicate an unexpected diversity.

Although a small area in Shelburne Bay with up to 65% heavy minerals has been identified, this is very localised and not representative of the area. The dunes in some areas are associated with aluminous laterite, possibly palaeosols, but only in the extreme north are these of economic grade.

The most significant economic resource in the dune fields is industrial silica sand. Whilst the Cape Bedford - Cape Flattery dune field has only restricted areas of high quality industrial grade sand, the Cape Grenville dune field has extensive areas. The central and western sections of the Cape Grenville dune field have grades of 99.8% pure silica, or better, over large areas. Whilst locally grades in the Cape Bedford - Cape Flattery area can be comparable, they can also be highly variable over short distances. As in many other areas of Cape York, this resource coincides with areas of great natural beauty and important biophysical attributes.

5.2.6 Princess Charlotte Bay

Introduction

Princess Charlotte Bay is one of a number of north facing embayments along the eastern coast of Cape York Peninsula, however, its considerably greater size has led to the development of a broader and more varied Quaternary strandplain than its counterparts. The bay is protected from the dominant southeast winds, and this, plus the combination of several rivers discharging from an extensive catchment area and a shallow offshore profile extending to an inner shelf barrier of coral reefs, has established the conditions for a broad prograded plain to develop. This extensive plain is characterised by groups of beach ridges toward the eastern and western bay margins, while in the central bay broad hypersaline supratidal mudflats interspersed with isolated chenier ridges and clay dunes have developed between estuaries.

Geological framework

Princess Charlotte Bay is underlain by the Mesozoic Laura Basin, which formed in the northern section of the more extensive geosynclinal Hodgkinson Basin. This basin developed during an earlier Late Proterozoic?-Early Palaeozoic orogen as downwarping occurred on the eastern flank of the Precambrian shield (White 1961).

In the Laura Basin a thick sequence of Mesozoic sediments dip gently to the southwest (Lucas and deKeyser, 1965). The basin is bounded to the west by the Coen Inlier, composed of massive Palaeozoic granites and associated metamorphics which form the main north-trending Cape York batholith. To the east the Laura Basin is bounded by exposed basement consisting of steeply folded and partly metamorphosed rocks of the Hodgkinson Formation which were folded in a Carboniferous orogeny. These rocks were subsequently intruded by granites of late-Palaeozoic age of which Melville Range is composed. Structural trends in the basin are governed largely by the Palmerville Fault Zone which developed in the Upper Silurian (Whitaker and Gibson, 1977).

Physiography

The coastal zone in the Princess Charlotte Bay is backed by a stream dissected alluvial plain, interspersed with residual weathered sandstone formations which have defined the landward boundary of Quaternary strand-plain deposits. Near surface structural trends related to the underlying Palmerville Fault Zone are seen to have influenced both pre-Holocene and Holocene deposition in the embayment. This structural control is expressed as a series of northerly-trending lineations identified by both inflexions of the coastline and depositional discontinuities in ridge barriers.

Four substantial rivers discharge into Princess Charlotte Bay: the North Kennedy, Bizant, Normanby and Marett Rivers, which collectively drain an extensive catchment approximating the underlying Laura basin. The Kennedy River system has the second highest average annual sediment discharge (~2.7×10^6 tonnes) of all the North Queensland drainage basins (Belperio, 1983). As observed by Chappell and Grindrod (1984) the combination of this high volume of sediment being delivered to the coast, and the inner shelf physiography with a reef barrier lying some 45km offshore, would have led to rapid shallowing of the offshore profile leading to accelerated progradation within the embayment.

Southwestern to western embayment

Two generations of strand-plain deposition are observed in the southwest and western embayment (figure 14). Relict ridges of a degraded inner barrier are dispersed across the southwestern coastal plain, becoming more compressed and elevated in the northwestern embayment. The distribution of these ridges clearly reflect the influence of the substrate over which they have been deposited. The preservation of these pre-Holocene coastal deposits is due to the lesser landward penetration of the transgressing Holocene sea, as may be expected due to it not achieving the same elevation as the previous (Pleistocene) sea level high.

In the southwestern embayment the more recent Holocene strand-plain deposition is characteristically separated from the pre-Holocene deposits by a back-barrier swamp, forward of which a compressed series of beach-ridges formed. Progressing seaward of this ridge series a broad supratidal mudflat stretches to the present shoreline. This mudflat is bisected by a single prominent chenier. A narrow tidal beach backed by a small coastal dune demarcates the transition from these supratidal flats to extensive intertidal mudflats extending offshore. This shoreline is presently in retreat as evidenced by exposure of old mangrove stumps in the nearshore, mature trees undermined and collapsing, and the eroded forward edge of the supratidal mudflat protruding through the beachface. The coastal dune is a small transient feature supporting young eucalypt vegetation, which unconformably overlies the supratidal mudflat over which it is transgressing. In the western embayment mangrove vegetation is confined to stream mouths and minor estuaries.

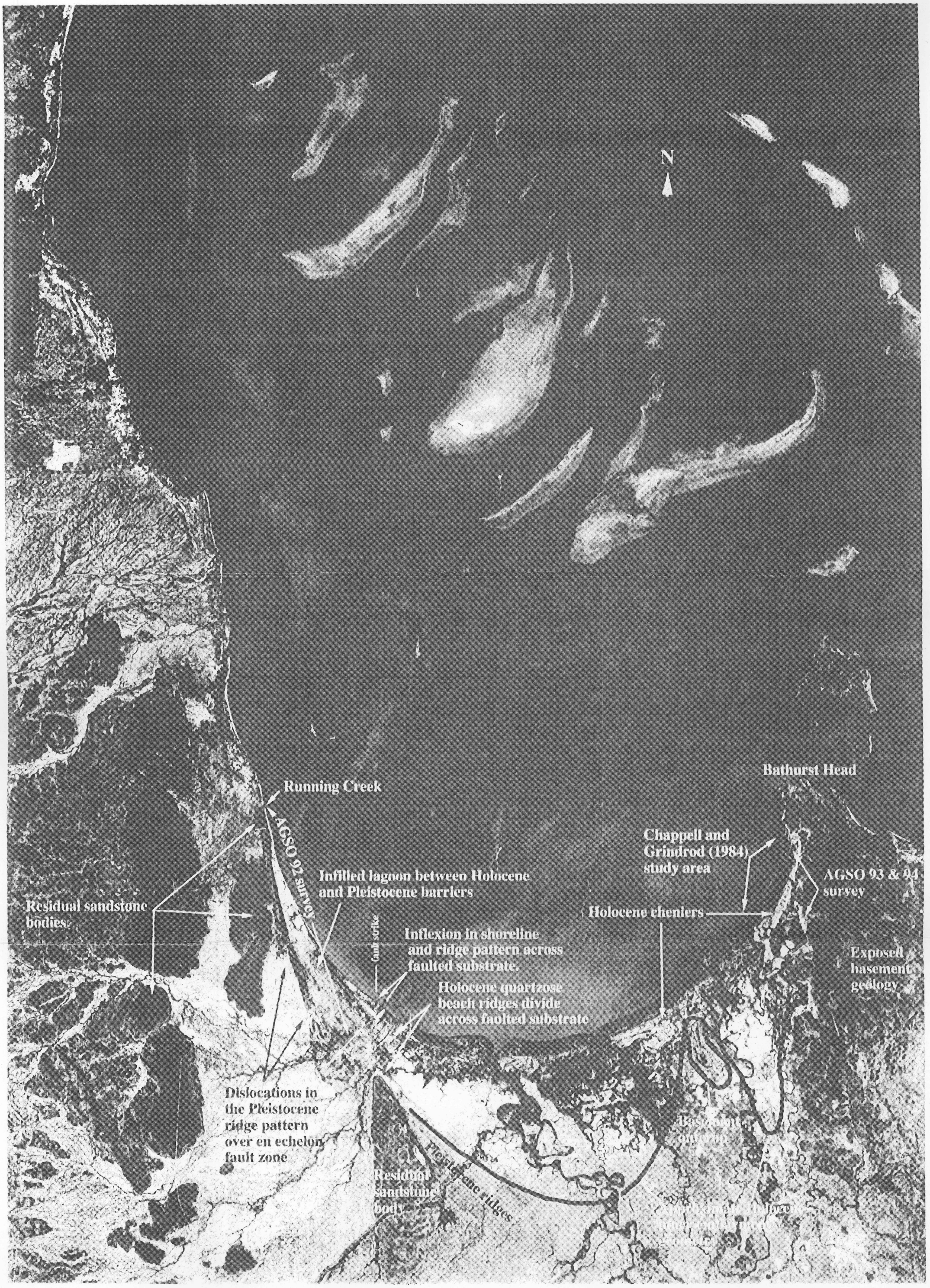
Southeastern to northeastern embayment

In the eastern embayment Holocene sedimentation has commenced against the emergent basement rocks of the Bathurst Range, forming two hypersaline back-barrier lakes. The most north-easterly portion of the depositional sequence is characterised by a compressed series of ridges which divide into groups of cheniers as the coastal plain expands toward the southeastern embayment. Mangrove vegetation dominates the shoreline and drainage systems in the eastern embayment, and has isolated a lagoon in the far north-eastern section.

The formation of the strandplain in the eastern section of Princess Charlotte Bay has been investigated extensively by Chappell and Grindrod (1984) as will be discussed in greater detail in the following section. The cheniers ridges and clay ridges stranded across the plain represent the coalesced product of multiple depositional events. These ridges and the intercalated mudflats are described by these authors as follows:

`*Supratidal clays*. The upper 10cm or so of the deposits of the mud flats between cheniers, in areas inundated only in the wet season, are gray to buff-coloured salty clays. These tend to form silt or fine sand-size pellets in the dry season, presumably through precipitation of weakly cementing salts in the capillary fringe, and they visibly deflate in strong winds.

Chenier ridges. Long, low ridges of clean shelly gravel with crests typically 1 to 2m above MHWS, are vegetated with grassy shrubland or mixed woodland with local groves of `vine forest' with deciduous elements (e.g. Bombax). The base of the most recent chenier ridge (at the northeast end of the study area) is about 0.3m below the level of the highest mangrove forest floor.


N
Running Creek
AGSO 92 survey
Bathurst Head
Chappell and Grindrod (1984) study area
AGSO 93 & 94 survey
Infilled lagoon between Holocene and Pleistocene barriers
Residual sandstone bodies
Holocene cheniers
fault strike
Inflexion in shoreline and ridge pattern across faulted substrate.
Exposed basement geology
Holocene quartzose beach ridges divide across faulted substrate
Dislocations in the Pleistocene ridge pattern over en echelon fault zone
Basement outcrop
Residual sandstone body
Pleistocene ridges

Clay dunes. Vegetated dunes of buff-coloured clay overlie the upwind side of cheniers, building to as much as 4m above MHWS at sites where broad upper intertidal and supratidal mudflats lie to windward. Most examples currently are eroding, and they are inferred to have formed in the past from wind-transported pelletised supratidal clays.'(p.203)

Where these separate ridges coalesce into a continuous series of ridges at the northeastern end of the strandplain Chappell and Grindrod have labelled them 'beach ridges' in accordance with strict definition. However, these beach ridges are laterally continuous with the chenier ridges extending to the central bay, and resemble them by both being composed of the same material (ie. 100% shell) and unconformably overlying a mud substrate.

