Queensland University of Technology
School of Natural Resource Sciences
Brisbane

GEOMORPHOLOGY, SEDIMENTOLOGY, AND SHORELINE PROCESSES IMPACTING ON THE STABILITY OF THE BRIBIE ISLAND SPIT

by

JARED MARK LESTER
B. App. Sci
2000

SUPERVISOR
Dr Brendan Brooke
Queensland University of Technology

CO-SUPERVISOR
Dr Malcolm E. Cox
Queensland University of Technology

A thesis submitted in partial fulfilment of the requirements of the degree of Bachelor of Applied Science (Honours) at the Queensland University of Technology.

Abstract

For several years there has been considerable community and government concern about the possibility of an ocean breakthrough of the spit at the northern end of Bribie Island. This study represents a synthesis of previous research and published data, field studies and laboratory analyses to provide a detailed assessment of processes affecting the stability of the Bribie Island spit.

Radiocarbon dating of shell material indicates that the spit formed prior to 3330 yBP. At that time the spit extended considerably further east of its present position and the estuarine environment of Pumicestone Passage was much wider than it is today. Stratigraphic relationships indicate long-term erosion and barrier retreat, with estuarine sediments, previously part of Pumicestone Passage, now exposed on the eastern shore of the spit. Aerial photograph interpretation indicates erosion of the eastern shore of the spit over the last 60 years as the eastern shoreline has retreated landward by at least 75 m.

The main deposits within the study area comprise reworked marine sand and estuarine sediments. Field and laboratory studies have indicated a mainly closed sediment system through analysis of grainsize, grain characteristics and mineralogy. Most sediment is supplied to the system by recycling of existing sand deposits, with a minor input of fluvial sediment.

Sediment budget calculations for the spit system between 1978 and 1993 have indicated an increase in the rate of erosion of the eastern shore of the spit since 1972. Between 1978 and 1993 the eastern shore of the spit experienced erosion at a rate of approximately 144 000 m^3yr^{-1} with approximately 80% of the eroded sand being deposited in the flood tidal delta of Caloundra inlet. The system experienced a loss of sand of approximately 30 000 m^3yr^{-1} by littoral and offshore drift, which highlights the negative imbalance in the sediment system.

Severe storms constitute the main erosional events impacting on the spit. However, as the rate of erosion has increased since 1972 without a commensurate increase in storm activity, it is suggested a number of other factors are involved in the present erosional regime. They include a reduction in the rate of sediment supply from offshore, an increase in the rate of longshore drift, a rise in sea level, and anthropogenic impacts such as dredging in the inlet and North West Channel.

Human impacts on the stability of the spit are confined to localised activities, namely the dredging of sand resources in the flood tidal delta. Although minor volumes of sediment are removed from the system by dredging in comparison to the volumes of sediment moved by natural events, accommodation space is increased. As a consequence, more sand is moved into the passage from the spit.

A close correlation exists between storm frequency impacting on the study area and Southern Oscillation Index (SOI) variations. The present SOI forecast indicates that the onset of the next period of high storm activity, with potential for further erosion of the spit, will occur in February 2001.

Field observations and analysis of modern processes impacting on the spit shows the spit is presently accreting northward in association with a steady landward retreat of the southern section of the spit. If this trend continues it is likely that the spit will break through somewhere in the vicinity of Fort Bribie. Closure of the present inlet may occur following breakthrough of the spit. If erosion continues at the present rate, a breakthrough of the spit is likely in approximately 50 years. However, if the rate of erosion continues to increase as it has since 1972, breakthrough of the spit may occur in approximately 20 years.

Contents

Contents

List of Figures

List of Figures

List of Figures

List of Tables

Table

List of Appendices

Appendix

Statement of Original Authorship

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signed: [redacted]

Date: 27/10/2000

ACKNOWLEDGMENTS

I would like to take this opportunity to thank everyone who has helped out with this project in any way shape or form. First and foremost, I would like to thank my parents and sister for their infinite support and encouragement, and giving me the opportunity to have a go. For that I am most grateful.

- Dr Brendan Brooke for reading, editing and commenting on text, always being available to talk about the project, helping out in the field. Your encouragement throughout the year has been greatly appreciated.
- Dr Mal Cox for getting the project up and running, making funds available and giving me the opportunity to take it on. Thanks also for reading and commenting on text and your encouragement and support throughout the year.
- Special thanks also to Dr Michaela Preda for her amazing assistance with XRD and the intricacies of Surfer and Map Info. Your support is greatly appreciated.
- The Natural Heritage Trust in provided funding for this project in collaboration with Caboolture Shire Council and DPI Forestry (allocated by M. Cox).
- Caloundra City Council (Tony O'Keefe, Bill Haddrill, Dennis Shaw) made available aerial photography and provided useful local knowledge.
- Queensland Parks and Wildlife Services for their assistance with fieldwork and providing useful local knowledge.
- Thanks to Tim Ezzy for being available to bounce ideas off, reading and commenting on text, MapInfo advice, helping out in the field and a constant source of motivation. Dave Purdy also provided assistance with reading and commenting on text. To my fellow Honours students, it's been a great year and your support and helpful comments have been very much appreciated.
- Mal Jones and Andy Stephens were available to talk to about this project and clarify some finer features of the study area.
- Thanks to Sifu, Simu and everyone at WCKFO. Without you guys I couldn't have made it this far.
- Thanks to all my friends. Although there hasn't been much time to catch up this year, your never ending support and understanding is greatly appreciated.
- And finally a lasting thanks to Huey, the legendary god of the ocean, you are a tremendous source of energy and inspiration.

INTRODUCTION

On the relatively highly developed east coast of Australia, beach and dune erosion has for several decades been a problem of major concern to residents, planners, engineers, miners, conservationists, and tourists (Thom, 1974). Periodic storm waves and tides and strong onshore winds result in marked beach recession and foredune erosion. Additionally there is an unrelenting pressure on the coastline generated by a growing population with an increasing interest in coastal environments for residential, commercial, industrial and recreational developments.

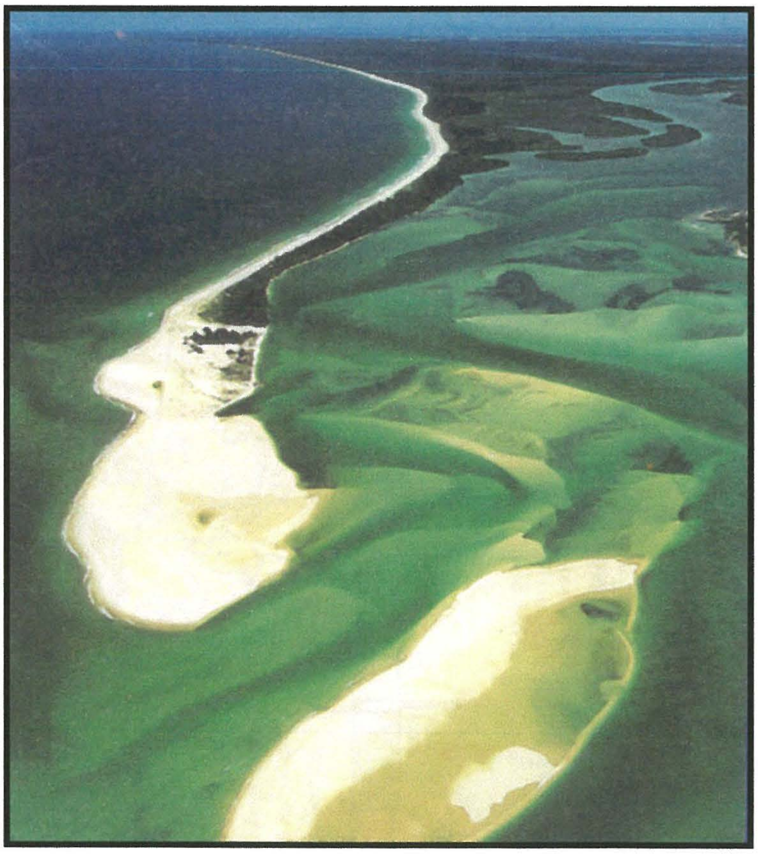
Severe offshore meteorological events such as tropical cyclones and intense low-pressure systems have regularly caused significant beach erosion along the southeast Queensland coastline. The most recent erosion event to affect that coast occurred in April 2000, when an intense low-pressure system (998.3 hectopascal) formed in the Coral Sea and moved southward along the Queensland coast. This weather event produced large storm waves of up to 9.7 m high (recorded at Brisbane Wave Recording Station), and storm surges along the southeastern coast resulting in substantial beach erosion. One area particularly affected by this erosion was the spit at the northern end of Bribie Island, the subject of the present study.

One section of the spit at the north end of Bribie Island has been reduced from a width of 120 metres to 65 metres by severe erosion in recent years. That rate of erosion indicates the potential of a breakthrough of the spit by the ocean. The residential and tourist area of Golden Beach, Caloundra, is threatened by a breakthrough as this estuarine beach is protected from the open sea by the spit. A breach of the spit would also significantly alter the hydrodynamics of Pumicestone Passage, impacting on its present ecology and morphology.

For positive action to be taken in order to address this problem, a detailed understanding of the processes that effect sedimentation and erosion on the spit and the northern section of Pumicestone Passage needs to be developed. That understanding requires an analysis of the geological, geomorphological and climatic characteristics of the area. This thesis provides significant insights into those features of the passage and spit and, based on the findings, indicates likely future geomorphic changes.

Thesis Outline

A wide range of geoscientific methods are employed in this project as a means of determining the past, present and future rates of landform change in the study area. The thesis is divided into six chapters. The first two chapters establish the geological and geomorphological background upon which the present study is based. In Chapter 1, previous studies of barrier islands and spits are reviewed. Chapter 2 presents a description of the coastal landforms and geology of the study area, as well as an outline of climatic and marine processes. The methods employed in the study, ranging from the recovery of vibrocores to the analysis of historical climate data, are detailed in Chapters 3 and 4. The results of the field and laboratory work are summarised in Chapter 5 and discussed in Chapter 6. The detailed results are supplied in tables and graphs in the Appendices. In Chapter 7, the wide range of data generated in the study is reviewed and the major findings collated. Additionally, recommendations for further research are made.



Looking south over the spit and flood tide delta
(date of photograph approximately 1994-1996).

1.0 BACKGROUND

Bribie Island is a barrier island with a distinctive elongate spit attached to its northern coast. Before informed interpretation of the island's geology and morphology can be undertaken, a thorough knowledge of the past major investigations of these types of environments is necessary.

1.1 Barrier Islands

Barrier islands are major depositional landforms that currently comprise approximately 15% of the world's coast (Glaeser, 1978). A barrier island is an elongate, essentially shore-parallel island composed predominantly of unconsolidated sediment, which protects the adjacent landmass, and is separated from it by some combination of wetlands (Davis, 1994).

The prerequisites for barrier formation have been defined by Davis (1994) as:

1. A significant supply of sediment.
2. Marine and wind processes that will develop and maintain the barrier.
3. A geomorphic setting where barrier formation can take place.

1.2 Barrier Evolution

A study by Roy & Thom (1981) on Late Quaternary marine deposition in New South Wales and southern Queensland has highlighted different modes of barrier formation for regions with varying inner shelf gradients (Fig. 1). Marine deposition in southern Queensland has involved a rising sea level inducing landward translation of the shoreline across a relatively shallow and low gradient shelf (Fig. 1A); (Roy & Thom, 1981). This has resulted in a shallow and gently graded nearshore slope where stored sediments are mobilised by normal shoreline processes. In contrast, the southern region of New South Wales has relatively steep and deep offshore profiles and an erosional transgressive stratigraphic pattern predominates (Fig. 1B); (Roy & Thom, 1981).

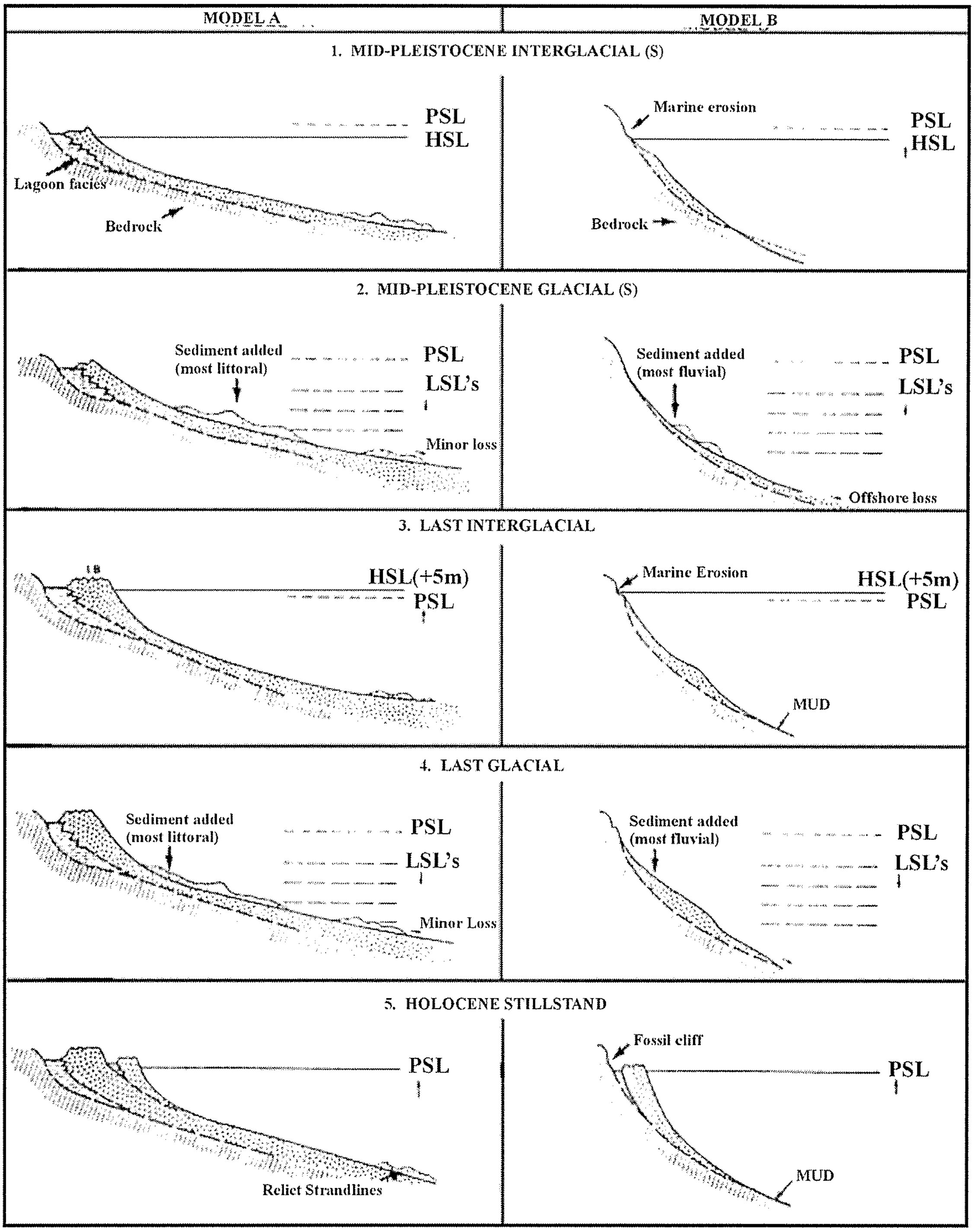


Figure 1. Schematic model of Late Quaternary coastal and inner shelf sedimentation and subsequent sand barrier genesis in New South Wales and southern Queensland. Southern Queensland is represented by model A, New South Wales by model B. Summary of processes in Table 1 below. (after Roy & Thom, 1981).