Site Investigations

Residual sand bodies - As discussed above the distribution of late Quaternary coastal deposits in the western embayment is substantially influenced by several geological formations forming a structural template within the embayment. These bodies exhibit a residual quartzose sand character at the surface and are likely to be related to sandstone formations such as the one exposed in a coastal cliff exposure at the mouth of Running Creek. This sandstone is believed to be of Mesozoic age (Whitaker and Gibson, 1977), and three main units were recognised in this exposed sequence during ground survey, of which the near surface unit (I) can be further sub-divided by its character:

III - (the lowest unit) is closely parallel-bedded and highly ferruginous,

II - conformably overlying unit-III, with broader planar beds of interbedded ferruginous sandstone and thin beds of less indurated pale sandstone,

Ic - a more homogenous, massively bedded unit which has obliquely truncated the lower units,

Ib - deeply weathered profile of unit I,

Ia - an unconsolidated, residual quartzose sand at near the surface.

The character of the regolith over this sandstone sequence (ie. units - Ia & Ib) are similar both in description, and radiometrically in satellite imagery, to the other residual sand bodies identified in the near coastal plane, suggesting a similar genesis. This sandstone was also found to form the resistant bed of Dinner Creek near its confluence with the Annie River. It is likely that the substrate control observed in the pattern of Quaternary coastal deposition is largely due to this faulted sandstone formation underlying the coastal plain at a shallow depth.

Pre-Holocene Coastal Deposits - The distribution of pre-Holocene coastal deposits is shown in figure 14. Within the study area these deposits vary from a degraded series of compressed, dune-capped ridges developed in indentations between the sandstone bodies near Running Creek, to lower relief beach ridges separated by broad swales on the more expansive strand-plain in the southern Annie River area.

Ridge to swale relief in this southwestern ridge landscape is of the order of 2m over distances of 500m. Pre-Holocene ridges are distinguished in aerial photographs and satellite images primarily by variations in the vegetation response to topography, however, this can be deceptive within the study area. In the northwestern degraded dune landscape the vegetation thins progressively with elevation, transforming from a tall eucalypt and paperbark forest in the large swale seaward of the system to progressively lighter eucalypt forest with low scrub and exposed patches on the dune crest. Conversely, across the southwestern ridge terrain the broad swales between ridges are occupied by sparse paperbark forest, progressing to a greater density of vegetation (ie. light eucalypt and scrub forest) on the ridge crests.

Three sites were investigated in the pre-Holocene barrier; two in the broad, substantially degraded central western beach-ridge plain (ie. a forward ridge and rearward ridge), and a site in the elevated dune section approaching Running Creek. Logs of shallow pit excavations at these sites are illustrated in figures 15 and 16. The two sites in relict beach ridges had undergone a considerable degree of clay development, but distribution analysis of the primary quartz grains reveals a close correlation with the character of the lower intertidal muddy facies in its Holocene equivalent (figure 17).

<u>Holocene coastal deposits</u> - Holocene strandplain deposits were investigated across two transects; one near 'Harry's Hole' in the broader southwestern plain, and a second where the plain narrows toward Running Creek in the northwestern embayment. A single mechanical auger hole was placed to a depth of 9.5m in the beachridges adjacent Harry's Hole before mechanical problems halted drilling. The hole intersected a primarily quartzose sand and gravel ridge facies before a sharp transition into an organic-rich shelly, muddy sand and gravel (lower intertidal) facies (figure 15). At 5.5m depth a further boundary was encountered to a translucent gravelly sand facies with abundant shell fragments, which radiocarbon aging may show to be a lag related to the initial transgression by the Holocene sea. Seaward of the ridge complex a series of pit investigations were carried out in a transect that crossed the extensive supratidal flats (including a single prominent chenier), continued through beach and coastal dune facies at the present shoreline, and finally into the plastic lower-intertidal muds offshore.

At the second location (toward the mouth of Running Creek) Holocene deposition is characterised by an elevated ridge platform extending landward from an erosion scarp at the back of the present beach. As discussed previously this marine ridge series is separated from the earlier dune ridges behind by a prominent swale vegetated with a dense eucalypt and paperbark forest. A 2.3m pit excavated in the first permanent Holocene ridge behind the present beach revealed similar facies to those witnessed on the present beach. Substantial cementation has occurred below 2m, which is consistent with analogous beachrock formations presently armouring the modern intertidal beach. Moving up-section coarse, shelly laminated sands similar to the present beachface were encountered, progressing to foredune facies with isolated well-defined shell layers. A medium-coarse shelly veneer forms the final near surface sediment.

This progradational sequence is interpreted to have developed under similar conditions to those present today, under which sufficient energy was available to redistribute fine sand and mud size sediments offshore. The stratigraphy indicates the progressive progradation of the beach through the site followed by a foredune development. Isolated shell layers amongst this dune sand indicates occasional high swash runup infiltrating the backshore. The reversion to medium/coarse sand in the upper 1m probably indicates truncation of the dune sediments, and deposition of coarser sediment during high energy (cyclonic) events.

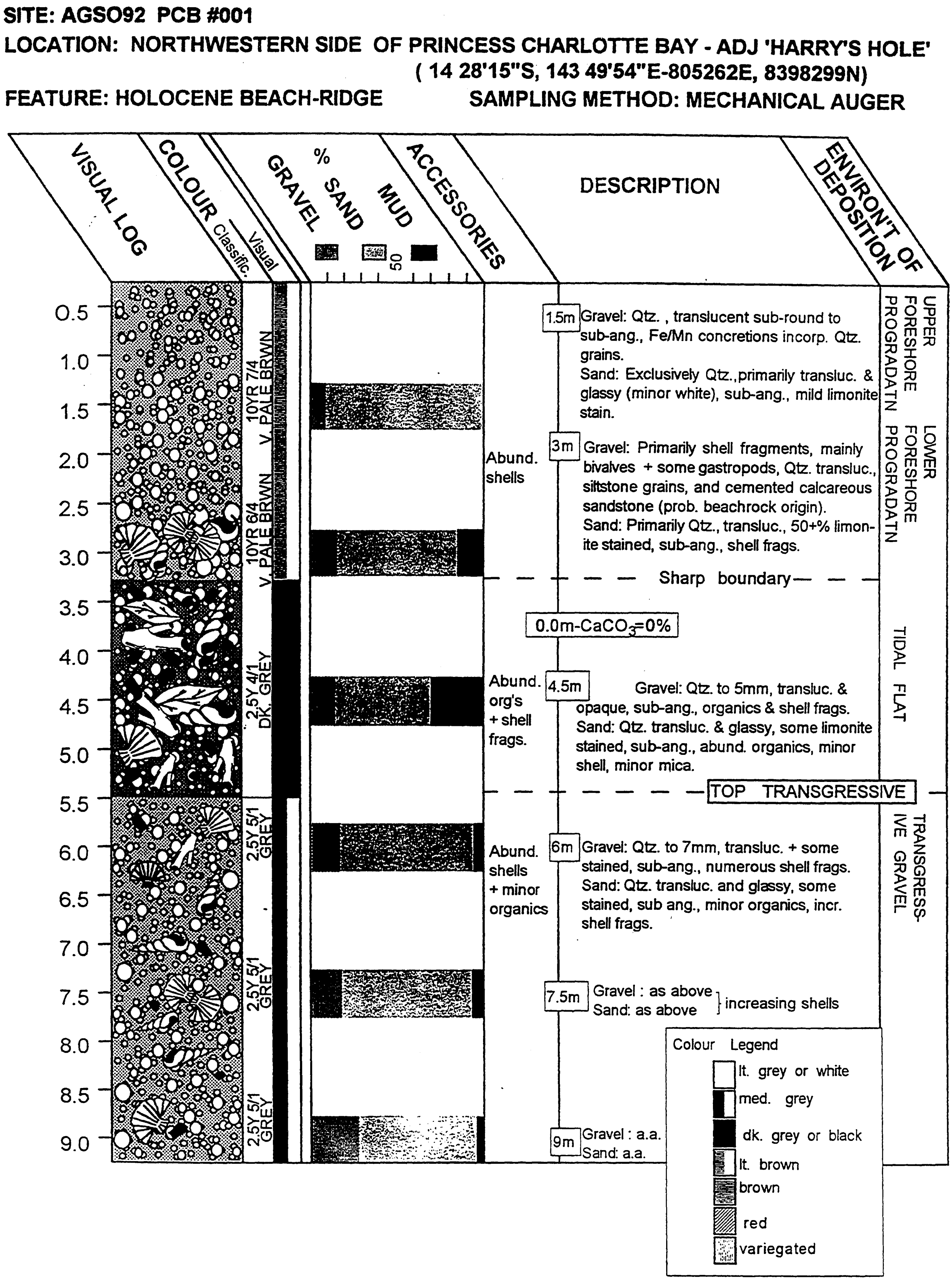
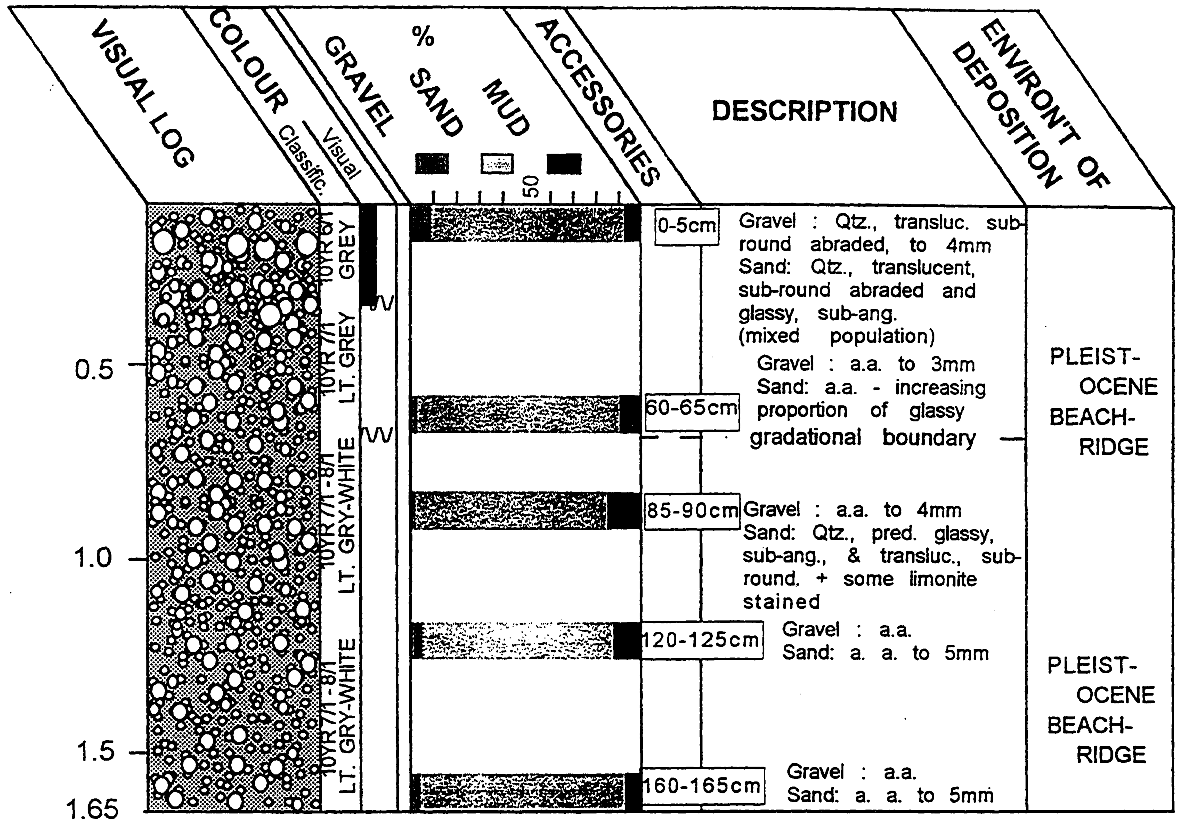


Figure 15 Log of drillhole PCB #001 in the Holocene sequence southwestern Princess Charlotte Bay.