Table 1. Summary of schematic models of Late Quaternary coastal and inner shelf sedimentation and subsequent sand barrier genesis in New South Wales and southern Queensland, as shown in Figure 1 (after Roy & Thom, 1981).

A-1	Low barrier shorelines are formed on the gently sloping surfaces where shoreline processes result in their landward migration. Superficial reworking processes produces a transgressive sand sheet, which has formed the parent sand body from which modern sand barriers have formed (Roy & Thom, 1981).
A-3	Transgression has terminated with wave energy being dissipated over a broad and shallow shelf region. Net onshore transport of sand occurs by wave shoaling processes and results in beach ridge progradation.
A-4 & A-2	During periods of low sea level sand is added to the shelf by littoral and fluvial processes.
A-5	Sediment added to the shelf during the Last Glacial period (A-4) was available for onshore transport to form Holocene barriers.
B-1	An equilibrium profile is maintained throughout a sea level rise by continual shoreface erosion, associated with an equal volume of aggradation on adjacent sea floor. Sediment is lost seaward during a transgression and becomes a sand blanket unable to be activated by shoreline processes due to deep water. The sediment is stored until reactivation during a following regression.
B-2	At lowest sea levels there is probably permanent loss of sediment due to coastwise transport.
B-3	The Last Interglacial Marine Transgression and high sea level (s) had an erosional impact providing a flatter, residual slope than encountered in previous transgressions for the following Postglacial Marine Transgression (B-4). This allowed landward reworking of local sediment surpluses to form bay barriers of Holocene age.
B-5	During the Holocene Stillstand, conditions in southern New South Wales were more conducive to the development of transgressive depositional stratigraphy than at any other time.

In addition to the model of inner shelf sedimentation and sand barrier genesis (Roy & Thom, 1981), outlined above, three primary modes of barrier formation (prograded barrier, stationary barrier and receded barrier) that have been described by Roy et al (1994) are summarised below (Fig. 2).

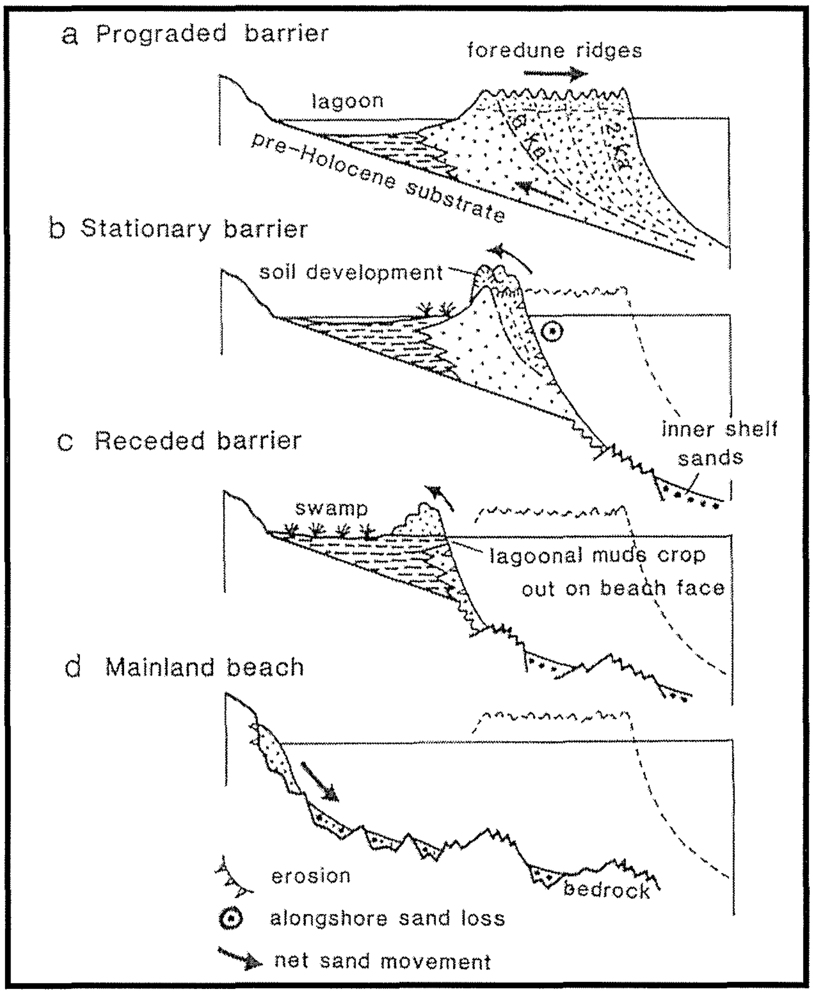


Figure 2. The three primary modes of barrier formation are prograded barriers, stationary barriers and receded barriers (after Roy et al., 1994). Erosion and retreat of the barrier to the mainland beach (d) is the final stage of barrier evolution.

1.2.1 Prograded Barriers

Prograded barriers or strand plain complexes are characterised by multiple, coast parallel beach or foredune ridges (Fig. 2a; Roy et al., 1994). In Australia, the beach and foredune ridge plains of prograded barriers represent an episode of coastal progradation that spans the last 6.5 ka (Roy et al., 1994). Foredune ridges have an aeolian cap representing an influence of sufficiently strong winds to transport sand and a climate able to support the growth of dune vegetation to allow sand to be trapped on the upward accreting dune surface (Hesp, 1984). Beach ridges are relatively low relief and represent wave formed berms rarely reaching more than 3 m above mean sea level, whereas foredune ridges and swales have a greater amplitude of 3-5 m, often reaching elevations of 7-10 m above sea level (Thom, Polach & Bowman, 1978).

Prograded barriers are usually well developed near large, active river mouths on wave-dominated coasts, however in southeast Australia the sand source is mostly the offshore sea bed (Thom, 1984). In southeast Australia, prograded barriers tend to completely infill bedrock embayments leaving space only for small wetlands at their landward margin, contrasting with stationary barriers that more commonly enclose substantial estuaries (Roy et al., 1994).

Prograded barriers formed within bedrock embaymants where inlets are relatively stable, such as southeast Australia, ridge patterns are more or less regular and aligned sub parallel to the coast (Roy et al., 1994). However, some coastal plains give rise to complex ridge morphologies where some parts of the barrier are eroding while other parts, such as adjacent to inlets, are accreting (Roy et al., 1994). In these environments 'drumstick' barrier islands may form (Fig. 3). These barriers are associated with a mixed energy regime of both tidal and wave influences. 'Drumstick' barrier islands occur where large ebb tide deltas locally cause wave refraction and the convergence of littoral drift at the mouths of tidal inlets and are characterised by recurved spits and flared ridge patterns (Hayes, 1979). In environments where wave energy tends to dominate, a well-defined terminal lobe develops on the ebb tide delta.

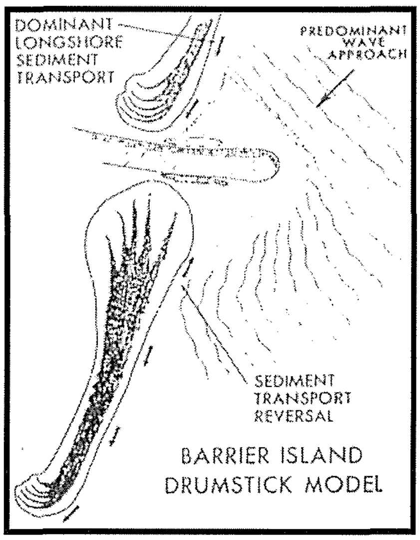


Figure 3. Features of the 'drumstick' model are subject to both wave and tidal influences. Wave refraction and littoral drift convergence at the mouth of the tidal inlet, recurved spits, flared ridge patterns and a well defined terminal lobe at the end of the ebb delta are characteristics of this 'drumstick' model (After Davis, 1994).

The depositional surfaces of prograding barriers generally dip seawards parallel to the present beach and shoreface (Kraft and John, 1979), and drilling data has shown the barrier sands to be uniformly fine to medium grained and moderately well sorted (Roy et al., 1994).

Studies by Thom et al. (1978, 1981) and Thom (1984) have used radiocarbon dating of numerous barriers to confirm seaward progradation during the Holocene stillstand. An early phase of seaward growth of some barriers at the beginning of the stillstand (6500 – 3000 yBP) may be due to initially abundant sand reserves (Roy et al., 1994). Further, Roy et al. (1994) have suggested that barriers ceased growing in the last 1000 - 2000 years based on the aforementioned radiocarbon evidence.

1.2.2 Stationary Barriers

Roy et al. 1994 have recognised stationary barriers (Fig. 2b) on the basis of two major criteria:

1. The absence of significant evidence of progradation over the past 6000 years.
2. The presence of complex dune structure.

Studies by Roy and Thom (1981) and Thom (1984) have surmised that in southeast Australia, stationary barriers tend to occur in compartmented embayments that, at the end of the postglacial marine transgression, had limited reserves of sand available for barrier building. They often enclose substantial estuary water bodies and may appear to be anchored to remnants of earlier Pleistocene barriers (Roy & Thom, 1981).

Stationary barriers are usually narrow (0.5 to 1.0 km wide), with beach and dune facies fronting a well developed back barrier sand flat (Thom et al., 1978). The preservation of back barrier facies behind stationary barriers is considered to be evidence of shoreline stability, as eroding coasts will lead to the destruction of back barrier facies by landward translation of the shoreface (Roy et al., 1994).

The presence of a stationary barrier may represent a transitional stage from a prograded barrier to a receded barrier (Roy et al., 1994). Roy et al. (1980) have hypothesised that barrier coasts experienced a growth phase in the mid Holocene as the sea bed re-equilibrated after sea level reached its present position and sand moved onshore, followed by an erosional phase in the late Holocene as shelf sand reserves were depleted and coastal sand budget losses exceeded gains. Further, Shepherd (1991) has noted that stationary barriers appear to be intermediate between eroded and prograded coasts and possibly fluctuate between these two conditions to give the impression of relative stability over time.

1.2.3 Receded Barriers

Based on extensive research on parts of the coast of New South Wales, Roy et al. (1994) have recognised that receded barriers (Fig. 2c) occur on coasts undergoing a marine transgression and long-term erosion either because relative sea level is rising or because of a negative balance in the sediment budget. In these settings, beach and foredune deposits form a relatively narrow and low ridge on top of relict back barrier sediments over which they have translated (Roy et al. 1994). The relict back barrier sediments consist of tidal flat muds or fresh water peats that outcrop on the beach, indicating that the shoreface has retreated landward to erode the former barrier (Roy et al., 1994).

From radiocarbon ages reported by Thom (1978) from southeast Australia, Roy et al. (1994) have determined that in southeast Australia barrier recession has occurred over the past 3000 years. Additionally, it has been proposed that barriers with long recession histories indicate embayments with very limited sediment input throughout the Holocene (Roy et al., 1994).

Another barrier-recession scenario involves sediment loss creating a negative sediment imbalance, and subsequently coastal erosion (Roy et al., 1994). Under the stable sea level conditions of southeast Australia, erosional retreat of the barrier superstructure involves slow encroachment of the foredune into the estuary/lagoon systems located behind the barrier with washovers being virtually non existent (Roy et al., 1994).

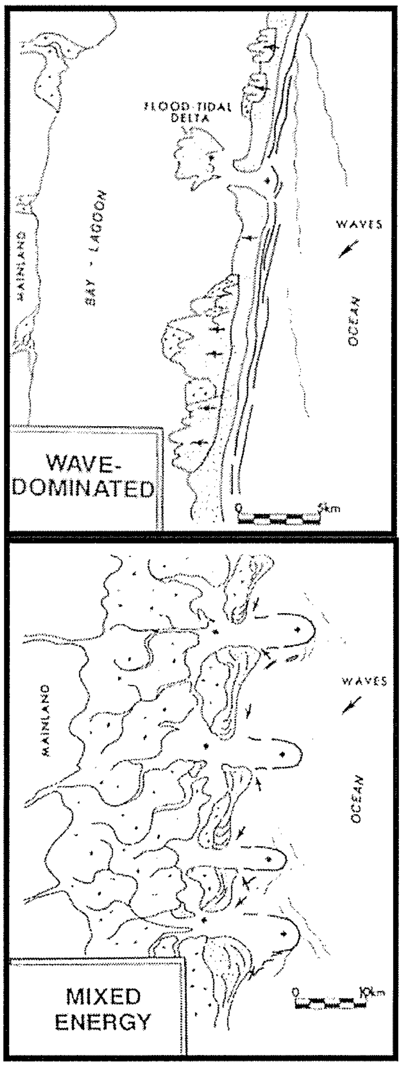
Thicknesses of receded barrier deposits are typically less than 10 m in contrast with transgressive barriers, which are also associated with coastal recession (Roy et al., 1994). Transressive barrier deposits are typically thicker than receded barriers and storm washovers and tidal inlet deposits form the barriers dominant lithofacies (Roy et al., 1994)

1.3 Barrier Island and Spit Development

A prominent feature of many barrier islands is the formation of a sand spit at either end. Spits may be described as stillstand barriers that have principally grown alongshore in response to a dominant littoral drift (Allen, 1982).

In addition, there are three primary morphologies generally exhibited by barriers that have spits or form islands. These have been classified as attached barriers, wave-dominated barriers, and mixed-energy barriers (Davis, 1994). Examples of wave-dominated and mixed-energy barriers are shown in Figure 4.