SITE: AGSO92-PCB #007

LOCATION: SOUTHWESTERN PRINCESS CHARLOTTE BAY - ADJACENT LILYVALE TRACK - (799777E, 8394066N)

FEATURE: PLEIST. BEACH-RIDGE (REAR)   SAMPLING METHOD: PIT EXPOSURE



SITE: AGSO92-PCB #008

LOCATION: SOUTHWESTERN PRINCESS CHARLOTTE BAY - ADJACENT LILYVALE TRACK - (804370E, 8396493N)

FEATURE: PLEIST. BEACH-RIDGE (FORWARD)   SAMPLING METHOD: PIT EXPOSURE

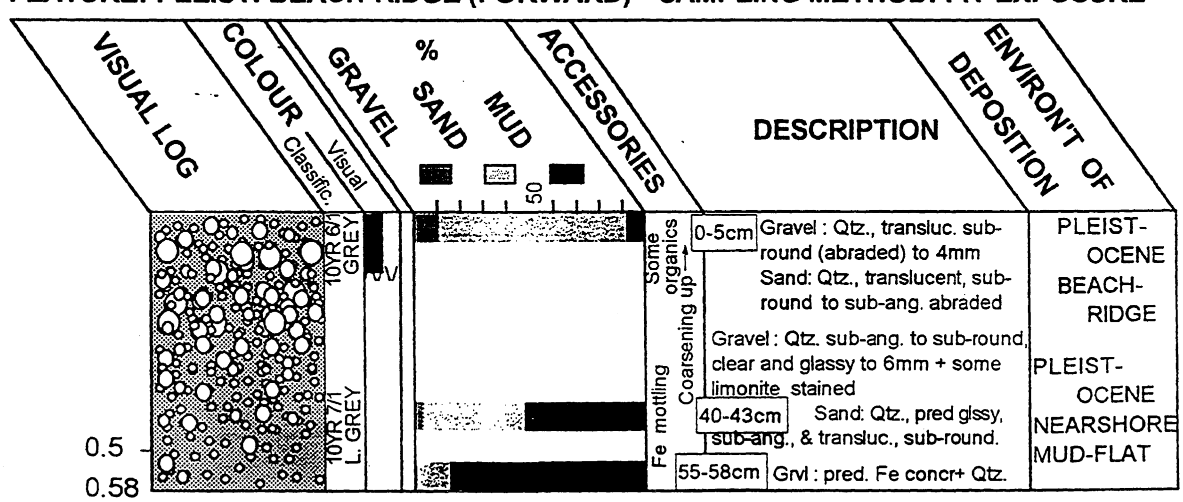
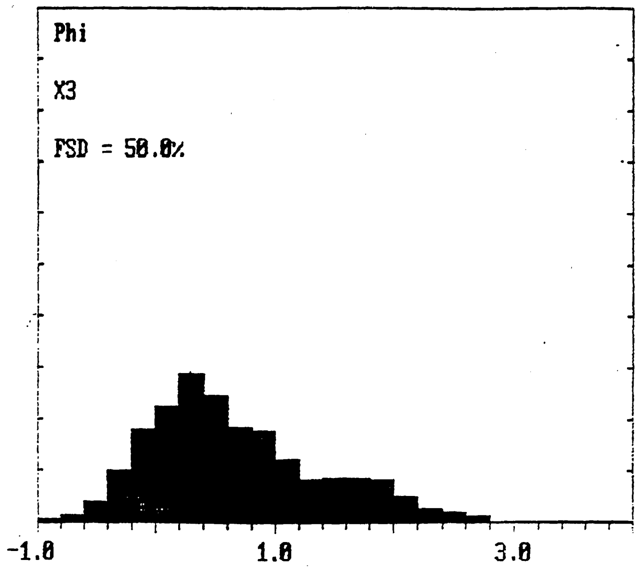


Figure 16 Log of exposures PCB #007 and PCB #008 in the Pleistocene sequence - southwestern Princess Charlotte Bay.



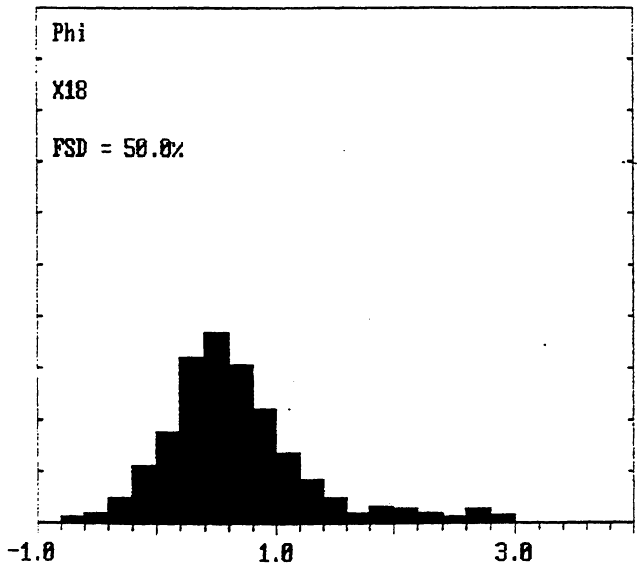
Mean: 0.67

Std. Dev.: 0.72

Skewness: 0.315

Kurtosis: -0.165

Sample analysis PCB #001 - 3.0 m depth.



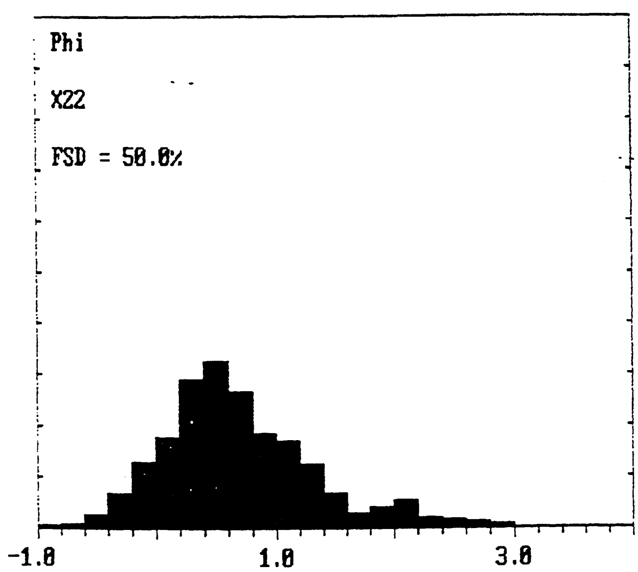
Mean: 0.67

Std. Dev.: 0.62

Skewness: 0.584

Kurtosis: 2.115

Sample analysis PCB #007 - 0.9m depth



Mean: 0.69

Std. Dev.: 0.64

Skewness: 0.387

Kurtosis: 0.752

Sample analysis PCB #008 - 0.43m depth

Figure 17 Grain size distribution graphs and statistics for samples PCB #001-3m depth, PCB #007 - 0.9m depth, and PCB #008 - 0.43m depth.

Evolution of the Princess Charlotte Bay coastal plain

Western embayment - Both the pre-Holocene and Holocene barriers of the western embayment are characterised by a number of depositional discontinuities across which the ridge pattern has either abruptly become detached and translated further inland, or a relatively compressed group of beach-ridges has begun to splay across a broader plain. These patterns suggest that the transgressing seas of both Pleistocene and Holocene ages encountered a series of rock terraces, most likely formed by en echelon fracturing of the Mesozoic sandstone substrate related to underlying Palmerville Fault zone. In the northwest embayment the Pleistocene sea would have formed a rocky shoreline against the residual sandstone bodies still prominent on the coastal plain. In low lying areas between these prominences barriers would have formed such as those observed near the mouth of Running Creek (ie. adjacent to the disused airstrip in figure 14).

The Holocene sea would have encountered a similar shoreline, although as may be expected it has not penetrated as far landward. As mentioned previously Holocene progradation directly abuts earlier sediments near Running Creek, being separated by only a prominent swale. A large dune feature lies immediately landward of this swale, and although no age confirmation is available it is considered likely that this dune is younger than the Pleistocene barrier it fronts, and would be consistent with a phase of earlier-mid Holocene age dune emplacement as observed in other locations. As described in the previous section Holocene progradation has proceeded seaward from this swale in a compressed fashion across an apparently elevated substrate. Extensive beachrock outcrops are observed along sections of the shore.

In the southwestern embayment the pre-Holocene strandplain is characterised by ridge deposition which again was influenced by a terraced substrate and prominent sandstone bodies. Holocene ridge deposition also reacted to this rock shelf substrate as illustrated by the fanning out of ridges toward the central embayment from a fault scarp. These ridges are dominated by quartzose gravel, and testify to a period when a steeper offshore profile allowed sufficient energy to maintain a coherent longshore transport of coarser material to the northwest. The Annie River at this stage would have discharged material from the alluvial hinterland at a shoreline toward the rear of the current strandplain. As illustrated in figure 18 a bayline formed between the rock-shelf substrate in the southwestern bay and similar shelves near Running Creek. Quartzose ridges formed along this shore isolating a broad back-barrier area which probably formed initially as a lagoon, and has since vertically accreted to finally form the hypersaline supratidal marsh deposit witnessed at present. Strandplain geometry suggests that early quartzose ridge development preceded any chenier development across the embayment, while later ridges in the series appear contemporaneous with the development of cheniers laterally across the central and eastern portions of Princess Charlotte Bay.

Relatively continuous development of the coastal strandplain across the entire bay can be traced from this period. A comprehensive investigation of the eastern embayment was carried out by Chappell and Grindrod (1984), who were able to reconstruct the progradational history using detailed radiocarbon dating and palynological analysis of samples. According to these authors slow progradation appears to have occurred in the far eastern embayment between c. 6,000yrs BP, when sea level first stabilised, and 3,000yrs BP when the first substantial phase of chenier and clay dune development is identified.