Attached barriers form under wave dominated conditions due a combination of updrift erosion, longshore transport and downdrift accretion. Attached barriers may be in the form of a spit emanating from a headland or barrier island. Another type of attached barrier, common along the central east coast of Australia, may form by landward transport and shoaling of sand forming a gently arcuate and concave seaward barrier (Roy, 1984).



(A) Features of wave dominated barriers. Under wave dominated conditions barriers are long, narrow, and with few inlets. Washover fans are common and dunes vary in size and distribution. Inlets associated with wave dominated barriers tend to be unstable in size and location and they often have a large flood tidal delta and a small or negligible ebb tidal delta. Wave-dominated barriers may be present on both microtidal and mesotidal coasts depending on the interaction between wave and tide processes. (After Davis, 1994).

(B) The features of mixed energy barriers result from the combined influence of waves and tides. The mixed energy system produces barriers with 'drumstick' morphologies (Fig. 3) and are characterised by islands only a few kilometres long that have one wide and prograding end, and one narrow receding end. A mixed energy barrier system commonly has a number of relatively stable inlets and prominent ebb tidal deltas. Mixed energy barriers may also be present on both microtidal and mesotidal coasts depending on the interaction between wave and tide processes. (After Davis, 1994).

Figure 4. Barrier forms as a function of wave and tidal energy.

Given the classifications, outlined above, it is possible to determine a measure of the shoreline processes giving rise to spit morphology by plotting mean wave height versus tidal range on the graph below (Fig. 5).

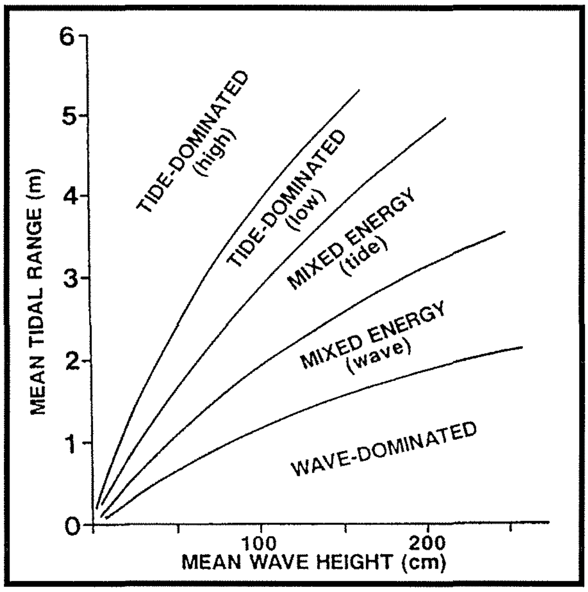


Figure 5. Plotting mean wave height versus mean tidal range allows the determination of influences on spit development, which produces distinctive morphologies (Davis, 1994).

1.4 Late Quaternary Sea Level Changes

Changes in sea level relative to its present position result from variations in the shape or volume of the oceans (by growth and decay of ice sheets), the redistribution of water within the ocean basins, and the vertical movement of coastal areas (Fleming et al., 1998). Of these controls on sea level, the growth and decay of land ice has dominated sea level changes in the Quaternary (Williams et al., 1998).

The Huon Peninsula in Papua New Guinea has provided a well-preserved record of Quaternary sea level changes in the form of fossilised coral reefs extending above the present coastline due to tectonic influences. The uplift of the fault block housing the fossilised reefs has occurred at a steady mean rate of 0.5 – 3 mm per year and is related to ongoing plate tectonic processes during the Late Quaternary (Williams et al., 1998). The steady rate of uplift combined with dating of coral remnants and comparison to oxygen isotope records derived from marine microfossils provides an accurate determination of past sea level positions in relation to present sea level (Fig. 6; Williams et al., 1998).

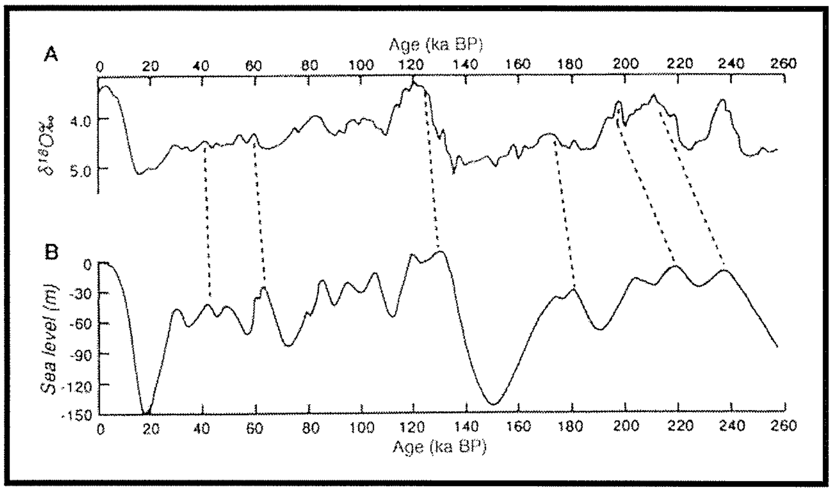
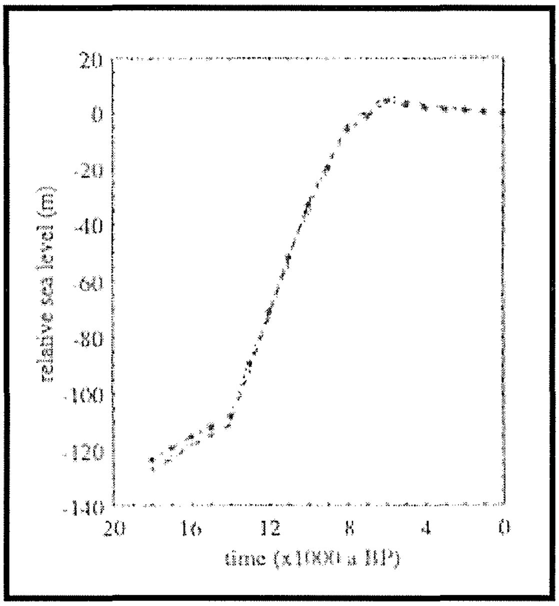


Figure 6. Late Quaternary sea level and associated oxygen isotope record from coral terraces, Huon Peninsula, Papua New Guinea. (A) Oxygen isotope record; (B) sea level record. (Aharon and Chappell, 1986).

Based on the age of the radiometrically dated coral terraces, the Last Interglacial sea level (140 000 – 120 000 yBP) stood about 6 m higher than present (Williams et al., 1998). After this highstand, sea level trended downward, with a number of oscillations during short warming episodes until about 20 000 yBP, when it reached about 120 – 150 m below present. The last major Quaternary glaciation is represented by the oscillating downward trend in sea level between 80 000 yBP and 20 000 yBP (Williams et al., 1998).

Lambeck (1993) has characterised several features of sea level since the last glacial maximum (20 000 yBP) in areas such as Halifax Bay, near Townsville, on the Queensland coast. These features are summarised in Figure 7 and show a steady rise in sea level since 18 000 yBP to slightly above present sea level at 6 000 yBP. Since then there has been a slight fall of approximately 1 m to present sea level.

In modern times, global warming is a potential cause for a rise in sea level. Historical and contemporary records have indicated a rise of as much as about 10 – 15 cm over the past century (Gornitz et al., 1982; Gornitz, 1993). The present rate of rise is of the order of 1-3 mm per year (Williams et al., 1998), although this may vary in regions undergoing tectonic or isostatic uplift or subsidence.



Late Quaternary sea level changes at Halifax Bay on the Central Queensland coast (after Lambeck, 1993).

The main features of this diagram are:

1. A stationary or nearly stationary sea level at a depth of 120-130 m below present sea level when the ice sheets were at their maximum limit (18 000 yBP).
2. A rapid rise in sea level at the time the icesheets melted and the ocean volume increased (13 000 – 7 000 yBP).
3. Sea level reached its present value about 6 000 yBP, when all melting ceased, followed by a small highstand.
4. A slight fall in sea level at a uniform rate from the highstand until the present time.

Figure 7. Late Quaternary sea level changes at Halifax Bay on the Queensland coast (after Lambeck, 1993).

2.0 Location of the Study Area

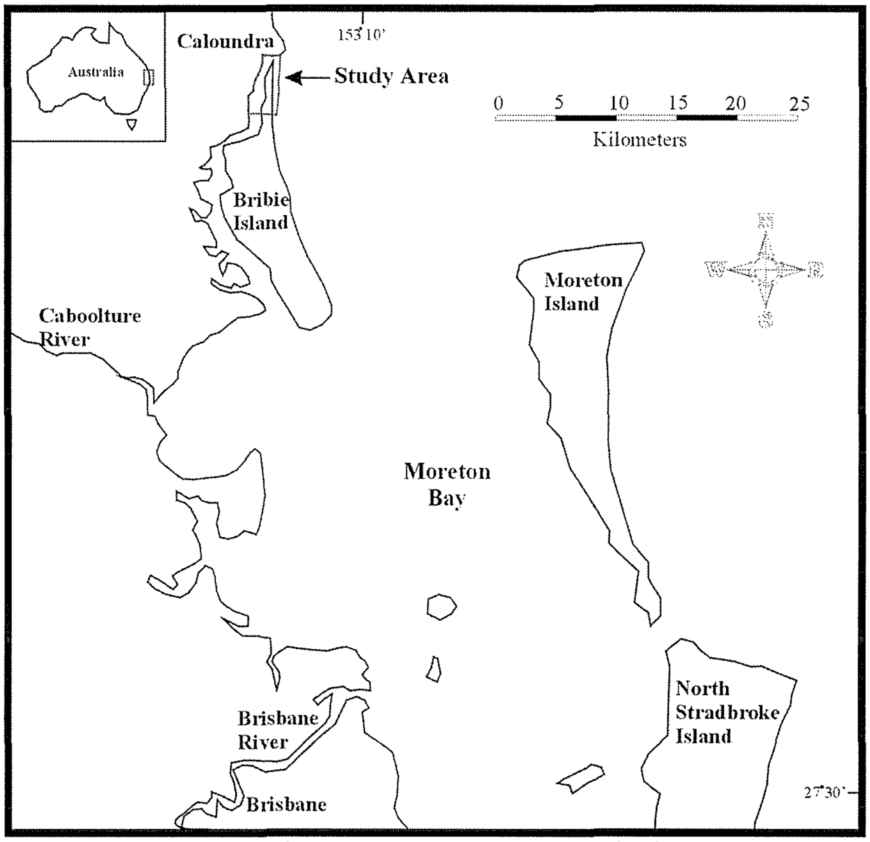


Figure 8. Location of study area, at the northern limit of Moreton Bay.

The study area is the spit at the northern end of Bribie Island (Fig. 8). However, the effects of processes occurring in the northern section of Pumicestone Passage, adjacent to the spit, are also examined.

Although Bribie Island is part of Caboolture Shire, the study area is considered to be part of the Caloundra region. Caloundra is located at the southern end of Queensland's Sunshine Coast, which is about 95 km north of Brisbane. The Caloundra region is separated from Bribie Island by Pumicestone Passage. The northern inlet of Pumicestone Passage opens into Caloundra Bar, with the sandspit at the northern end of Bribie Island located on the southern side of Caloundra Bar.

2.1 Aim

The aim of this study is make an assessment of the long-term stability of the north Bribie Island spit and environs based on a synthesis of geologic, geomorphologic, hydrodynamic and climatic data.

2.2 Hypotheses

The stability of the spit at the northern end of Bribie Island appears to be influenced by a number of natural and land-use factors. Three working hypotheses are proposed that will be tested with the results of this study. They are:

1. Geologic and geomorphologic factors in the context of Holocene sea level fluctuations are the major controls on the study area.
2. Anthropogenic activities resulting from increased urbanisation of the coastline are the major influences on the spit's stability.
3. The impact of severe weather events on the spit overrides the effects of urbanisation and geologic and geomorphologic controls.

2.3 Objectives

Several objectives have been proposed in order to make an assessment of the stability of the spit at the northern end of Bribie Island. Those objectives are:

1. To characterise the sediments that comprise the spit and construct a stratigraphic framework for the spit.
2. Preparation of maps and cross sections of the spit showing contemporary shoreline processes, geomorphology and vegetation.
3. A description of contemporary hydrodynamics of sediment transportation in Pumicestone Passage and the nearshore zone adjacent to Bribie Island spit.
4. To establish an evolutionary model of Bribie Island spit and identify areas of the spit most at risk of ocean breakthrough.
5. The development of a sediment budget for the study area.
6. Investigate climatic data that may provide insights into changes that have occurred on the spit during the period covered by the data.
7. Development of specific recommendations in relation to the stability of the north Bribie Island spit based on the outcomes of this study. Both the local and global significance of the outcomes of this study will be considered.

2.4 Significance

The outcomes of this study will be beneficial in three ways:

1. A greater understanding will be gained of the factors that influence the dynamic character of the spit.
2. This study will provide important geomorphic information that can contribute to an effective coastal management plan for the study area.

3. The approach, methods, and design of this study may also be applied to other coastal erosion problems in similar settings.

2.5 Previous Work

A number of studies have been conducted in the Moreton Bay – Pumicestone Passage region in recent years that are of relevance to a study of the geology and geomorphology of the northern end of Bribie Island. However, no studies have provided a detailed assessment of the stratigraphy or stability of the spit.

2.6 Physical Setting

The study area is situated adjacent to the urbanised coastal region of Caloundra (Fig. 9). The present population of the Caloundra region is 70 000 people, increasing from just 10 327 people in 1971. The projected population of the area is 123 000 by 2010, highlighting the rapid rate of population increase in the region, which is part of the fastest growing population centre of Australia (Skinner et al., 1998).

The Caloundra region is a diverse section of coast consisting of long sandy beaches, a large tidal inlet and estuary, numerous tributary creeks, and a large bedrock headland. The coastline has a different character north and south of the bedrock promontory at Caloundra Head, due to differing exposure to wave and tidal influences (Jones, 1992).

Additionally, humic sandrock crops out in the nearshore zone off Bribie Island, near Caloundra Head (Fig. 9). These sandrock exposures are believed to be of Pleistocene age (A. Stephens pers. comm., 2000) but no radiometric ages have been published. The offshore sand banks of Hamilton Patches and North Banks, and the North West Channel (Fig. 9), separating Hamilton Patches and Bribie Island, give the region a complex submarine topography (Fig. 10) and geological setting.

Bribie Island is one of three large sand islands in Moreton Bay, and consists predominantly of a succession of beach ridges. Bribie Island is relatively flat with a mean elevation of 5 m and a maximum elevation of 17 m above sea level, while the other two islands, Moreton Island and North Stradbroke Island, contain massive dune systems up to 200 m above sea level (Harbison and Cox, 1998). These sedimentary features indicate that a different depositional regime occurs on Bribie Island compared to the larger sand islands.

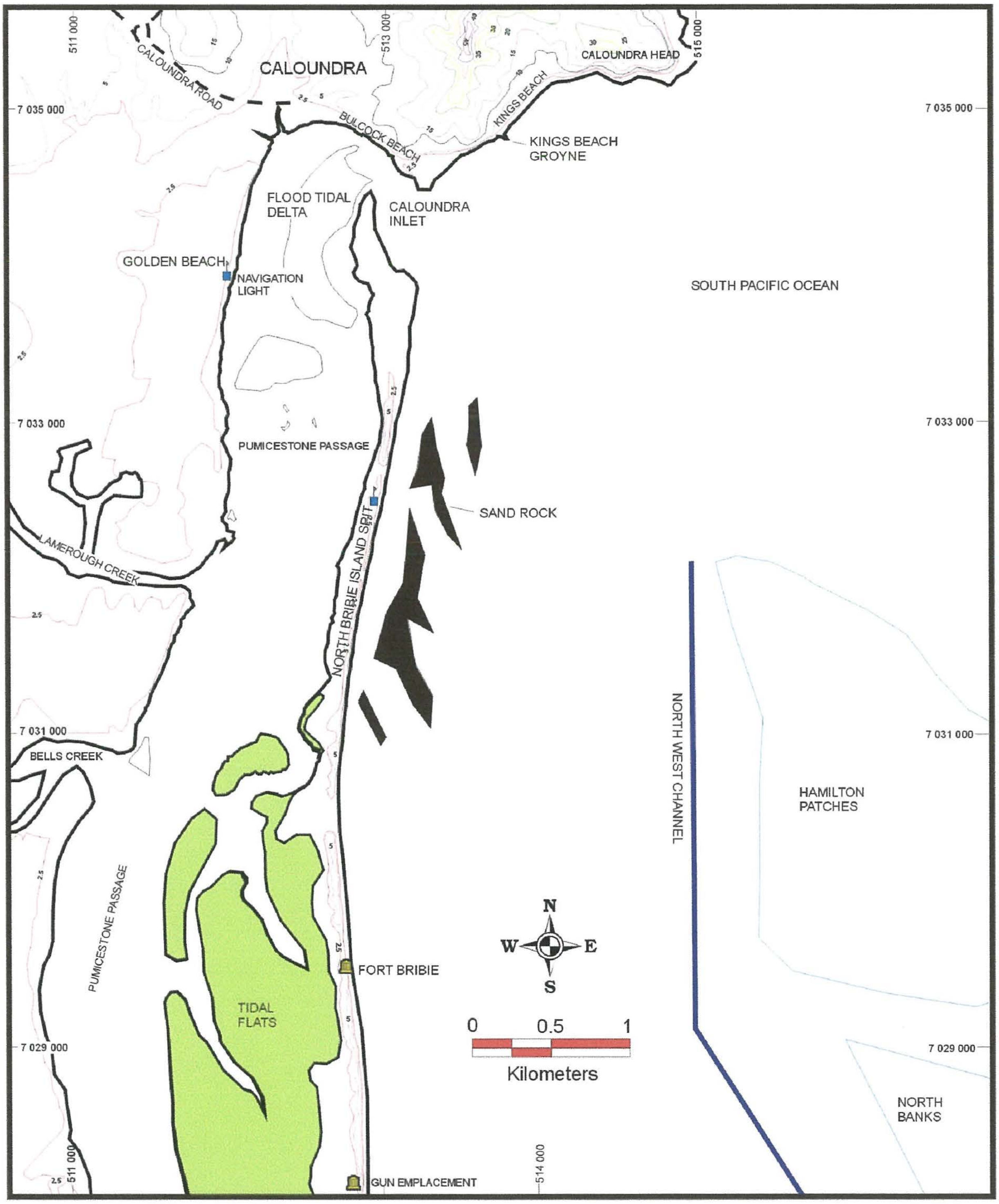


Figure 9. Physical setting of the study area.

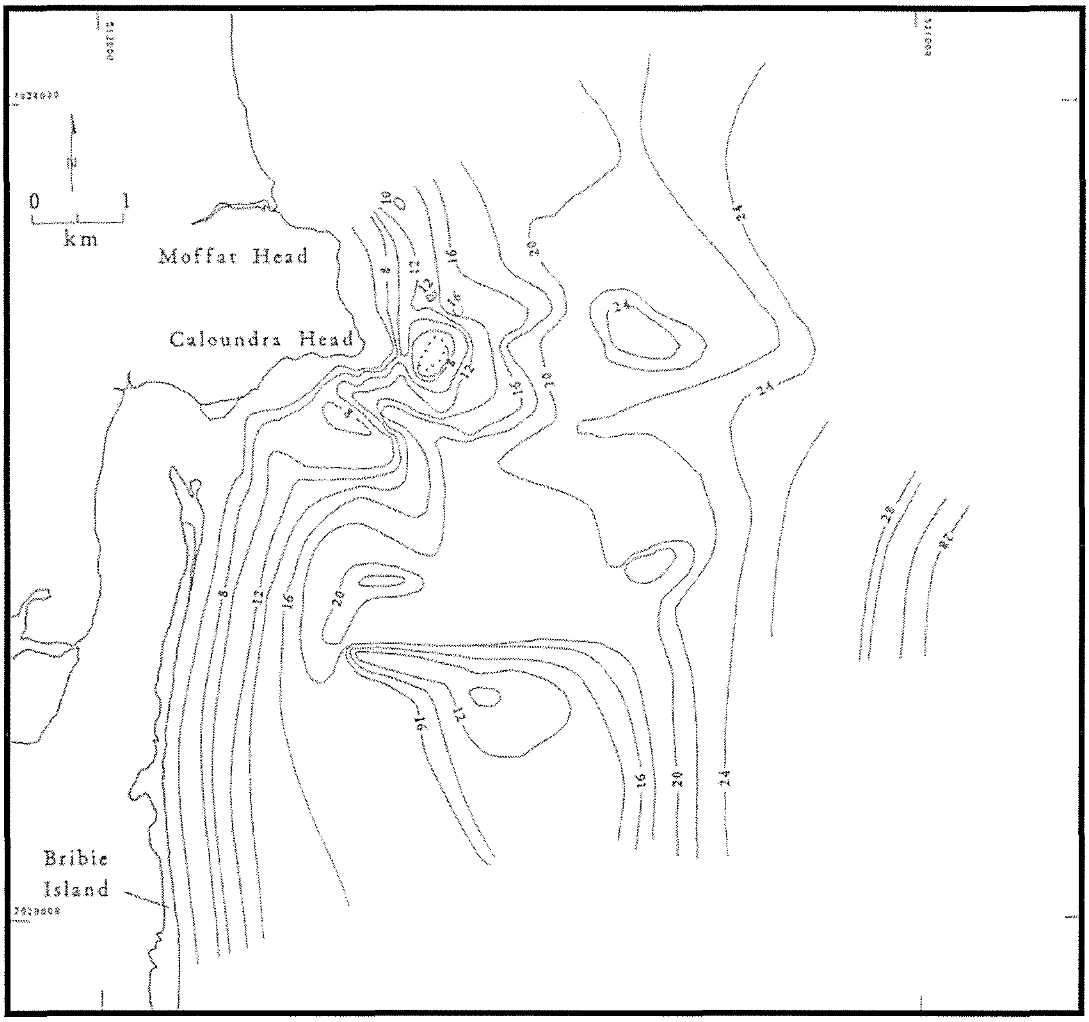


Figure 10. Bathymetry offshore from north Bribie Island and Caloundra Head (after Jones, 1992).

Bribie Island consists of an extensive strandplain of prograded Holocene and Pleistocene beach ridges separated from the mainland by Pumicestone Passage (Lang et al. 1998). Therefore the island can be classified as a barrier island that protects the mainland from the ocean.

The study area consists of estuarine and tidal delta deposits, foredune ridges, and low sand dunes (Hekel and Day, 1976; Ward et al., 1977), comprising predominantly quartz sand. Beach ridges on the island reach a maximum elevation of 5-6 m.

At Caloundra Head, bedrock outcrops of Jurassic Landsborough Sandstone occur extensively along the shoreline and in the nearshore zone (Jones, 1992). Additionally, the underlying basement of Bribie Island and the adjacent mainland coastal plain is Landsborough Sandstone, which is predominantly fine-grained quartzose sandstone, containing shale beds and underlain by conglomerate (Harbison, 1998). Seismic profiles off Caloundra Head and Kings Beach have indicated that bedrock outcrops occur extensively in the nearshore zone and continue seawards at a shallow depth below the unconsolidated seafloor. Offshore sediments comprise undifferentiated Pleistocene deposits, transgressive nearshore deposits, and nearshore and tidal delta deposits emplaced during the Holocene stillstand (Jones, 1992).

South of Caloundra Head, the tidal inlet, spit and eastern shore of Bribie Island form the open coast. The shoreline is gently embayed, and oriented roughly NNW – SSE. Offshore from Bribie Island, in the northern entrance to Moreton Bay, lies a large mass of sand banks termed the North Banks (Fig. 11). The well-defined North West Channel of 11 – 19 m depth separates the North Banks from Bribie Island. The North West Channel is a naturally formed channel and is periodically dredged in isolated areas in order to maintain a channel depth of at least 11.9 metres (Rail, Ports and Aviation Division pers. comm., 2000).

Further south, the northern entrance to Moreton Bay lies between the southern tip of Bribie Island and Moreton Island. The northern entrance to Moreton Bay is a large tidal delta with a dynamic environment of both ebb and flood dominated channels (Fig. 11; Stephens, 1978).

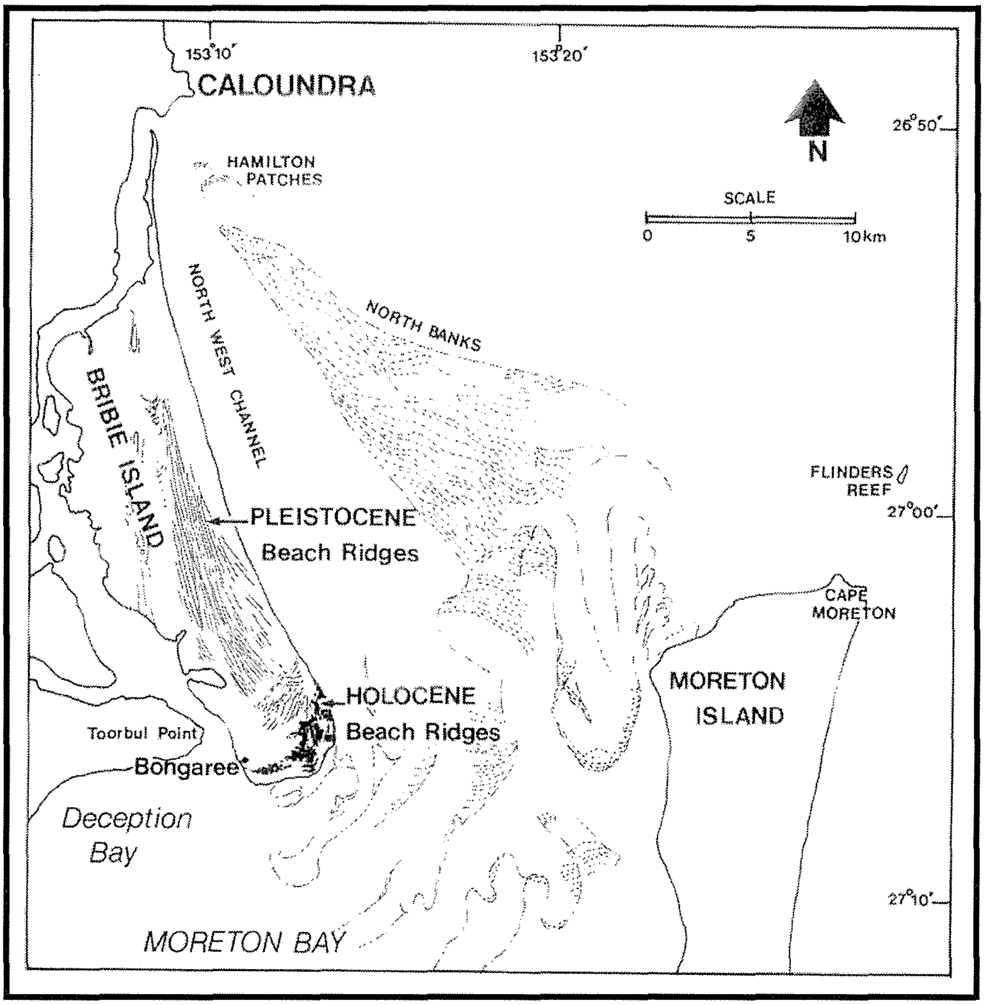


Figure 11. Location of offshore features from Bribie Island. Beach ridges on the island and sandbanks are marked (after Stephens, 1978).

Along the Bribie Island shoreline, both wave and tidal currents are active, with tides becoming more dominant to the south, as protection from Moreton Island increases (Stephens et al., 1983). The eastern side of Bribie Island spit is exposed to wave and tidal influences from the South Pacific Ocean, while the western side, adjacent to Pumicestone Passage, is tidally dominated.

Pumicestone Passage represents a mesotidal, elongate back-barrier lagoon estuary, and has a tidal inlet at both the north and south end (Lang et al., 1998). Two main tributaries, Bells Creek and Lamerough Creek flow into the northern section of Pumicestone Passage. The north end of Pumicestone Passages opens into a tide delta complex forming Caloundra Bar.

The popular tourist beaches, Golden Beach and Bulcock Beach lie on the mainland side of the northern end of Pumicestone Passage. Besides attracting many tourists during holiday seasons, these two areas also have many permanent residents. A new housing estate being built along the Golden Beach area of Lamerough Creek will significantly add to the residential population.

Erosion of the foreshores of Golden Beach has resulted in the implementation of a beach nourishment program. In 1991 approximately 40 000 m^3 of sand was dredged from the northern end of Pumicestone Passage. In 1999 approximately 20 000 m^3 of sand was dredged by a similar process in response to further erosion (D. Shaw pers. comm., 2000).