Chappell and Grindrod(1984) identify a progressive acceleration in progradation seaward which appears to have occurred in two distinct phases: a period of major chenier and clay

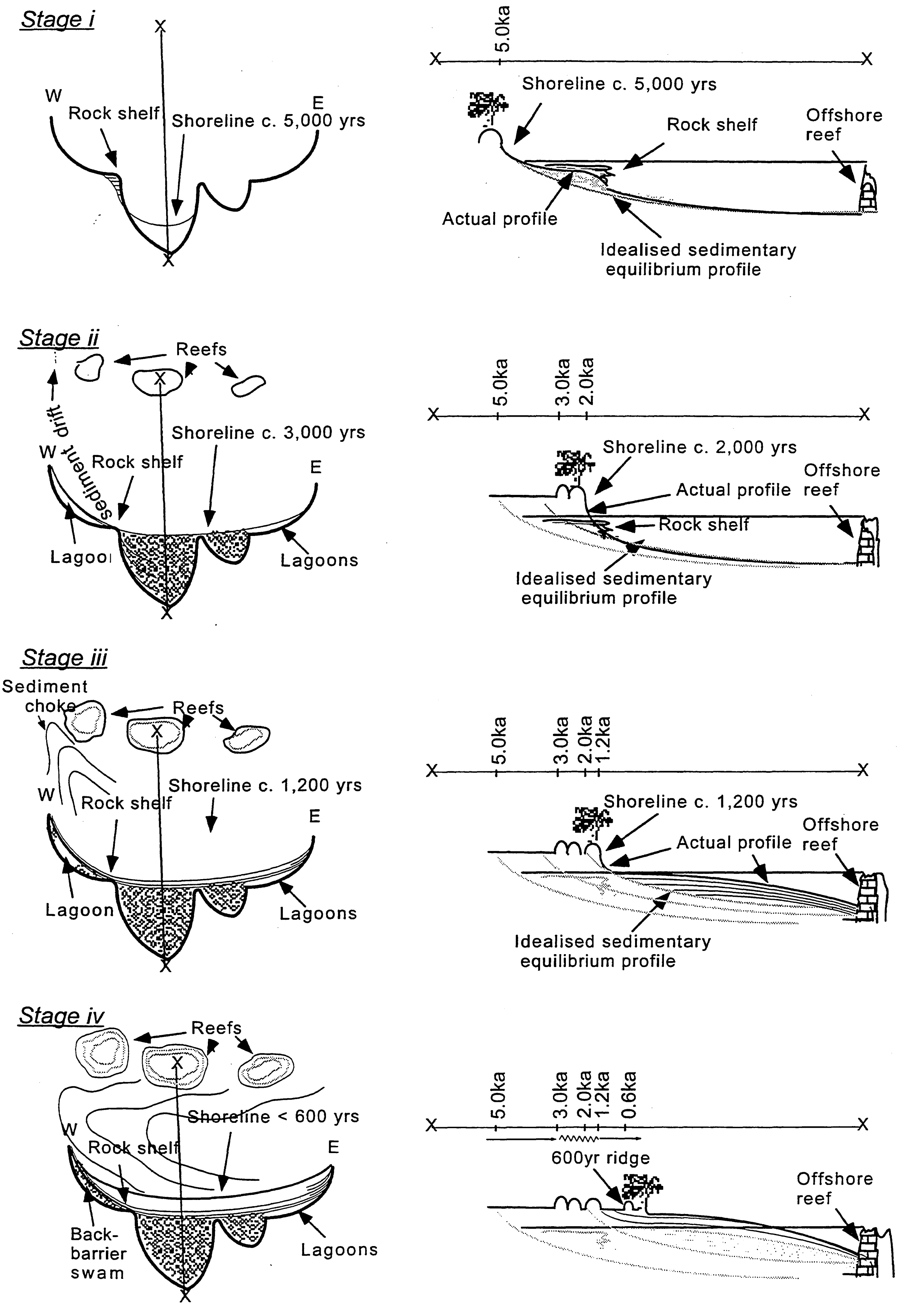


Figure 18 Holocene evolutionary stages of Princess Charlotte Bay coastal plain.

dune formation between c.3,000yrs BP-1,200yrs BP, and then an accelerated phase of primary mudflat progradation with a single intermittent chenier forming c. 600yrs BP. Contrary to the explanation offered by other authors (Rhodes 1980, 1982, Lees et al., 1993), Chappell and Grindrod do not invoke major climatic changes to explain either the distinct phases of greater ridge building or of accelerated progradation they have identified. Rather, they attribute this general acceleration in progradation largely to embayment and inner shelf geometry, with the inner shelf reef barrier trapping sediment offshore.

They identify two major modes of progradation: i. a *cut and recover* mode, and ii. a *rapid prograding* mode, the latter mode commencing approximately 1,200yrs BP and extending to present. The majority of chenier ridges are identified as having formed according to the former of these modes, with shell material winnowed from the muddy nearshore being driven onshore during high energy (cyclonic) events to weld a new deposit onto previous such accumulations. In this model a relatively narrow fringe of mangrove lines the shore allowing shell material to be driven straight through until it encounters a previous deposit, thereby forming a composite ridge. The authors point out that far fewer ridges exist than cyclonic events, and therefore hypothesise that ridge formation is dependant on a concatenation of prior circumstances that have provided abundant shellfish production in the nearshore and winnowed it to provide a ready source of material. During the second (rapid progradation) phase, which they explain as resulting from the embayment geometry, chenier development has been restricted because the rapid accumulation of muddy sediment in the immediate offshore has not been conducive to shellfish habitation, and a broader mangrove fringe has baffled the penetration of shell material to the mudflat at the rear.

Despite these fluctuations in the supply of chenier building material in the central bay, a more continuous series of ridges have developed toward the northeastern end of the embayment (ie. the 'beach ridge series'). This Chappell and Grindrod attribute to a more constant supply of shell material via longshore storm drift from the more rocky shore to the northeast.

While this model offers a satisfactory explanation for chenier development under two different progradational regimes, it fails to adequately account for the sudden turn-on of the accelerated progradation phase c.1,200yrs BP. It could be expected that reef development on the inner shelf had reached the surface thousands of years previous to 1,200yrs BP, and any changes in reef development at this time would not be sufficient to result in a sudden change in sedimentation rates in the bay. Similar variation in the rate of progradation have been observed in other North Queensland sequences (Graham, 1993), where it can be explained wholly in terms of basin geometry. At Cowley Beach, near Innisfail, it can be observed that groups of more compressed and elevated ridges align to emerged basement features downdrift which have formed temporary headlands within the strandplain. Progradational pauses occur at baylines established to these features while coherent longshore processes allow sediment to bypass the headland and move out of the embayment. In the case of Cowley Beach this occurred until gradual shallowing of the nearshore led to commencement of tombolo formation to offshore islands. Once this occurred tombolo growth became rapid, trapping the northern drift of sediments and resulting in highly accelerated infill of the bay. As a consequence rapid low elevation progradation of ridges occurred until progress was arrested at a new bayline where bypassing again occurred. A similar explanation related to basin interaction with sediment movement may be applied to Princess Charlotte Bay.

The following scenario incorporates the results of Chappell and Grindrod (1984) from the eastern embayment into a picture of progradation across the whole embayment as it responded to the inherent geometry (illustrated in figures 14 & 18).

i. inner embayment fill stage - a rock shelf can be inferred from the major faultline infection of the ridge series near 'Harry's Hole' in the western embayment. This rock outcrop and a basement intrusion into the east-central bay would have formed palaeoheadlands within the protoembayment, essentially forming smaller embayments within the larger profile recognised today. Early progradation would have progressed to a bayline stretching from the rocky outcrops near Running Creek, across these temporary headlands in the central bay, to finally connect to the rocky eastern shore,

ii. reduced progradation at bayline - upon achievement of this bayline a pause in the rate of progradation would have occurred while the offshore of the larger embayment slowly infilled. This would correlate with the period of slower progradation identified by Chappell and Grindrod (3,000 to 1,200yrs BP) when larger cheniers formed from multiple depositional events. Initial chenier development would have responded to a bayline incorporating the basement outcrop in the southeastern bay, before detaching and forming a bayline directly between the eastern rocky shoreline and the rock shelf headland in the southwestern embayment. Such adjustments could explain periods of mudflat development intercalated with periods of 'cut-and-fill' chenier development. Despite recurving of cheniers into river mouths across the embayment a distinct forward margin of this main phase of chenier development can be traced from inside Bathurst Head to the seaward extent of the compressed series of ridges that formed over the southwestern rock shelf.

As illustrated in figure 18 the effect of the inner embayment geometry would have been to advance progradation more rapidly to this bayline by trapping sediments within the smaller inner bays. Upon achievement of a bayline between palaeoheadlands the shore would steepen as storm deposits stacked ridges onshore, while in the nearshore region sediments continued to be evacuated by longshore processes. A narrow mangrove belt would have developed on this steeper shoreline, and the combination of higher energy and reduced mud retention would be such that shell material would be reworked periodically to the shore as modelled by Chappell and Grindrod (1984),

iii. inner shelf fill phase - the inner shelf adjacent to the Princess Charlotte Bay coastline is dominated by a chain of coral reefs, the foundation of which have probably formed on relict deltaic sediments from previous sea level events. As noted by Chappell and Grindrod (1984) the presence of these inner shelf reefs would have led to greater retention of sediment on the inner shelf. However, the scenario illustrated in figure 18 (iii) proposes that the primary effect of this reef tract was to provide a sediment choke where it approaches the shore to the north of the embayment, progressively capturing the northerly drift of sediment along the coast. This mechanism would have led to a relatively rapid acceleration of sedimentation in the embayment and, because of the basin like configuration of the inner shelf resulting from the reef barrier, this accretion surface would rise more horizontally than in an unrestricted geometry,

iv. rapid progradation - the final stage of Holocene plain development would have witnessed a relatively sudden turn-on of progradation due to the rapid development of a shallow profile nearshore foundation as described in the previous paragraph. The progressive shallowing of this offshore profile would have resulted in a concomitant reduction in energy approaching the shore, resulting in the retention of finer sediments. There is probably a threshold below which the amount of fine sediment in suspension in the nearshore further disables the ability of processes to transport material away from the nearshore as described by Rhodes (1982). As a consequence of this nearshore shallowing and mud retention, the shoreline rapidly prograded out to a bayline created between the basement rocks of Bathurst Head and a nearshore extension of the faulted substrate in the southwestern embayment. A continuous curve can be traced between these two points interrupted only at major stream mouths by a deltaic convexity.

Given sufficient time at a stable sea level a series of shorelines would be expected to form intermittently between various headlands in the embayment, finally incorporating offshore islands. However, as discussed previously, the observed trend for the western coastline appears to be erosional, which may be an early effect of the generally forecast global sea level rise.

In summary, the apparent period of negligible progradation observed in the eastern embayment by Chappell and Grindrod (1984) probably relates to a period when early progradation was confined to inner embayments. Subsequent phases of progradation were probably largely governed by an initial pause while the nearshore of the bay-proper infilled, followed by a relatively sudden turn-on of progradation resulting from the manner in which it did infill. This scenario does not require the fluctuation in shellfish population through time invoked by Chappell and Grindrod (1984). The disparity between the number of depositional phases identified in the composite chenier features and the number of storm events observed by these authors, may be explained by progradation shifts of the bayline in response to new headland features (both prominent and shallow submerged), during which a more muddy regime dominates and the energy of nearshore processes is sapped. A discussion on how changes in the energy flux and the response time of systems may precipitate these shifts in depositional mode is given by Graham (1993), following an earlier discussion on the cause of variability by Chappell and Thom (1986).