2.7 Influence of Late Quaternary Sea Level Changes on the Caloundra-Moreton Bay Region

The coastline of the Caloundra region consists of landforms that developed during the Late Quaternary period. Sea level fluctuations are considered to be the major influence on coastal evolution during this period.

During the Last Interglacial (~140 000-120 000 yBP), sea level was a few meters higher than present (Fig. 6) and large quantities of sand moved along and onto the shore forming coastal sand barriers (Galloway, 1978). Since the Last Interglacial highstand there have been several episodes of sea level rise and fall, but sea level has remained at least approximately 20 m below the present sea level until the end of the Last Glacial (Evans et al., 1992).

Unconsolidated Pleistocene deposits represent the oldest units on Bribie Island, and occur as stranded dunes, beaches, and tidal deltas (Jones, 1992). Those deposits accumulated between 140 000 and 120 000 yBP, during the Last Interglacial highstand (Armstrong, 1990) when sea level was approximately 4-6 m higher than present (Marshal and Thom, 1976).

At about 18 000 yBP sea level had fallen between 120 m and 130 m below its present level and the shoreline had migrated east of Moreton Island (Stephens, 1992; Fig. 12A). Sediment supplied to the shelf by the Brisbane River during this time could have been transported by waves to nearby beaches. Some sand was probably also supplied to the shore as littoral drift from other river deltas on the continental shelf further to the south (Jones, 1992).

From 18 000 to 6 500 yBP, sea level rose rapidly to its present position, and possibly 1-1.5 m higher. The coastline of southeast Queensland retreated to slightly landward of its present position and the deepest parts of the coastal valleys were incised (Fig. 12B), transforming fluvial environments into marine depositional environments (Evans et al., 1992).

Sea level has remained relatively stable or has fallen slightly by approximately 1.5 m since about 6,500 years ago (Lang et al., 1998). Additionally, radiocarbon ages of estuarine shells collected from older, abandoned tidal flats and beach ridges that are located above the present sea level, from the coastal plains of Deception Bay were reported by Flood (1981). From the position of the radiocarbon dated shells, Flood (1981) determined that sea level had reached its present position approximately 5,790 years ago; it was 0.7 m higher than present approximately 4,685 years ago, and 0.4 m higher approximately 3,330 years ago. A major phase of shoreline progradation sometime during the past 3,330 years was apparently accompanied by a sea level fall to slightly below its present level (Flood, 1981).

Woodroffe and Grindrod (1991) have noted that sea level change and the consequent change in the extent of intertidal habitat has been a major control on the distribution of mangrove forests, and perhaps other intertidal communities. Those impacts of sea level change have been reported to the south of the study area, where mangroves (*Avicennia*) were found to have invaded a salt pan and supra-tidal algal flat areas as well as a Melaleuca swamp on the coastal plains of Deception Bay (Flood, 1981). It is interpreted by Flood (1981) that the rapid expansion of the area covered by mangrove vegetation is related to a slight rise in sea level in the order of 1 mm per year during this century, particularly during the past 40 years, in the Deception Bay area. That apparent rise appears to have resulted in the relocation of the junction between various intertidal ecological zones to approximately 50 m inland from their previous position (Flood, 1981).

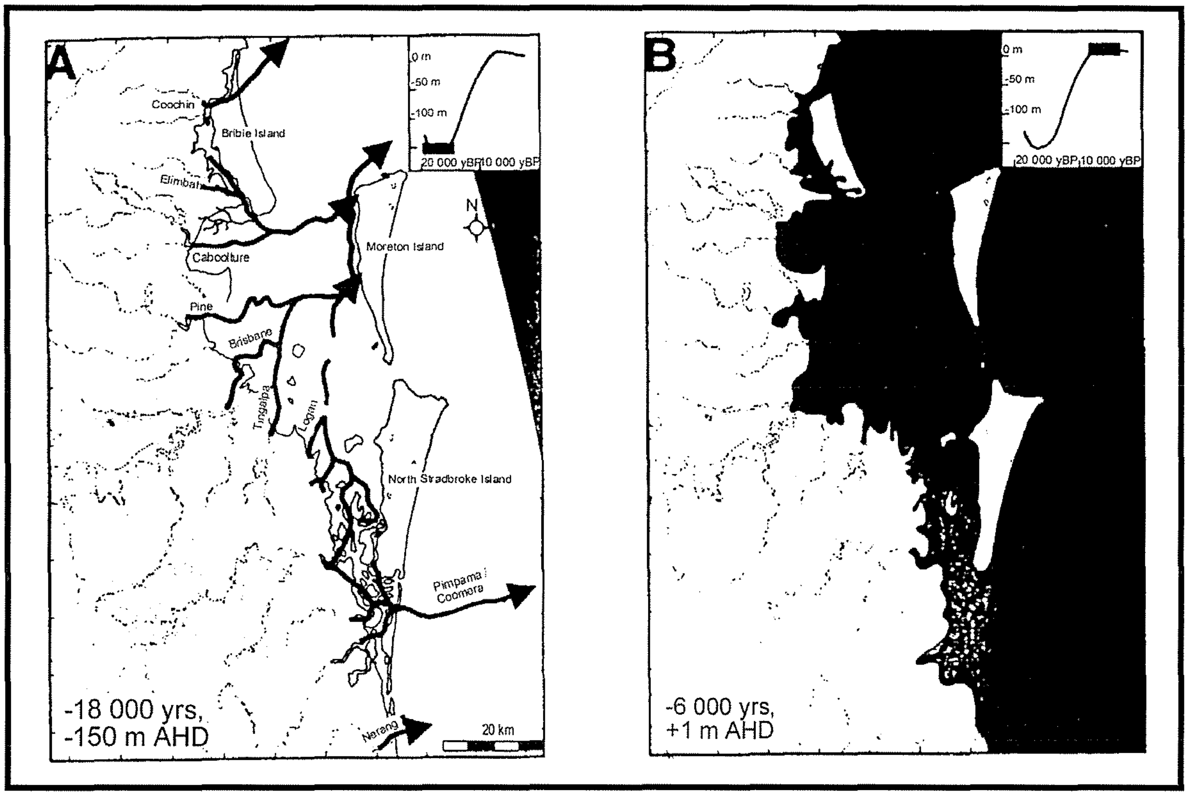


Figure 12. Paleogeography of Moreton Bay. **A**: Late lowstand, 18 000 yBP, showing incised valleys traversing Moreton Bay towards the Paleoshoreline well to the east of North Stradbroke and Moreton Islands. **B**: Beginning of sea level highstand / stillstand, 6 000 yBP. Note the drowning of river valleys forming extensive estuaries, a generally broader Moreton Bay, and the lack of a sand spit attached to the northern end of Bribie Island (after Lang et al., 1998).

2.8 Modern Day Climate and Marine Processes

The climate of the Caloundra region is moderate subtropical (CCC, 2000), with relatively warm and temperate conditions. During summer, from November to April, humid conditions are created by moist tropical air flowing south from the South Pacific region. During winter, from May to October, dry and cool air flows in from the southwest. Conditions during winter are relatively stable. Caloundra experiences average summer and winter temperatures of 28 and 22°C respectively, with an average annual rainfall of 1700 mm (CCC, 2000).

2.8.1 Wind Influences

During the summer months from November to April, moist, unstable air flows in from the Pacific Ocean causing predominantly onshore winds in the Moreton Bay region. During winter months from May to October, dry southwesterly offshore winds predominate (Musk, 1998).

Additionally, periodic storms such as tropical cyclones may induce strong, onshore winds, with the potential to transport sediment and create storm surges. These events usually occur during the summer months, however, 'east coast lows' can have a similar effect during winter months. For example, the east coast low impacting the coast in April 2000 created 40-50 knot onshore winds at Cape Moreton.

2.8.2 Cyclones and East Coast Lows

Thom (1974) has noted that weather generated forces are chiefly responsible for the erosion of sandy coastlines in eastern Australia. Tropical cyclones that move south (Fig. 13), or intense low-pressure systems that develop at mid latitudes result in maximum wave heights along the east coast. Cyclones have an irregular incidence and form during late summer to autumn. 'East coast lows' develop near the coast between southern Queensland and Tasmania (Fig. 14), mainly between autumn and spring, and can often match tropical cyclones in strength and destructive power.

These major storm events may influence the coast by:

1. causing the longshore transport of large amounts of sediment;
2. overtopping the frontal dune and transporting sediment inland, sometimes resulting in the landward migration of barrier spits; or
3. causing the breakthrough of spits and the formation of new river and creek mouths.

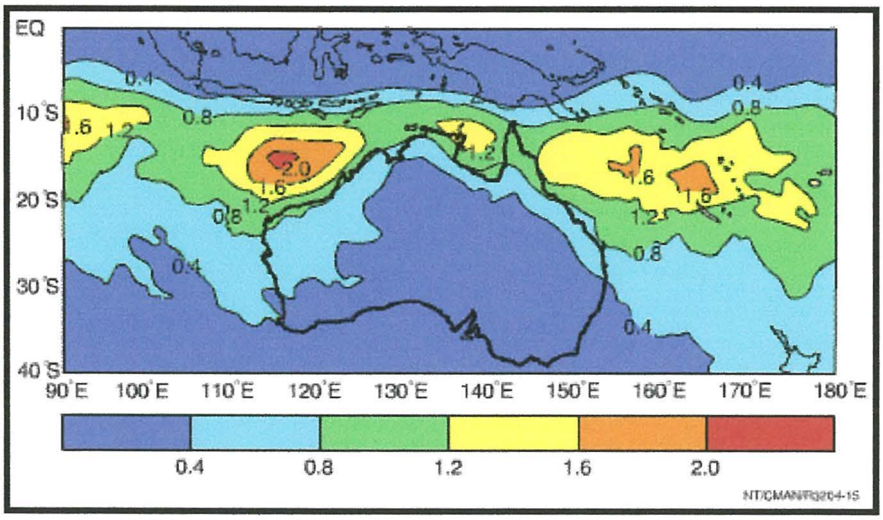


Figure 13. Average annual tropical cyclone frequency for Australia (Bureau of Meteorology, 2000). The study area is affected by approximately 0.4 to 0.8 cyclones per year on average.

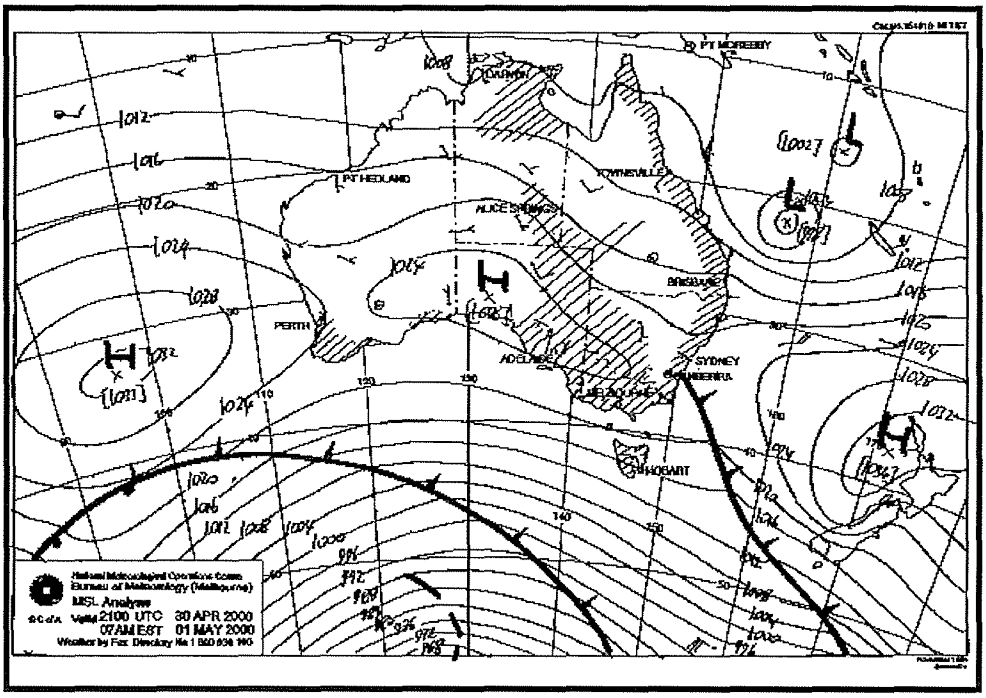


Figure 14. Synoptic chart showing an 'east coast low' off the southeast Queensland coast in April 2000. This low-pressure system generated 9.7 m high storm waves and 40 knot winds resulting in extensive erosion on southeast Queensland beaches.

2.8.3 Effects of Southern Oscillation on Climate Variations

When considering meteorological events, their controlling factors should also be considered. One particular control on meteorological patterns is variation in atmospheric circulation over the South Pacific Ocean, measured in terms of Southern Oscillation Index (SOI). The Southern Oscillation Index relates to a difference in atmospheric pressure measured in Tahiti and Darwin defining an overall set of atmospheric conditions across the Pacific region (Williams et al., 1998). Southern Oscillation is the variation in these atmospheric conditions between the two extremes of El Niño and La Niña conditions. La Niña episodes (Fig. 15A) are associated with stronger easterly trade winds and warmer sea surface temperatures. The warm surface waters create warm moist air above them, which rises and yields low pressures and storms on the western side of the Pacific region (Stowe, 1996). La Niña episodes are represented by positive values of SOI. In contrast, El Niño episodes are represented by negative values of SOI. El Niño cycles (Fig. 15B) are essentially the opposite of La Niña cycles, and are usually associated with weaker trade winds and warming of the eastern side of the Pacific region. In this case the warm, moist, rising air generates low pressures and storms on the eastern side, rather than the west (Stowe, 1996).