5.2.7 Bedrock and regolith dominated cliffed and embayed coasts

Coasts of this type occur where substantial areas of bedrock or regolith are protrude into the marine environment, exposing them directly to active marine processes. On a larger scale these prominent regions provide the framework bulwarks between which the sedimentary progradation of extensive sections of coastline takes place (ie. mega-embayments), while their irregular interface with the sea creates a series of smaller embayments at an order of magnitude lesser scale.

The areas of Cape York Peninsula that fall within this category are as follows:

i. <u>west coast</u> - between the Archer River estuary and the Weipa estuary, Vrylia Point, Mutee head to Cowal Creek,

ii. <u>Cape York and Torres Strait Islands</u> - Peak Point-Punsand Bay-Cape York to Albany Pass, plus all Torres Strait Islands,

iii. east coast - Turtle Head Island, the entire east coast excluding Princess Charlotte Bay and those areas previously designated as either estuarine or dune coast.

Physiology and Geology

In areas where softer lithologies and regolith are exposed directly to marine conditions long stretches of cliffed coastline develop. This results from a continuous process of the sea cutting a notch at the base of the cliff, causing periodic collapse of the face. Examples are found on the west coast where aluminous laterites are exposed between the Archer River and Weipa, and at Vrylia Point, while on the northeast coast they occur where ferruginous laterites are exposed between Newcastle Bay and Shelburne Bay.

Cliffs also develop in hard lithologies where they are exposed on prominent headlands and capes, and are often accompanied by wave-cut platforms in these situations. The susceptibility of rocks to mechanical and chemical erosion (and therefore to cliff formation), is influenced by a number of factors such as their original mineralogy and depositional geometry, and post-depositional physical and chemical metamorphosis. For example, bedded sandstones and layered and folded metamorphosed rocks such as found at the mouth of Running Creek (Princess Charlotte Bay) and Lookout Point respectively, are more susceptible to cliff formation than the amorphous rhyolite formations around the tip of Cape York Peninsula.

Land use considerations

Rocky headlands and capes have traditionally provided protection from prevailing weather conditions for both vessels and population centres (eg. Portland Roads and Cape Flattery). Additionally, they often provide routes of access to the coast, solid building foundations, and more contentiously a source of solid building material in the midst of otherwise unconsolidated coastal plains. Currents being directed around capes scour the nearshore area, providing deep water access to the shore for large seagoing vessels (eg. Cape Flattery sand loading facility).

The sheltered environments created by embayed bedrock coastlines often provide attractive sites for tourist developments. From an engineering perspective the Quaternary sedimentary fill of most small embayments provide a poorly consolidated foundation, and seasonally high water tables. Shallow drilling in embayments generally reveals that sand bodies overlie fine mud facies. Habitats such as swamps in the rear of embayments and mangroves are often in conflict with the engineering requirements for siting structures and providing access roads.

As discussed further in section 6 tourist facilities, anchorages and population centres developed in embayments have the potential to effect coastal habitats in a variety of ways which can generally be grouped under the headings: *i.* structures, *ii.* mechanical damage, and *iii.* toxins.

5.3 Offshore

5.3.1 The eastern coastal seas of the Gulf of Carpentaria

Bathymetry and currents

The western side of Cape York Peninsula forms the eastern boundary of the Gulf of Carpentaria, one of the largest (511,000km^2) epeiric (shallow shelfal) seas in the world. The Gulf forms a large, shallow depression and several large rivers drain into it. The floor of the Gulf of Carpentaria is a flat featureless plain, 50 - 60m deep. Its deepest parts (65m) are on the eastern side, at the base of a wide slope that flanks the western shore of the Cape York Peninsula.

Tidal currents dominate the transport of sediment in the areas of strong tidal mixing adjacent to Endeavour Strait, and cyclone related effects also dominate sedimentary processes. Wind-driven circulation results in a clockwise rotation of the Gulf waters with current speeds up to 8 cm/sec. Sediment transport paths essentially flow southwards down the eastern shore of the Gulf.

Quaternary history

During the Quaternary, the Gulf was subaerially exposed a number of times as a result of sea level fluctuations. A lake formed in the closed basin within the gulf at times when low sea level was below the level of the sill that separates the gulf from the Arafura Sea. The maximum depth of this lake was 15m. At these times fluvial drainage passed across the eastern slope of the Gulf.

During periods of lower sea level, particularly when sea level was lower than 53 m , most of the floor of the Gulf was dry, but in the centre there was a large fresh to brackish water lake, known as Lake Carpentaria. This lake came about because the Gulf was dammed to the west by a ridge between Arnhem Land and Irian Jaya and by another ridge to the east across Torres Strait.

During these periods of lower sea level, the eastern side of the Gulf was above sea level, and so was channelled by rivers and covered to some extent by peaty soils. Around 10,000 years ago, sea level rose sufficiently to overtop the western ridge and began to flood the Gulf. Lake Carpentaria disappeared and normal marine conditions were re-established, with a mangrove-fringed shoreline being developed. However, between 10,000 years and 6,000 years sea level continued to rise, with eventually the eastern ridge across Torres Strait being drowned. This rise in sea level was of the order of 6-10 millimetres per year, and while in geological terms this is a fairly rapid rate, to the indigenous Australians living along the shoreline it would have been hardly perceptible within an individual's lifetime.

As the sea gradually encroached across the gently sloping coastal plain of the eastern Gulf, the stands of mangrove were overwhelmed and had to re-establish themselves along the new shoreline. Eventually, by 6,000 years ago, when sea level stabilised to about its present position, an almost continuous, but thin (1-3m) deposit of mangrove peat had been laid down on top of the older coastal plain deposits. This peat layer was then buried by another thin layer of marine sands and muds.

The surficial sediments of the Gulf are largely relict, greenish muddy sands, and the distribution of commercially important species of prawns has been related to sediment type in the Gulf.

Nearshore deltaic sands and prodelta sandy muds are associated with the rivers of the Cape Coast. A sand rich tidal delta occurs at the western end of Endeavour Strait. Linear tidal sandbanks have also been formed by ebb tidal currents on both sides of the shipping channel at Weipa.

Site investigations

A sequence of events related to this Quaternary history can be seen in the seismic records obtained as part of this study. On the Gulf of Carpentaria side the seafloor is broad and shallow, and the prominent subsurface horizon is shallow and relatively smooth. The 30 metre depth contour can be as much as 50 km from the coast.

At about 5m beneath this almost level seafloor there is a prominent seismic reflection that represents the old exposed surface that is common in northeastern Australia. In places this surface is cut by fairly broad, but shallow channels that can be related to the onshore drainage. Above this surface is a layer of sediment that includes the mangrove peat at the base and marine sands and muds above that. The thickness of this younger sequence varies reasonably uniformly from the shoreline out to 30m depth. The sequence tends to be thickest nearshore and gradually thins seawards. This style of deposition can be related to a prograding sequence.

In some areas, what could be termed "acoustic basement" was detected by the seismic system. These knolls or ridges of bedrock form part of the underlying geology, but have resisted weathering in places to form these bedrock highs. In most examples, the bedrock is buried under several metres of sediment, but in one example near Weipa it is present as a topographic high above the general level of the seafloor. Delineation of these bedrock exposures in the nearshore area is often necessary for engineering purposes. Further offshore, their distribution can be important for fisheries; either they could cause problems with bottom trawls or conversely they may be sites for pelagic fisheries.

In most examples on the western side of Cape York Peninsula, the bedrock appears to be Tertiary laterite. These laterites under the floor of the Gulf do contain a fair amount of bauxite, and some years ago there was a reconnaissance exploration project in the Gulf to determine if the Weipa deposits extended out beneath the sea.

Michaelsen (1994) found that the Holocene sequence north of Weipa comprised a basinward thinning veneer formed during the Holocene transgression and subsequent high stand. This is 4m thick offshore of Weipa, and thins to 0.7m at -32.5m water depth, 27km from the coastline. This part of the sea floor is characterised by the presence of major palaeo-topgraphic highs up to 1,100m long and up to 3m high. North of this the area is characterised by asymmetric bedforms with a height of 1m and a wavelength of up to 1,100m.

The surficial sediments of this area are characterised by a complex facies distribution and are comprised of seven broad facies units:

- modern shore-connected sand;

- relict gravel;
- inner-shelf silty-sand;
- shelf-platform palimpsest sand;
- inner-shelf shelly silt;
- shelly silty sand; and
- embayment silts.

Vibrocores reveal that the Holocene sediments are dominated by greyish-green, shelly, muddy sand. There are modern, shore-connected sands, shelf-platform sands, and estuarine carbonaceous mud, lacustrine peat, and shell hash. These overlie indurated pre-Holocene, ferruginised cemented sand.

The complex lithofacies distribution is not correlateable between the shoreface and the inner shelf. This may be due to low sediment supply and rapid remixing of the thin Holocene sediment package as bioturbation outpaces the rate of sediment accumulation on the inner shelf. Both these factors lead to a complex modern distribution, and this may have been the case for much of the Holocene.

The surface and subsurface sediments consist of three main components:

- a relatively high biogenic carbonate component (with up to 66% weight). The carbonate component consists of whole and broken molluscan and gastropod taxa, echinoderm fragments and minor foraminiferal tests and ostracods,
- modern terrigenous sediment, and
- relict reworked sediment (i.e. iron-stained quartz sand, bioeroded foraminiferal tests and ferruginous pisoliths).

Palynological analysis of the basal carbonaceous silty sand (9,360 ± 70 yrs BP), peat and carbonaceous mud facies in one of the vibrocores records the replacement of *Myrtaceae* dominated communities occupying a dune swale system by estuarine mangrove communities via a transitional lacustrine phase in which ferns were common. Furthermore, the palynosequence shows evidence of an overall Early Holocene decline in floristic diversity, possibly generated by an arid trend.

Deposition of 80cm of shell hash on the upper part of the shore-connected sediment wedge apparently took place over less than 1,000 years from ca 2,700 yrs BP. The shell hash overlies an erosion surface, but rather than being a transgressive deposit, it was apparently deposited during the late Holocene high stillstand when deposition may have been related to successive cyclonic events.

5.3.2 The Northern Great Barrier Reef

Physiography

The overall features of this area have been described by Hopley (1982), and Harris et al. (1991). The continental shelf on the eastern side of Cape York Peninsula is wide in the north, but narrows appreciably to the south. The outer part of the shelf is dominated by the reefs of the northern Great Barrier Reef (GBR). By contrast, the nearshore zone contains lesser, and generally smaller, reefs, and is dominated by sediments derived from the coastal rivers. Only 9% of the GBR shelf is covered by reefs.

There is a gradual deepening of the shelf towards the south. The zone of reef development diverges from the mainland coast towards the south, so the northern reefs are more prone to mainland influences in the form of terrigenous sediments and runoff.

The far northern section of the GBR, south to Cape Grenville consists of a broad shelf, physiographically part of the Gulf of Papua. It is generally less than 50m deep. The outer edge of the shelf is 50km from the mainland opposite Cape Weymouth, but widens further north to over 150km. The inner shelf contains a number of small oval reefs, many of which are island capped. The outer shelf is occupied by a zone of complex and massive submerged reefs up to 60km wide.

Only south of Cape Grenville, on the western margins of the reef complex, and around the high islands such as Quoin, Forbes, Sir Charles Hardy, and the Cockburns do reefs reach modern sea level. Elsewhere depths average about 10m.

The outer barrier is formed by the distinctive Ribbon Reefs, offshore of which the continental slope drops to depths of 600m within 12 km. Small detached reefs rise from this slope within 25km of the main barrier, but are separated from it by water depths in excess of 250m.

Between Cape Weymouth and Cape Bedford the continental shelf is generally not more than 50km wide, and depths in excess of 50m are only found in the narrow channels between the reefs on the outer shelf edge. The inner shelf has a gentle slope seawards from the more steeply sloping Near Shore Zone of Maxwell (1968) in which sand movement is actively taking place, and which is characterised by shoals and sand ridges. Beyond this zone the inner channel floor is relatively featureless, ranging in depth from 12m near the mainland to 35m near the large midshelf reefs. The inner channel is not entirely reefless and small ovoid reefs up to 4km in diameter, rise from it. Many are capped by distinctive low wooded islands.

To the east the shelf deepens to 30 - 40 m , but many large reefs rise from these depths. In the Princess Charlotte bay area they include some of the largest reefs of the whole Province. These reefs extend to within 20km of the mainland. Beyond them the shelf maintains a depth of about 40m, but is relatively reefless. However, occupying much of the outer shelf and marked by a sharp rise on both western and eastern sides, is an area of reefal shoal with depths within the range 20 - 25 m. This zone may be relatively continuous, broken only by larger channels of about 40m depth that lead to the main passes through the Ribbon reefs. On some of these shoals a few irregular reef patches reach the surface. However, near Cape Melville, crescent shaped reefs rise from the inner rim of the shoal.

The continental shelf edge is occupied by a continuous line of linear or ribbon reefs. These reefs, up to 28 km long, are separated by narrow passes, most of which are less than 1 km in width. The majority of the reefs are between 400 and 600m wide. The backreef area consists of a steeply inclined detrital sand ramp sloping into water depths of about 14 m, from which rise isolated massive coral colonies. The continental slope off this part of the reef drops away very sharply from depths less than 50m to greater than 500m within a few hundred metres lateral distance. Depths of at least 1,000m are found within 1km of the shelf edge.

Irregular shaped, mound-like deposits formed by the *in situ* accumulation of calcareous secretions formed by the green alga *Halimeda* occur shoreward of the outer reef barrier. In seismic profiles these bioherms are 25m thick, and grow on a Pleistocene erosional surface. Interbank areas are rough textured, a characteristic of limestone exposures. The nutrient requirements of *Halimeda* have been thought to restrict the occurrence of the bioherms to locations adjacent to reef passages where nutrient rich waters flow behind the reef. Our mapping shows that the bioherms are actually more widely distributed.

South of Cape Bedford the bathymetry of the continental shelf becomes simpler, due in part to the lack of submerged reefal shoals. It marks the southern most extension of both the low wooded island reefs of the inner shelf and the ribbon reefs of the outer shelf, although submerged counterparts of these continue to 17° 20'S. The inner shelf extends from the active nearshore zone to the 36m isobath - a featureless area apart form some high islands. Coral reefs occupy the deeper outer 50% of the shelf.

Sediments

50% of the GBR shelf falls within a non-mud or a low mud facies. Quartz sands dominate along the coast whereas carbonate sands occur in the outer shelf reef areas. These are generally in depths less than 20m. Only Torres Strait has less than 1% mud (due to the high tidal energy). Muddy sediments cover large areas of the middle shelf, and an outer shelf pocket off Princess Charlotte Bay.

The high carbonate facies is restricted to areas of reef growth and adjoining areas where the reef derived sediment are dispersed by waves and currents. Sediments of the *Halimeda* bioherms are 50% *Halimeda* with forams, molluscs and bryozoans, plus 25% terrigenous mud. *Halimeda* gravel decreases with depth. Narrow shelves have less pure outer shelf carbonates with terrigenous muds being transported offshore (which accounts for the high terrigenous mud content of the *Halimeda* bioherms.

Inter-reefal surficial sediments consist of:

(i) fluvially supplied quartz and clay minerals,

(ii) reworked relict carbonates and terrigenous sediments,

(iii) sand derived from reworking of submerged aeolian dunefields, and

(iv) modern biogenic carbonates.

Maxwell (1968) defined four facies based on carbonate content with cut-offs at 20%, 40%, 60%, and 80%. These formed broadly parallel zones. Areas with a wide terrigenous zone are related to the mouths of the major rivers (Belperio and Searle, 1988) with the river mouths acting as point sources. North of Princess Charlotte Bay this zone is less than 2 km wide. Rate of sediment supply is 10 tonnes per metre of coastline.

Quaternary History

The pre-Holocene erosional unconformity, discernible in seismic sections, which underlies the Holocene sediments of the region is termed "reflector A". Three pre-Holocene units are important - bedrock (B), Pleistocene fluvial deposits (P_f), and cemented reef carbonate (P_r), while Holocene units include fluvial and estuarine channel fill (F), relict delta front deposits (M_2), relict transgressive veneer (M_1), modern low-energy coastal deposits (C_1), modern coarse coastal deposits (C_2), modern reef growth (R_1), and modern reef talus (R_2). The history of the area since the last glacial period is summarised in the following.

17,000 yrs BP - sea level 135m below present forming a shoreline on the continental shelf slope. Shelf dominated by fluvial and subaerial erosion generating surface now seen as "reflector A" in seismic sections. Sediment supplied directly to the top of the continental slope.

14,000 to 11,000 yrs BP - sea level rise to -70m then -50m to form an indented morphology with estuaries, promontories and offshore islands. Sediment trapped in estuaries and Pleistocene drainage channels are infilled. Upper slope starved of terrigenous sediments and carbonate sedimentation commences. *Halimeda* bioherm growth commenced in the lee of offshore islands.

9,000 - 8,000 yrs BP - shoreline at -20m at the outer part of the inner shelf. Tops of offshore limestone platforms submerged. Coral reefs first colonised, and Torres Strait first opened.

6,500 yrs BP - cessation of eustatic sea level rise (ie. commencement of stillstand). Reef and *Halimeda* bioherm development on the outer shelf, and autochthonous carbonate sediments being deposited over transgressive (terrigenous) sediments.

Since this time crustal flexuring has occurred as a delayed response to the additional loading of offshore areas by glacial meltwaters (ie. the cause of the general sea level rise). This effect, known as hydroisostacy, brings about movements of the land surface relative to the stable sea and are therefore termed 'relative' sea level changes. Relative sea level in northern Australia did not stop rising until c. 5,900-5,800yrs BP (Chappell et al., 1982, Woodroffe 1987). Since this time the redistribution of molten material beneath the crust away from the ocean basins has caused the land surface at the edge of continents to rise. This rise in the land surface results in the shoreline retreating seaward, leaving the original mid-Holocene shorelines stranded inland from the present shore. The degree of flexuring varies from area to area according to local geological structures. In the Townsville-Cairns area the c. 5,900yrs BP shoreline is identified has ~1m higher than present (Chappell et al., 1982), while at Karumba this shoreline has been elevated ~2.4m higher than present (Rhodes, 1980). Although evidence of these adjustments in sea level would be barely perceptible within a human lifetime, if they could have been observed over thousands of years from a fixed point on the rising land surface it would have appeared that sea level had fallen steadily to its present location.

Currents

In the Great Barrier Reef Lagoon, wind driven currents flow northward under the influence of the southeast trades between April and November. Across shelf components of wind-driven currents are generally much smaller than along shelf components. Tidal current reworking and transport of sediments occurs in inshore areas and in the passes between reefs where surface tidal current speeds exceed 50cm/sec. Cyclone events are likely to be the deciding factor in determining the net sediment transport over much of the region. Wind driven currents are likely to be significant only for fine-grained sediments.

Site investigations

These concentrated on the nearshore clastic wedge and the shelf inside the reef. They will be reported in detail at a later date.

5.5.3 Endeavour Strait and Southern Torres Strait

Physiography

According to Harris et al. (1991) the waters of Torres Strait are generally no more that 6 - 9m deep, and contain large continental islands with massive east - west orientated reefs lying between them. The intervening narrow passes, 2 - 3km wide, are rarely more then 12m deep and are areas of strong tidal scour which has resulted in a large area of non-deposition spreading from Cape York to Saibai Island with zones of submarine dune formation occurring to the east and west. The eastern edge of this zone is marked by a terrace break down to a 12 - 15m level. Only small and isolated reefs are developed on this feature, and continental rocks are limited to small outcrops. To the east, a line of large reefs, including the Warrior Reefs, appear to continue the line of the mainland Cape York. Narrow channels up to 4.5km wide and 27m deep cut through the reefs and lead down to the next zone further east. This zone forms another terrace like feature between 20 and 30 metres in depth which extends southwards from Bligh entrance to form the inner shelf as far as Cape Weymouth. Towards the northern limit, in water depths deeper than 35m is a group of Pleistocene volcanic islands with fringing reefs, including the Murray Islands, Black Rocks and Bramble Cay. Maxwell's (1968) deltaic reefs occupy the outer edge of the shelf and form an effective barrier that is continued further south by the distinctive ribbon reefs.

Endeavour Strait is also an area where sedimentation is prevented by tidal scour, though its western entrance is almost blocked by a large series of sand banks that form a submarine tidal delta known as Inskip Banks. Here the seafloor is hummocky, the tidal currents having created a series of large sandwaves up to 8 metres high. The sand waves are "asymmetric", the northern side of the sand wave is long and flat while the southern side is short and steep. This shape indicates that the dominant current is to the south, and its intensity has sculptured the seafloor into this shape. While the sedimentary layers beneath the surface do not show this style of bedding, they do show that they have built upwards and outwards in the same direction.

6. NATURAL AND ANTHROPOGENIC CONSIDERATIONS RELEVANT TO THE SUSTAINABLE USE OF COASTAL ENVIRONMENTS

6.1. Coastal erosion

Beach erosion and marine inundation of freshwater bodies near the coast are among the most pressing environmental concerns in coastal areas at the present time. Evidence of this shoreline retreat manifests itself in a number of ways. The most obvious evidence is the widespread occurrence of an erosion scarp at the back of beaches cutting into mature vegetated coastal features. Commonly associated with these scarps are a series of undermined and collapsed mature trees around the coast of Cape York Peninsula. On open sandy coastlines such as the northeastern flank of the Cape this erosion will continue to mobilise a fringe of dune sand behind the beach, which may over time increase to progressively larger transverse dunes. Consideration of both the erosional retreat of the shoreline and this mobile body of dune sand should be incorporated in future land use planning.