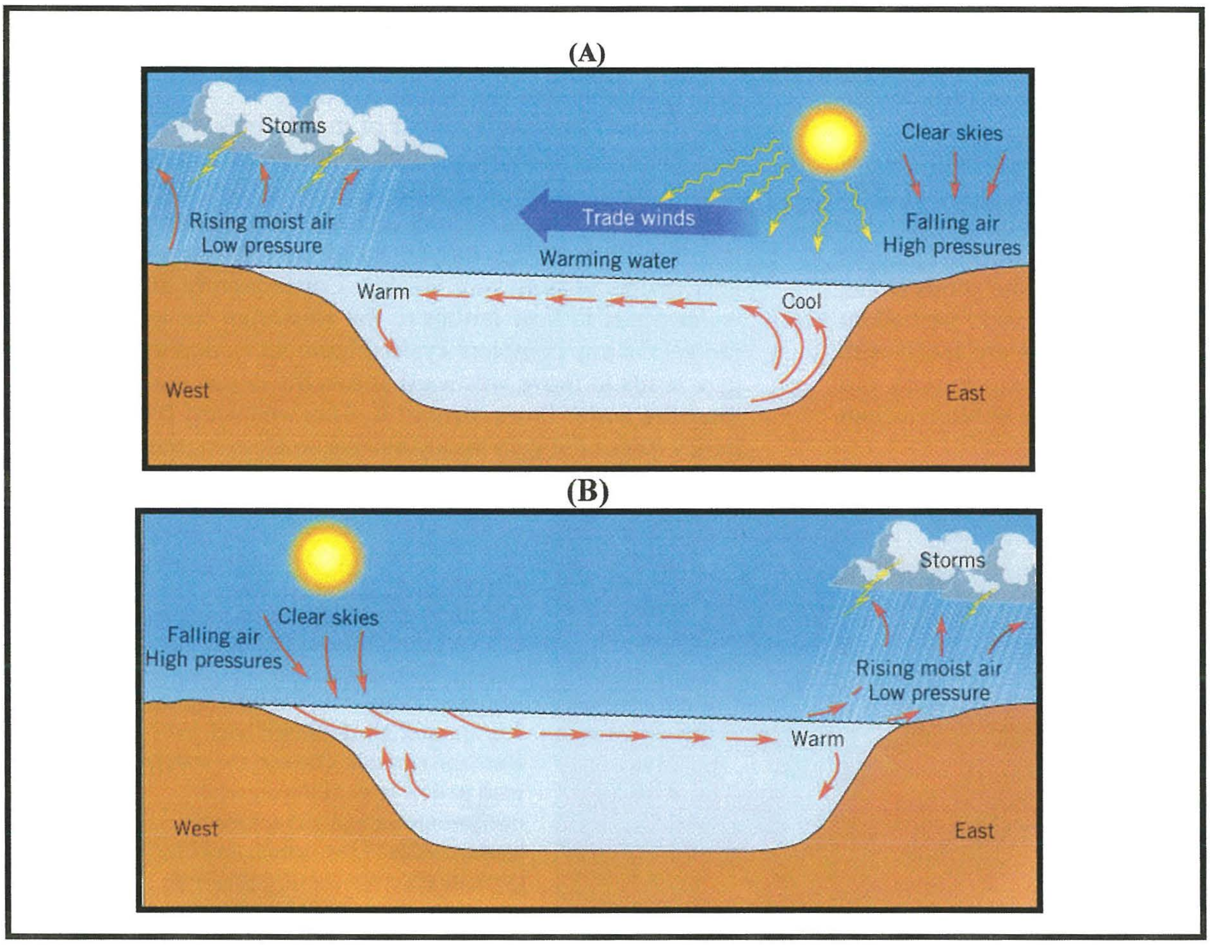


Figure 15. Schematic representation of meteorological processes occurring during a La Niña cycle (A) and an El Niño cycle (B) (after, Stowe, 1996).

Studies by Phinn and Hastings (1992, 1995) have investigated Southern Oscillation influences on the summer wave climate of the Gold Coast (approximately 150 km south of the study area) between 1972 and 1989. It was found that during summers over which El Niño conditions prevailed, cyclone activity is displaced eastward and away from the principle wave generating area for eastern Australia (Fig. 16A) thereby decreasing the average deepwater wave power impacting on Gold Coast beaches. Conversely, under La Niña conditions, cyclone activity is concentrated in the vicinity of the eastern Australian wave generation area (Fig. 16B; Phinn and Hastings, 1995). The closer proximity of cyclone activity during La Niña conditions has caused increased average deepwater wave power impacting on Gold Coast beaches compared to El Niño conditions (Phinn and Hastings, 1995).

Additionally, studies have also associated Southern Oscillation cycles with temporarily raised sea levels caused by expansion of water due to warmer sea surface temperatures and lower air pressures. Bryant (1983) has associated a positive SOI (La Niña) with a temporary slight rise in sea level on the south coast of New South Wales. Although it has also been observed that beach recession has followed periods of both positive and negative SOI (Bryant, 1983).

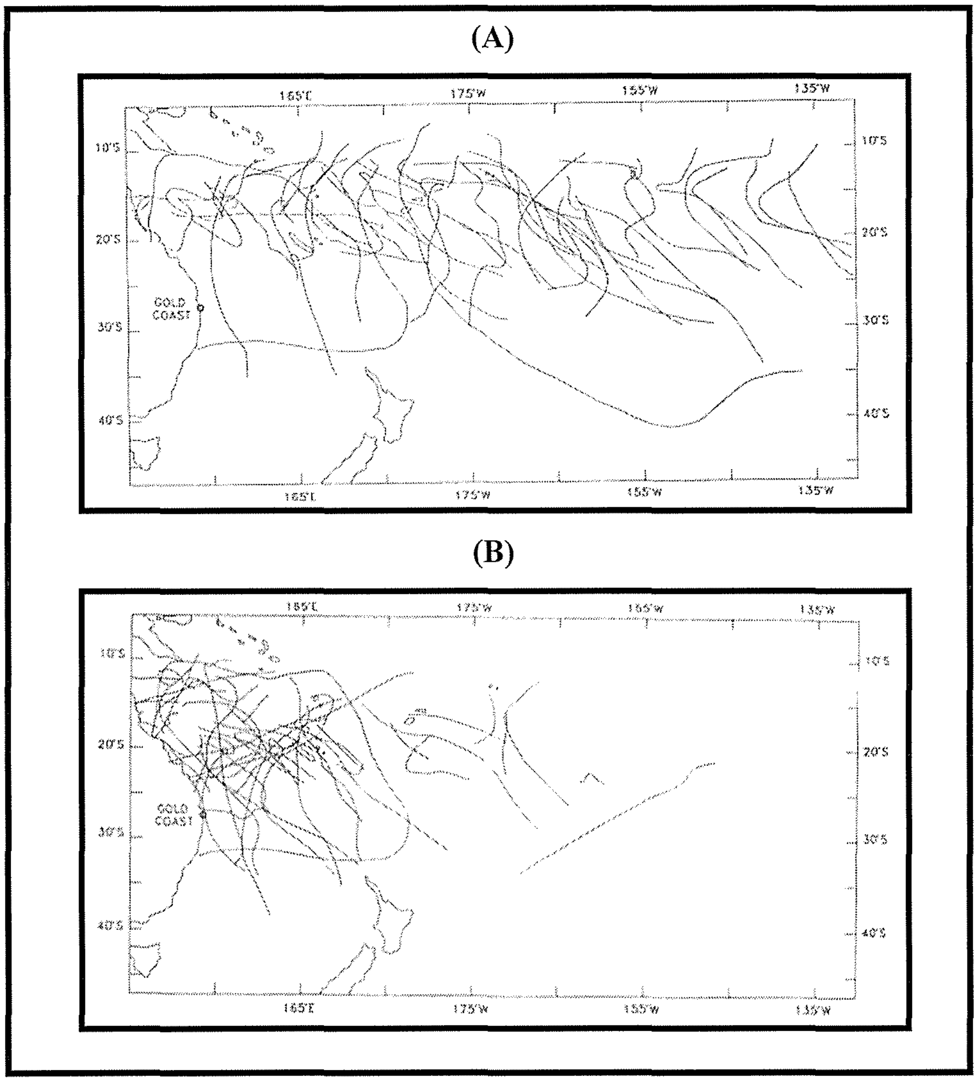


Figure 16. Cyclone activity in the vicinity of the eastern Australian wave generation area under (A) El Niño conditions and (B) La Niña conditions (after Phinn and Hastings, 1995).

2.8.4 Waves

Wave action is the predominant factor in sedimentation processes along many coasts (Silvester 1959, 1970). On the Australian East Coast periodic storm waves generated from a variety of weather systems are superimposed upon a persistent background swell from the southeast (Thom et al., 1973). Moreton Island protects the southern part of Bribie Island from the prevailing south-easterly ocean swells, while the northern section is less protected. Northerly swells may also affect the eastern shoreline of Bribie Island.

The wave climate for the Caloundra region is provided by nearby Waverider buoys moored off North West Banks and North Stradbroke Island. These data indicate that south of Caloundra, much of the wave energy is dissipated on the offshore banks before reaching Bribie Island (Jones, 1992), as shoaling on these banks leads to a reduction in wave energy. A monitoring buoy stationed on North West Banks (Fig. 11), north of Moreton Island has measured an average wave height of between 0.8 and 1 m AHD (Beach Protection Authority, 1988), which is equivalent to the average wave height at the Bribie Island spit. Additionally, measurements of breaking wave heights at Kings Beach between 1973 and 1988 have reported that this average wave height occurs 65-75% of the time (Fig.17; Beach Protection Authority, 1988).

The predominance of southeasterly trade winds and swell waves along the southeast Queensland coast gives rise to net northerly directed littoral drift (Lockhart et al., 1998). However, in the Caloundra region, Caloundra Head lies at a littoral drift divide, with slow southward transport on the southern side of the headland, and slow northward transport on the northern side (Fig. 18; Jones, 1992). However, ocean swells generated from the north may induce a littoral drift anomaly at times, creating northward transport on the southern side of the headland caused by a variation in wave height due to wave refraction (Fig. 19; Flood, 1991).

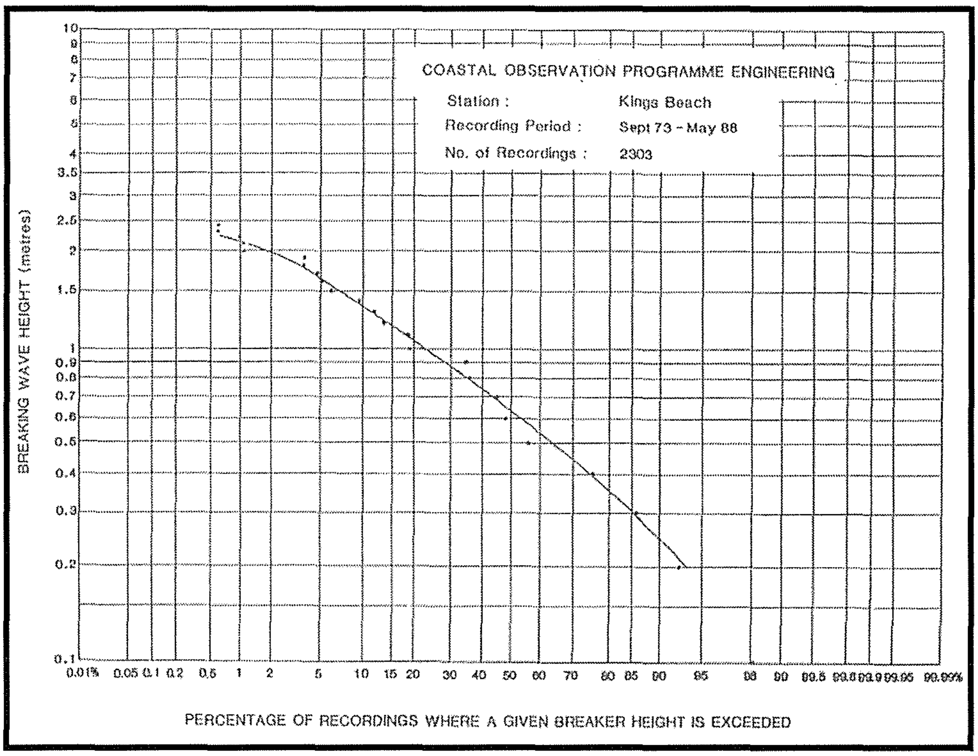


Figure 17. Breaking wave height data from Kings Beach, Caloundra.

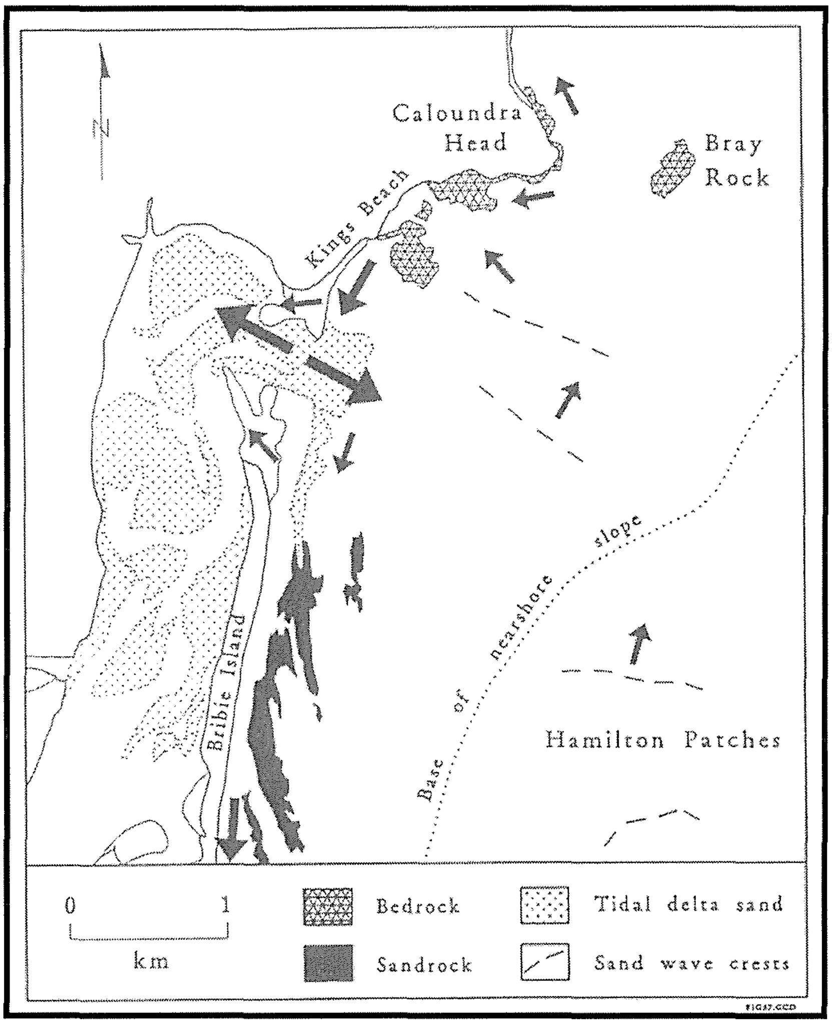


Figure 18. Sediment transport pathways for the Caloundra – Bribie Island region (after Jones, 1992).