Another observed erosional indicator is the exposure of older, formerly buried stratigraphy through the eroding beachface. This was observed on the western side of Princess Charlotte Bay where mudflat facies were emerging through the beachface, and a small coastal dune with immature vegetation testified to the retreat of the coastline. Also, at this Princess Charlotte Bay site erosion had exposed a formerly buried mangrove sequence, while in other locations buried reef sequences are being exposed. Radiocarbon dating of samples from these sequences presently in progress will reveal their age of formation.

More subtle, but no less critical to land use, is the progressive saltwater invasion of water bodies and low lying flats adjacent to the coastline. This encroachment is observed more readily in the low lying areas such as Princess Charlotte Bay where salinity has turned former stands of forest into vast areas of deadwood.

Of significance to grazing in the area is the invasion of waterholes by saltwater. Anecdotal evidence from a local grazier suggests that saltwater invasion of streams has progressed more than a kilometre further inland in his lifetime. Additionally, supratidal invasion of coastal flats will progressively restructure the vegetation toward more salt tolerant species at the disadvantage of grazing.

Many beaches on the west coast of the Cape were observed to be in a generally constructive mode during 1994 survey work, despite the evidence of a substantial erosion scarp at the rear indicating long term erosion. Sections of coastline appear to be building out over bar platforms, and substantial berm development was observed in several locations. It is likely that this construction phase is a relatively temporary phenomena within the longer term trend of net erosion. Observations over a period might indicate that these phases are in fact cycles geared to short term wetter and drier climatic periods.

The interaction of human activities and coastal erosion can be viewed from two perspectives:

i. humans as agents of change - localised activities of people in the coastal zone do not generally result in significant coastal erosion. Exceptions to this from other parts of Australia and the world have been where extensive seawalls have been erected, and where substantial quantities of sediment have been trapped by catchments or removed from fluvial channels and the nearshore by mining. Large scale removal of subaqueous deposits results in a lowering of the local base level to which the onshore-offshore profile is attempting to equilibrate, resulting in an increase in the shoreline slope and ultimately to a reduction in sediment on beaches.

Conversely, vegetation removal in stream catchments can lead to an increase in sedimentation to the coast.

By far the most profound influence on coastal erosion initiated by human activity is the more insidious effect of constant sea level rise resulting from global warming. Although difficult to quantify, there is general agreement between the majority of scientists that sea level is rising due to global warming of the atmosphere. This warming increases the volume of oceans both directly and by an increased contribution from melting ice. The general consensus from a meeting of the Intergovernmental Panel on Climate Change (1991) is that global mean sea level will rise between 3-10 centimetres per decade for the next century. Although the complex interaction of oceanic and atmospheric processes is difficult to model it is predicted that a general increase in coastal erosion and flooding will result (and present evidence indicates this is already occurring), while other less predictable changes in oceanic and weather systems such as the incidence of cyclones and changes in currents and winds are likely.

ii. humans as victims of coastal erosion - coastal areas have long been a preferred site of human habitation, however, in recent decades the mobility of natural coastal features has increasingly come into conflict with the survival of high cost permanent structures. Remedial measures such as groins and seawalls are expensive and of limited long term effectiveness against continuous sea level rise. Careful consideration of coastal mobility and future increases in near coastal flooding when siting new construction is the most viable hazard mitigation measure on the extensive Australian coastline. Florida (USA) has demarcated a Coastal Construction Control Line seaward of which is declared a zone subject to erosion and regulation.

6.2. Population centres, tourist and recreational resources

Properly managed coastal areas can be a very positive tourist and recreational resource, conversely, when poorly managed can lead to accelerated depletion of the primary resource (eg. beaches, stream quality, fringing reefs), and an associated reduction in aesthetic value. Although not exhaustive the following discussion notes some aspects of coastal management that need to be addressed with examples from Cape York Peninsula.

6.2.1 Waste water

In areas of concentrated population such coastal townships and tourist facilities contamination of water bodies with waste water can become a significant problem. Excess nutrients from sewerage and polluted waste from light industry and fuel storage can have a profound effect on the structure of biological communities, particularly coral reefs.

The destruction of coral reef ecosystems by nutrification stemming from sewerage and agricultural runoff is well documented in the Caribbean and Hawaii, and several studies on the effect of nutrients are presently underway in the Great Barrier Reef. The introduction of increased levels of nutrients encourage algal growth at the expense of corals, and increase the susceptibility of corals to other environmental stresses such as disease, coral bleaching and sediment smothering.

Careful attention should be given to waste disposal systems in coastal areas, and in particular where largely untreated waste is directly introduced into nearshore zones or into near coastal water tables (eg. via septic systems).

As discussed previously the central region of estuaries (ie. normally identified by meandering streams and mangrove/mud character) are energy voids in which very fine sediments are deposited. This is significant in the consideration of activities upstream as pollutants (in particular particulates) will tend to be pooled in this estuarine region. Once accumulated in these low energy environments pollutants have the potential to be further concentrated or transformed to more toxic substances by micro-organisms. These toxins may then be further concentrated by biomagnification as they are translated through the food chain.

6.2.2 Coastal structures

The long term erosional trend suggested in section 6.1 and observed on other Australian coastlines needs to be considered in the placement of coastal structures. In unconsolidated coastal sediments a small vertical rise in sea level can translate to a substantial lateral retreat of a shoreline. On open sandy coastlines both the actual landward retreat of the beach and the mobile dune fringe which precedes it can overwhelm near coastal structures, and truncate coastal real estate.

Where the survival of coastal structures is in conflict with the natural progress of coastal erosion the common response is to build a rock wall barrier to the sea. This can generate several undesirable responses:

i. It can generate a reflective wave which in harmonic combination with incident waves can cause deeper scouring of the nearshore, thereby allowing more energy to attack the shore.

ii. As a consequence of *i.* strong rip currents are generated in the immediate area.

iii. It can lead to accelerated erosion of the beach in areas adjacent to the wall.

Groins running perpendicular to the beach are effective in trapping sand locally, but modern engineering systems which increase seashore roughness in the nearshore and energy absorbing seawalls are the most satisfactory response.

Near coastal clearing on steep regolith for road or building construction in tropical areas presents an obvious siltation hazard to nearshore fringing reefs.

Although not a current consideration in Cape York Peninsula, damming of rivers in the future would regulate the discharge of water and sediment to the coast and locally further exacerbate erosion.

6.2.3 Tourist impact

The impact of tourism on coastal areas can be broadly divided into three categories: formal tourist facilities such as resorts and caravan parks, informal onshore activities including vehicles and camping, and offshore activities related to both of the former.

i. Formal activities

These generally imply concentrations of people and therefore the structural and waste considerations mentioned above apply. Vehicle and walking tracks which intersect the coastal foredune can become areas of accelerated wind and water erosion. In cases where these dunes are substantial large sand 'blowouts' which transgress rapidly inland can occur. A simple program of stabilising such tracks with 'log and chain' pathways, and restricting access over lightly vegetated dune areas can prevent this.

Associated with areas of concentrated tourist activity are requirements for water supply and garbage disposal. In the case of the former this can lead to unsightly but otherwise generally undamaging pit excavations in back dune areas, but in the latter can lead to poorly controlled dumping of rubbish including petroleum products and unbiodegradable waste.

ii. Informal activities

Four wheel drive vehicle tracks were observed crossing coastal dune areas in a number of locations. Where these areas are heavily trafficked multiple tracks had been established. In general the effect of these tracks is to destabilise and mobilise large quantities of dune sand. This effect is greatest across the crest of dune forms where they create breaches in the vegetated surface, and can be particularly damaging where they intersect the dune to beach interface.

In many situations closure of these routes along coastal dunes may not be an ideal solution as they provide the only access to favoured recreational/camping sites at the mouths of major rivers. The alternative here appears to be to upgrade a single access route (ie. by adding sections of 'log and chain' roadway for traction and stability on dune crests and difficult sections), and revegetation on either side of the track.

Unsupervised camping in coastal environments can result in several undesirable practices: accumulations of litter and excrement, destruction of living trees, accidental burning of areas of vegetation, encouragement of feral animals. The installation of garbage bins has been shown to be an unsuccessful response to the litter problem as they commonly become sites of accumulated garbage which are unsightly and attract animals. A successful strategy for managing camping in areas such as this is to introduce a point-of-entry supervision to areas where numbers can be controlled by permit camping, and a public education program on sound camping practices can be implemented. Suitable toilet facilities can be installed (ie. while considering the need not to pollute local water tables), and people should be encouraged to carry their garbage back out of the area. This implies some regular ranger interaction.

iii. Offshore activities

Boating, fishing, investigations of coral reefs, and snorkelling and SCUBA diving are popular coastal activities.

Boating and fishing activities can lead to damage to local fauna and flora by both mechanical damage (ie. by propellers and anchors) and pollution if sewerage is discharged directly or petroleum products are discharged with bilge water. This pollution can become quite significant where larger tourist boats are involved, or numbers of commercial fishing vessels are concentrated in bays. Areas of concentrated boating activity including activities such as paragliding and jetskiing can interrupt breeding and feeding patterns of larger endangered marine fauna such as dugongs and turtles. Commercial fishing nets can disturb vast areas of the inner shelf with associated damage to seagrass beds. Trawling puts fine sediment (and associated nutrients) into suspension, and if conducted close to coastal reefs on a regular basis (eg. when a number of vessels launch nets leaving embayments) can affect growth.

Coral reefs are the most vulnerable coastal environment to tourist impact. Sightseers damage reefs primarily by walking over and touching corals which causes both mechanical breakage, and removes the protective mucus layer that protects coral during low tides. Collection of shells and other reef specimens reduce the diversity of reef biota. Snorkelling and SCUBA diving can sustain considerable mechanical damage to reefs, and deplete them by collection if poorly conducted.

6.3. Grazing and agriculture

6.3.1 Grazing

Generally the present levels of grazing observed in Cape York Peninsula do not represent a threat to coasts in terms of erosion or delivery of excess nutrients. In fact, coastal areas may benefit at the expense of catchment areas where the accelerated erosion of soil increases the sediment supply discharged by rivers. There is, however, an associated toll on nearshore coral reefs with the addition of excessive amounts of sediment (ie. and a concomitant increase in nutrients). Nutrient enriched discharge from intensive grazing practices such as feedlots have the potential to seriously impact locally on coastal flora and fauna.

6.3.2 Agriculture

Commercial agriculture is not presently widespread in Cape York Peninsula, but in other tropical climates has been a recognised agent of destruction of coastal fauna and flora. Where fertilisers have been applied, excess nutrients find there way into coastal discharge and can have a profound destructive effect on reefs. Additionally, a severe salinity problem has developed in irrigated coastal soils throughout other tropical regions where intensive agriculture is carried out.

Lowland coastal environments may be underlain by the deposits of former estuaries and mangrove swamps. These may contain sulphide minerals and have the potential to give rise to acid-sulphate soils if exposed by agricultural practices or excavation for building, mining, or irrigation. The precise extent of these buried deposits cannot be mapped at the scale of sampling used in this study, however they are most likely to occur in areas of back-barrier and inter-barrier swamp.

6.4 Extractive industries

Exploitable minerals within the coastal regions generally fall into two main types:

i. heavy minerals (eg. ilmenite, zircon, rutile) and

ii. silica.

Bauxite may also become a consideration where it extends to coastal cliffs.