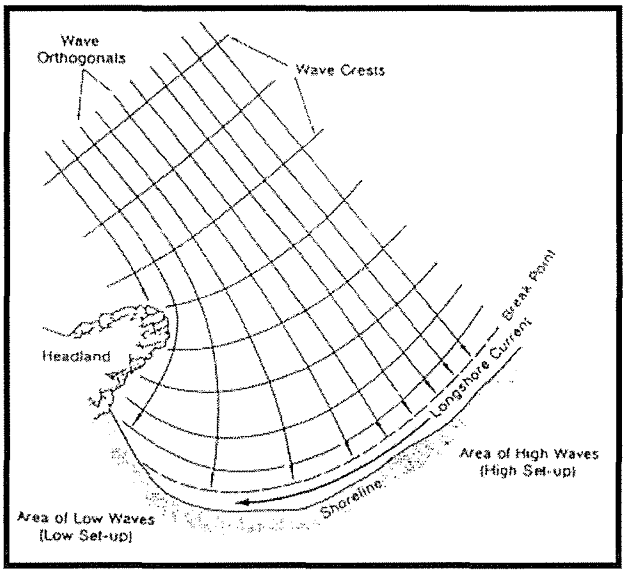


Figure 19. An example of a longshore current generated by a variation in wave height along a coast due to wave refraction around a headland (after Flood, 1991).

2.8.5 Tidal Influences

Tidal transport is important in the tidal inlet at Caloundra Bar due to sheltering of waves by the spit (Jones, 1992). Additionally, Jones has noted that tides are important agents of sediment transportation along the channel separating Bribie Island and Hamilton Patches (Jones, 1992). This is due to substantial sheltering of this stretch of the coastline from waves by the North Banks and Hamilton Patches (Jones, 1992). Moreton Island, located to the east of Bribie Island, also provides a degree of sheltering from waves.

A time difference in tides of 1 hour between Woorim and Caloundra Head reflects the closer proximity of the northern end of Bribie Island to the open ocean (Harbison, 1998), at the northern limit of the Moreton Bay area. Semi-diurnal tides have been observed in the region (Musk, 1998). With a maximum tidal range of 2.34 m (L.A.T – H.A.T) at Caloundra Head, the study area is subjected to meso-tidal conditions. Tidal information for Caloundra is presented below where the datum is Low Water Datum.

Table 2. Tidal information for Caloundra (BPA, 1988).

H.A.T.	2.04 metres
M.H.W.S.	1.60 metres
M.H.W.N.	1.30 metres
M.S.L.	0.90 metres
M.L.W.N.	0.50 metres
M.L.W.S.	0.20 metres
L.A.T.	-0.30 metres

Given a maximum tidal range of 2.34 m and an average wave height of 1 m, the Bribie Island spit is subject to a mixed energy regime (Fig. 5), and may fluctuate between tide dominated and wave dominated depending on seasonal influences.

2.8.6 North Entrance Tidal Delta

The Northern Entrance tidal delta is located between Bribie Island and Moreton Island at the northern end of Moreton Bay (Fig. 11). The Northern Entrance tidal delta system is dominated by currents generated by a mesotidal range, with little influence by waves. Approximately eighty-five percent of the volume of water entering Moreton Bay on each flood tide enters via the northern entrance (BR & MBWMS, 1997).

Tidal flows at Woorim, southern Bribie Island, were measured by a Department of Harbours & Marine current meter moored in 3-4 m of water from late 1988 to 1989, and the data have been analysed by Jones (1992). It was found that the area is flood tide dominated, with peak current velocities during spring tides reaching in excess of 0.5 m/s at a height of 0.3-0.4 m above the bed. The direction of flow is shore parallel at about 160° magnetic southwards along the eastern Bribie shore (Jones, 1992).

Such a large tidal flow probably affects shoreline processes in the Bribie-Caloundra region due to the close proximity of Bribie Island to the North Entrance Tidal Delta, and may contribute to southward littoral drift along the Bribie shoreline under fair-weather conditions when the effects of waves is small.

2.8.7 Storm surges

A storm surge is a raised dome of seawater, typically 60-80 km across and 2-5 m above normal sea level. A storm surge is meteorological in origin and can be induced by the passage of a low atmospheric pressure system or by strong winds piling water against the coast (Komar, 1998). Tropical cyclones and 'east coast lows' are the main causes of storm surges in southeast Queensland, where their associated high winds, storm waves and surge can severely impact on low-lying coastal areas.

A storm surge may add to the normal tide causing an extra high tide to occur. Storm surges can be very destructive with the potential to cause radical retreat of the coastline. Large waves superimposed on a storm surge that occurs at the same time as a high tide can have dire effects on a coastline (Komar, 1998).

More intense and faster moving cyclones or 'east coast lows' lead to higher winds and greater storm surges. The impact of the storm surge depends on the normal tide and the water dome's height. If the cyclone crosses the coast at right angles, there will be a greater storm surge. Bays, headlands or islands can funnel the surge, increasing the water height and flow velocity as it passes into a semi-confined space (Qld Dept. Env. & Her., 2000).

2.8.8 Coastal Erosion

The shape of the present coastline is a reflection of the dynamic relationship between the ocean and the land (Batianoff and Elsol, 1989). The coastline incorporates a number of natural defences against the erosional impact of waves. Those defences include the offshore seabed, sandbars, headlands and dunes, which act as energy dissipaters.

Coastal erosion has been described by Thom (1974) as a basic geological process associated with changes in sea level, sediment supply and wave climate, and involves the recession of the shoreline, destruction of vegetated dunes flanking beaches, with or without beach retreat. Littoral and tidal currents, storm surges and winds acting on exposed surfaces also result in coastline changes.

Severe storm events such as cyclones and east coast lows create the hazards of large waves and storm surges in addition to strong winds and torrential rain (Flood, 1991). Of these hazards, the extent of erosion during major storm events is strongly dependent on the storm tide levels at the time of greatest wave attack (Flood, 1991).

Additionally, the increasing interest in coastal environments for housing and tourist developments, as well as industrial development, agriculture, sand mining and recreation results in modification of the shoreline which often reduces the coast's natural defences to erosion and increases the socio-economic impact of major storm events (Neil, 1998).

2.8.9 Vegetation

Vegetation studies on the Sunshine Coast show the major vegetation communities on Bribie Island are: *Banksia* woodlands, *Melaleuca* woodlands, *Eucalyptus*, Swamp Box, *Acacia*, *Callitiris*, *Casuarina*, creepers, and mangroves (predominantly *Avicennia marina*). The distribution of vegetation types in the pristine areas of Bribie Island is related to soil water availability, soil nutrient status, salinity and waterlogging tolerance, and landform age Harbison and Cox, 1998).

On sediments of apparent Pleistocene age, low *Banksia* woodlands dominate beach ridges while open *Melaleuca* woodland and open heathland dominate in swales. On Holocene beach ridges, *Acacia*, *Callitris*, and *Eucalyptus* forest is dominant (Harbison and Cox, 1998). Holocene coastal foredunes sustain salt-tolerant *Allocasuarina littorallis* (Harbison and Cox, 1998). Since the 1950's large areas of Bribie Island have been cleared for pine plantations.

2.9 Human Impacts on the Coast

Over 83 percent of the Australian population lives near the coast, with all of its major cities located on the coast (Komar, 1998). Urban development of the coast often interferes with the natural variability of the coastline in that once a house or road is built, human reaction is to maintain the property in the face of natural processes of shoreline erosion (Komar, 1998). Carter and Woodroffe (1994) have described two types of human activity that have adversely affected coastlines, firstly exploitation, and secondly, by trying to control natural processes and thus change. The history of coastal evolution is linked with the evolution of coastal catchments and drainage basins, and their ability to deliver sediment to the shoreline (Carter and Woodroffe, 1994). Exploitive activity such as the construction of dams and weirs, as well as dredging of sediment source areas may seriously restrict an external sediment supply to the coast. In addition, removal of coastal sediments from the coastline for commercial resources such as mining and construction may serve to unbalance natural coastal processes creating wide ranging impacts, while recreational activities such as four-wheel-driving on dunes and beaches may have a localised impact.

In order to protect our urban infrastructure, coastal management plans are designed to limit or prevent construction in areas at risk of erosion. However, much development of coastlines has occurred prior to comprehensive management plans being implemented, creating the need for protection of these areas from further erosion and restoration of the beach where possible.

Beach nourishment and stabilisation structures have been offered as solutions to limit or prevent erosion, however, their implementation often serves to unbalance the natural coastal processes operating in an area, creating further problems elsewhere. This has occurred recently on the Gold Coast beaches following stabilisation of the Tweed River mouth, south of the Gold Coast, by rock groynes. The extension of the rock groynes interrupted sand supply to the northern beaches by the natural flow of northward littoral drift. In an attempt to regain the sediment supply to the Gold Coast, sand that had built up on the southern side of the river mouth was pumped across the river to replenish the littoral drift supply moving north along the Gold Coast beaches.

2.10 Importance of a Sediment Budget

Evolution of the shore depends on both the balance between input and output of sediment (Fig. 20), and a more complex probabilistic relationship linking storms to sediment transport (Carter and Woodroffe, 1994). The calculation of a sediment budget for a beach system is a useful means of identifying long-term trends and to gain a better understanding of the behaviour of a coastal system (Flood, 1991). A sediment budget attempts to quantify sediment movement into and out of a coastal sediment system. A positive sediment budget, a net increase of sand, would denote beach and dune barrier accretion. In contrast, a negative budget, a net loss of sand, would denote a receding shoreline marked by erosion (Flood, 1991). The identification of inputs and outputs, and measurements of sediment flux are therefore a basic requirement of an assessment of beach systems.

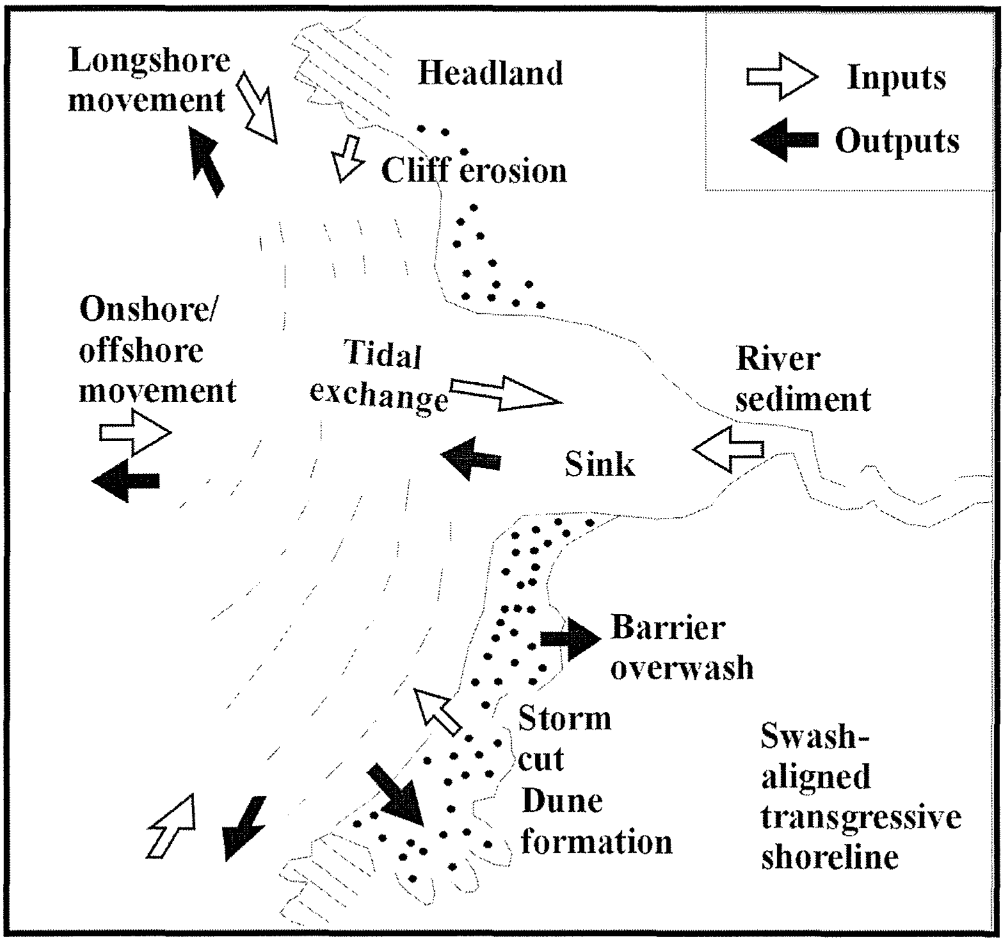


Figure 20. An example of a sediment budget and cell circulation on an estuarine coast. Riverine sediment may be deposited into an estuarine embayment, which may also receive sediment from the seaward direction through tidal processes. Note the swash-aligned barrier that retreats landward through washover or aeolian processes. (After Carter and Woodroffe, 1994).

3.0 METHODS

This chapter provides a summary of the methods employed in this study. Field mapping and sediment sampling are a major aspect of the study, and most detail is given to those methods.

3.1 Fieldwork

Fieldwork in the study area was undertaken between May and September 2000. As previously noted, a large 'east coast low' formed off the Queensland coast in April 2000 just prior to fieldwork commencing. This erosional event resulted in the exposure of many outcrops normally buried below the beach profile, which were surveyed and monitored as part of this study.

In order to fulfil the objectives of the study, a number of field methods were utilised. These included the mapping and monitoring of sites, measurement of cross sections, augering, vibrocoring, vegetation surveys, beach profile surveys, grab sampling, current velocity measurement and bedform mapping.

3.2 Progressive mapping and monitoring of sites

Progressive mapping and monitoring of sites was undertaken on the Bribie Island spit where pronounced erosion occurred as a result of the April storm. The initial round of site mapping occurred on 20 May 2000. Sites were marked on a base map (1994 aerial photograph) with the aid of a GPS. Photographs of the site were taken for time series analysis and profiles were surveyed. Subsequent rounds of mapping and monitoring enabled the sites to be observed for changes in morphology, and therefore sediment movement, over the duration of the study.

Along three cross sections profiles were surveyed and the stratigraphy of the spit examined to enable the qualitative assessment of shoreline processes. The locations of the cross sections were established after initial reconnaissance which identified sites on the spit that were accessible for surveying and provided adequate spatial coverage. Techniques employed were augering, vibrocoring, surveying, and vegetation surveys.