The presence of heavy minerals relies largely on the availability of a parent rock in the catchment area of coastal rivers to provide a source, whereupon coastal processes will then act to concentrate these minerals into beds that can be productively mined. Broad regional surveys in Cape York Peninsula have failed to find exploitable quantities of heavy minerals to date. The common method of mining heavy minerals in coastal areas is by floating dredge which progressively creates its own pond in coastal sediments, with mined areas being rehabilitated in its wake. Rehabilitation programs on both the east and west coast of Australia have generally proved responsible in the faithful rehabilitation of mined areas, however, a degree of loss of diversity, mature forest, and soils formation generally accompanies an operation such as this.

Vast quantities of high grade silica are found in the expansive dunefields of eastern Cape York Peninsula. As indicated previously (section 5.2.5) there are areas of conservation and cultural significance within dunefields, and proposals to mine in these areas need to consider the effect on the quantity and quality of the reservoirs of water contained within these systems. A large silica mining operation has been in progress at Cape Flattery for a number of years and has provided substantial economic benefit. Rehabilitation of the mined area is monitored by state government organisations.

The primary concerns for the coastal environments from such ventures are those discussed earlier relating to concentrations of population and intrusive structures (eg. breakwaters), and the potential impact of pollution from large vessels. The accumulation of old vessels and blasting of headland bedrock in the case of the Cape Flattery has imposed a long term aesthetic toll, however, the attitude of the mine population to local coastal environments appears to be conservationally sound.

Removal of fluvial/alluvial overburden for construction material has the potential to expose former estuarine and mangrove deposits to leaching. As discussed previously in the agriculture section these leached products contaminate waterways and can have a significant impact on aquatic biota.

Coastal sediments do not generally present desirable soils for commercial forestry, however, forest clearing in catchment areas or where regolith extends to the coast provides a potential siltation/nutrient problem affecting nearshore reefs.

6.5 Navigation

The ship channel inside the Northern Great Barrier reef is one of Australia's most restricted seaways, and at the same time one of Australia's busiest. There is a real risk of collision or grounding giving rise to significant levels of pollution. Much of the reef outside this channel is still uncharted.

There are three ports in the region. Cooktown is isolated by a bar which prevents the entrance of vessels except those of shallow draught, and then only at favourable states of the tide. The Port of Weipa is accessed by a dredged channel which is prone to siltation. The Port of Thursday Island is difficult to access and is not an ideal harbour. Port facilities formerly existed in current-swept Albany Passage, but are now abandoned.

Port Musgrave provides one of the best natural harbours in Queensland, but the entrance has numerous bars and is only navigable by shallow draft vessels.

7. GLOSSARY OF SELECTED TERMS

Many of the following definitions are taken in part from the Glossary of Geology (Bates and Jackson, 1987).

Aeolian

Pertaining to the wind (eg. aeolian sediments = wind blown sediments)

Batholith

A large plutonic mass that has more than 100 km^2 of surface exposure and no known floor.

Beach Ridge or Beach-ridge plain

Beach ridges are successive strandlines which have been deposited seaward of their predecessors on a prograding shoreline. They are usually separated by narrow swales [depressions] of varying width and depth depending on how closely the successive ridge crests have been formed (Rhodes, 1980). A broad sequence of such ridges is called a beach-ridge plain.

The dimensions of individual ridges vary considerably with amplitudes as low as 0.5-1m (Graham, 1993) to several metres, and distances between successive crests commonly in the range 20 to 100m on the east Australian coast. (Thom et al., 1978, Graham, 1993). The last generation of beach-ridge plains developed in Australia commonly fall within the range of a few hundred metres to 3km.

Several quite diverse theories have been proposed to explain beach ridge formation. Much of this confusion may arise from a failure to adequately distinguish between dune ridges, beach ridges and storm (shingle and pebble) ridges, all of which have the capacity to form shore parallel ridges, but have a distinctly different genesis. Beach-ridges in the present study are defined as being composed primarily of upper shoreface (ie. beachface) facies exhibiting laminated stratigraphy from multiple depositional events. Although these ridges may develop an aeolian cap their primary ridge and swale topography results from the emplacement of beach facies and are therefore distinct from dune ridges of wholly aeolian origin. Additionally, although these ridges may exhibit some preservation of coarse deposits washed over the apex during storm surges, they are distinct from coarse shingle and pebble ridges formed in one or a limited number of storm events.

The mode of formation supported for beach ridge formation in North Queensland is that proposed by Bird (1984) which follows the following stages:

i. continuous supply of sediment to the nearshore will lead to construction of a berm on the upper shoreface,

ii. an erosional event (eg. storm surge) erodes the berm crest translating the apex landward,

iii. with a continuing supply of sediment to the nearshore a new berm will form forward of the now isolated apex. This apex is then colonised by vegetation which traps an aeolian cap enhancing the relief.

This mode of formation has been confirmed on the North Queensland coast near Innisfail by (Graham, 1993), and during the present study where an incipient beach-ridge was investigated in a trench 20m long and 1-2m deep on the beach at Rutland Plains in the southeastern Gulf.

Carboniferous

The geological time period between 286-360 million years ago.

Chenier or Chenier plain

Russell and Howe (1935) first described the occurrence of a series of discrete long, narrow, sandy ridges dispersed across the marshes of southwestern Louisiana coast. These features which run roughly parallel to the Louisiana coastline support a luxuriant cover of large evergreen oak trees, and hence the derivation of their name 'cheniers' adopted by the local Creole inhabitants of that area from the French word for oak.

The essential distinction morphologically is that they are discrete, elongated sand and/or shell bodies stranded on a coastal mudflat or marsh. They are generally widely separated from other ridges, and where they are distributed across a wide plain, that feature is described as a 'chenier plain'.

The following description is extracted from Rhodes (1980):

'Individual chenier ridges vary from 50m to 500m in width and can extend for several tens of kilometres (Price, 1955; Hoyt, 1969). Deposits of this type are common in hot-wet regions where large quantities of fine sediments are carried by rivers (Brouwer, 1953; Davies, 1972). Crests of cheniers may extend above the highest normal level of swash runup, reaching levels where storm surges or similar meteorological variations in sea level temporarily create higher water levels.' [p.3]

Cheniers may overlie nearshore sediments or marsh/mudflat sediments. In the southern Gulf the base of the cheniers is demarcated by an abrupt change to low-tide muds (Rhodes, 1980).

Various models have attempted to explain the genesis of cheniers and most agree that they form in response to a fluctuation in the rate of sediment supply to the coast (Curray, 1969). Various mechanisms can cause this, primary amongst which are shifts in the location of major river mouths and climatic fluctuations. It appears that mudflat formation will tend to dominate during periods where the climate is wetter and rivers are discharging large amounts of sediment, while conversely during drier periods cheniers will form (Rhodes, 1980). It is considered that during prolonged periods of high discharge the transport ability of the already sediment laden nearshore waters is greatly reduced leading to the deposition of fine sediments. A reduction in the quantity of sediment delivered to the nearshore during drier periods enhances the ability of the nearshore processes to winnow finer sediments, and to remove them offshore leaving a coarser lag. This coarse residue is then available to be moved onshore by wave action, the impact of which is also enhanced by the reduction in fine sediment deposits extending offshore.

Clastic [sediment]

Sediment formed by the accumulation of fragments derived from pre-existing rocks or minerals and transported as separate particles to their places of deposition by purely mechanical agents (such as wind, water, ice, and gravity).

Confluence

A place of meeting of two or more streams.

Conformable

Said of strata or stratification characterised by an unbroken sequence in which layers are formed one after another.

Coral bleaching

Under stress coral polyps expel an algae (zooxanthellae) with which they normally coexist in a symbiotic relationship with, giving a bleached appearance.

Echinoderm

A solitary marine benthic invertebrate, characterised by radial symmetry and forming an endoskeleton (ie. internal skeleton in an animal) of plates.

El nino current

A warm current which migrates across the Pacific Ocean periodically and affects local climatic conditions and temporarily raises local sea level.

En echelon faulting

A staggered arrangement of parallel faulted features. (From French for steplike arrangement.

Epeiric or epicontinental sea

A sea on the continental shelf or in the continental interior.

Estuary

A simple geomorphological definition of an estuary is "...a funnel shaped opening of a river in the sea" (Reinick and Singh, 1980). Other definitions include criteria such as being tidally effected and dilution of marine and fresh water . A generally accepted definition is that of Pritchard (1967) who describes an estuary as "...a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."

A more recent geologically orientated definition by Dalrymple, Zaitlin and Boyd (1992) has recognised that estuaries form by the drowning of river valleys as sea level rises, and recognise the limits of an estuary by sedimentary criteria. They define an estuary as "...the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth" (p1132).

Eustatic sea level rise

Pertaining to worldwide sea level changes that affect all the oceans. Caused by major addition or subtraction of water as it becomes locked into major ice bodies during glacial periods and subsequently released.

Fluvial

Of or pertaining to a river or rivers

Gastropod

A class of mollusc forming in most cases a single shell closed at the apex, sometimes spiralled, but not chambered, and generally asymmetrical.

Halophyte

A plant growing in water or soil with a high salt content

Lacustrine

Pertaining to, produced by, or formed in a lake.

Mesozoic

An era of geological time from about 225-65 million years ago.

Mollusc

Phylum of invertebrate animal that develops a radially or biradially symmetrical mantle or shell.

Orogeny

Process by which structures within major fold-belt mountainous areas were formed including thrusting, folding, and faulting in the outer layers.

Palaeozoic

An era of geological time from about 570-225 million years ago.

Palimpsest

Said of relict sediments of the continental shelf, reworked by physical of biological processes.

Palynology

Branch of science concerned with studying pollen and seed of plants (ie. generally to reconstruct details of past climates and environments).

Precambrian

All geological time older than the start of the Palaeozoic era (ie. older than about 570 million years ago)

Proterozoic

The more recent of the two major divisions (eons) of the Precambrian (ie. about 2,500-570 million years ago).

Progradation

The building seaward of the shoreline. (refer discussion section 4 and figure 4).

Quaternary

A geological time *period* extending from 1.6 million yrs BP to present time. Incorporates both the Pleistocene and Holocene *epochs*.

Seismic (surveying)

The word seismic refers to the propagation of waves of energy through elastic solid bodies (ie. in the case of geology rocks and sediments). In geological surveying seismic waves, which are created by artificial sources, penetrate the earth's surface (ie. the seafloor in marine surveys), and are reflected from boundaries between rock or sedimentary strata with different acoustic impedances back to the surface where they are recorded by instruments. This method allows the mapping of subsurface strata over wide areas. In coastal studies shallow penetration seismic surveying techniques with an emphasis on resolving sedimentary structures in detail are commonly used.

Side-scan sonar

Conventional sonar records reflected acoustic signals which image the seafloor directly beneath a vessel. Side-scan sonar uses the same principle but records a width of seafloor either side of the vessel, imaging a swathe of seafloor in a single pass.

Transgression

The progressive envelopment of the land surface by advancing sea (ie. as sea level rises) or by aeolian sediments (dunes).

Unconformable

An interruption in the continuity of stratigraphy *yrs BP*

Years before present. As a standard for radiocarbon age dating methods the year *AD 1950* is used as the reference year for *present*.

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