3.3 Augering

Hand augering was undertaken at regularly spaced intervals, or where geomorphology indicated a possible variation in stratigraphy, along the cross section. In total twelve holes were augered throughout the fieldwork period (Figs. 41A, 43A, 44A). The augering equipment consisted of a steel sand auger and 1.5 m extensions. Each hole was logged at 20 cm intervals and samples were collected for grainsize and microscope analysis. A limiting factor of the hand auger was its inability to collect saturated sediments from below the water table.

3.4 Vibrocoring

Vibrocoring was undertaken to enable the recovery of sediment from below the water table of the spit and from the adjacent intertidal zone. The vibrocores aligned with the measured sections and corresponded with gaps in the augering (Figs 41A, 43A, 44A.).

The vibrocoring equipment consisted of a motorised air compressor pump connected to a vibrating head, which in turn was fixed to the top end of a 3 m length of 50 mm aluminium pipe. The weight and bulkiness of the equipment was a limiting factor in its use, thus the sites where coring took place were limited to areas accessible by 4WD on the eastern beach or, by boat on the western side of the spit.

Figure 21. Vibrocoring at section B-B'. Equipment mounted on 4WD for access.

The bottom end of the lengths of aluminium pipe were cut at an angle of 45° in an attempt to gain a better penetration rate. While penetration and recovery through muddy facies was quite successful, the rate of penetration through beach sand was considerably less, and in some cases impossible.

Penetration depths of the cores were noted in the field. Also, the difference between the top of the core material and the ground surface was measured before the cores were extracted to determine compaction and core loss. The cores were split, logged, photographed, and sampled in the laboratory. Each core was wrapped in plastic to prevent drying and half the core was archived and placed in refrigerated storage.

3.5 Vegetation Surveys

The main types of dune vegetation were mapped along each survey cross section. A catalogue of the major dune plant species for this region (Beach Protection Authority, 1981) was used as a key to identify the various types of vegetation. In cases where field identification was not possible, a sample was collected and compared with catalogued dune plant species contained in the Queensland University of Technology Herbarium.

3.6 Beach Profile Surveys

Beach profiles were surveyed on the ocean beach side of each cross section in order to gain an accurate representation of the beach profile, where no current contour data exists. Each profile was surveyed from the low water mark, with levels taken approximately every two metres, up to the base of the dune scarp. A Leico automatic level was used to measure the profile, and the profiles located using a GPS.

Figure 22. Equipment set up for survey of beach profiles.

3.7 Grab sampling

Throughout the fieldwork period, grab samples for grainsize and microscope analysis were collected on the spit, in Pumicestone Passage, and offshore from the spit (Fig. 23). GPS locations were recorded for each sample point, and then entered on a digitised base map in a Geographic Information System (MapInfo). Samples at depth in Pumicestone Passage and offshore were collected with a Van-Veen grab sampler.

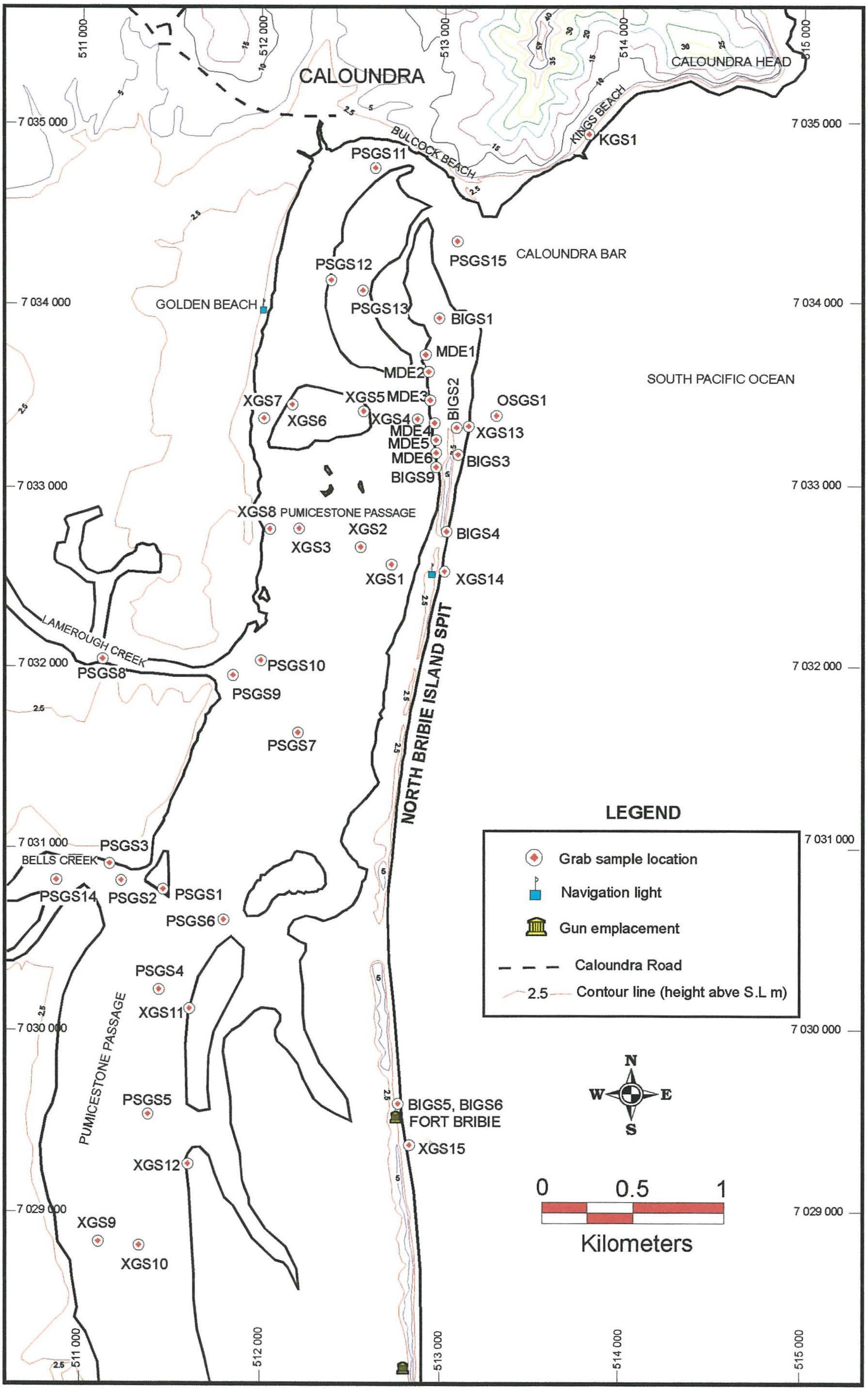


Figure 23. Location of grab samples

3.8 Current Measurement

A number of current measurements were taken throughout the study area on 24 August 2000, coinciding with both rising and falling tides, as a means of gaining insight into the average hydrodynamic forces acting in the area. A Marsh-McBirney portable water flow meter consisting of an electronic sensor attached to the end of a depth staff was used to gather the data.

To assess the maximum currents, initial readings in Pumicestone Passage and Caloundra Bar area were taken approximately one hour before the peak of low tide, and then re-measured approximately one hour before the peak of high tide. Each measurement was taken approximately 0.5 m below the water surface in the main ebb channel. All readings were taken under fair weather conditions.

Current measurements were also taken along the ocean beach side of the spit just behind the breaker zone under fair-weather conditions. One reading was also taken approximately 100 m offshore from the spit area in line with the most northerly cross section. Readings were taken during an incoming tide at approximately 0.5 m below the water surface.

3.9 Bedform Mapping

In order to gain an understanding of the present status of the flood tidal delta and establish possible future trends, bedform mapping of the flood tidal delta attached to Caloundra Bar was conducted on 11 July 2000 coinciding with the low tide period. Both small-scale and large-scale ripples were measured in terms of amplitude, wavelength and direction, with their positions recorded on a base map with the aid of a GPS. The results were plotted on a bedform map and trends analysed with the aid of rose diagrams. Selective grab samples were also taken for grainsize analysis, as a representation of sediments being transported within the flood tide delta.

4.0 Laboratory Work

In conjunction with field methods, laboratory work has also been employed in this study. Laboratory work has included aerial photograph analysis and interpretation, grainsize analysis, microscope analysis, x-ray diffraction analysis, preparation of samples for dating, computerised modelling and analysis of climate data.

4.1 Aerial Photograph Analysis and Interpretation

Interpretation of sequential aerial photographs from 1940 to 1999 was undertaken by digitising the photographs, importing them into a GIS (Mapinfo) and then comparing changes over time using the co-registered digital images.

Time-series aerial photography of the study area was obtained with the aid of Caloundra City Council. Photographs used in this study are listed in Table 3:

Table 3. Aerial photographs used in this study.

DATE	SOURCE
1999	Caloundra City Council
1996	Caloundra City Council
1994	Sun Map
1992	Beach Protection Authority
1982	Beach Protection Authority
1979	Beach Protection Authority
1972	Beach Protection Authority
1971	Beach Protection Authority
1961	Beach Protection Authority
1940	Beach Protection Authority

Photographs from 1940-1992, which were contained in a 1993 Queensland Beach Protection Authority report on the island (BPA, 1993), were deemed most useful for observing changes to the study area over time as they have all been photogrammetrically corrected and reduced to a constant scale of 1:12000. It was found that the older films (1940 and 1961) exhibit poorer resolution than the modern photography (from 1971 to 1992), which have quite good resolution. Accuracies of photogrammetry conducted on the photos from 1940 to 1992 were measured by Queensland Beach Protection Authority (1993) and are shown in Table 4.

Table 4. Estimated accuracies of Beach Protection Authority Photographs (1993).

ESTIMATED ACCURACIES			
Year	Scale	Standard Deviation X/Y (m)	Standard Deviation Z (m)
1992	1:12000	0.2	0.2
1982	1:12000	0.2	0.2
1979	1:12000	0.2	0.2
1972	1:11000	0.3	0.25
1971	1:24000	0.5	0.4
1961	1:12700	2.0	1.5
1940	1:18200	3.0	2.6

As part of its study, the Beach Protection Authority utilised a digital terrain model for each time period to generate a contour surface at a vertical interval of 1 m, with auxiliary contours of 0.5 m where appropriate. In this study, the 0 m contour line digitised on each photograph is a reference for the location of the low water mark.

As there was no 0 m contour mapped on the aerial photographs of 1994, 1996 and 1999, the low water mark was mapped as the water line evident on the photographs. An error of $\pm$ 1 m vertically was used to account for tidal variations. The photographs for 1994, 1996, 1999 have also been orthophoto corrected, and were geographically referenced to permit a comparisons with the older photographs.

4.2 Grain Size Analysis

Grainsize analysis was performed on grab samples, hand auger samples of each lithological unit, and similarly selected vibrocore samples. The grainsize analysis consisted of dry sieving of samples followed by graphical and mathematical presentation of results. Each of the samples were dry sieved using the sieve range –2 phi (4 mm) to >4.5 phi (Pan).

Table 5. Size interval measured for sieve analysis.

Metric Size	Phi Size
4 mm	-2 φ
2 mm	-1 φ
1 mm	0 φ
710 μm	0.5 φ
500 μm	1 φ
355 μm	1.5 φ
250 μm	2 φ
180 μm	2.5 φ
125 μm	3 φ
90 μm	3.5 φ
63 μm	4 φ
45 μm	4.5 φ
Pan	>4.5 φ

Each sample was shaken for a period of 10 minutes, after which the mass of sample retained on each sieve was weighed. From the sieving data mean grainsize, sorting, skewness, and kurtosis were calculated mathematically using McManus' (1988) method of moments where:

(i) The mean grain size is the average grain size calculated for the sample by:

$$\chi = (\Sigma f m_\phi) / 100 \qquad \text{Eqn. 1.}$$

Where x = mean grainsize

f = frequency in weight percent

m_ϕ = the mid-point of each class interval

(ii) Sorting gives the standard deviation of particles around the mean size and is calculated by:

$$\sigma^2 = (\Sigma f (m_\phi - x)^2) / 100 \qquad \text{Eqn. 2.}$$

Where σ^2 = sorting

f = frequency in weight percent

m_ϕ = the mid-point of each class interval

(iii) Skewness is a measure of the symmetry of the sorting about the mean size, and is calculated by:

$$\alpha^3 = (\sum f(m_\phi - x)^3) / 100 \qquad \text{Eqn. 3.}$$

Where α^3 = skewness

f = frequency in weight percent

m_ϕ = the mid-point of each class interval

Positive skewness indicates a distribution with a tail extending to more positive phi sizes (smaller grainsizes), while negative skewness indicates a distribution with a tail extending toward more negative values (larger grainsizes).

(iv) Kurtosis is a measure of the concentration, or peakedness, of the distribution and is calculated by:

$$K^4 = (\sum f(m_\phi - x)^4) / 100 \qquad \text{Eqn. 4.}$$

Where K^4 = kurtosis

f = frequency in weight percent

m_ϕ = the mid-point of each class interval

A very flat kurtosis curves indicate poorly sorted sediments, which are termed platykuritic. On the other hand strongly peaked curves indicate exceptionally good sorting and those sediments are termed leptokuritic (Tucker, 1993).

Sorting versus skewness has been graphically presented for each sample to determine the relationships between depositional environments and sediment texture throughout the study area. Wet sieving was not utilised due to the 'clean' nature of almost all the samples. In samples that contained some mud, a visual estimate of the mud portion was made by binocular microscope analysis.

4.3 Microscope Analysis

Due to time constraints, microscope analysis of samples has been limited to key vibrocore samples and a selection of grab and auger samples considered representative of the different lithological units and depositional environments in the study area.

Samples analysed under the microscope were semi-quantitatively evaluated for grain sorting, grainsize, grain shape, and sand / mud ratio using methods described by Harwood (1988). The results of the microscope analysis of vibrocore samples were incorporated into the core descriptions.

4.4 X-Ray Diffraction Analysis

X-ray diffraction analysis was performed on samples that were deemed to have significant mud content. This was done in order to compare the percentages of the various clay minerals present in muddy sediments in the study area. Samples from likely sediment provenance areas outside the study area were also analysed to compare with the sediment data

Samples analysed by X-ray Diffraction were dried in an oven and then crushed using a petzel and mortar. Following this, exactly 2.7 g of sample was weighed out followed by the addition of exactly 0.3 g of corundum. Corundum was used in order to standardise the samples, which permits the amount of organic matter present in each sample to be assessed. That allows the accurate determination of percentages of minerals in the samples. Each sample was then micronised for 10 minutes and dried overnight. The samples were analysed in the QUT X-ray Diffraction Laboratory using a Phillips PW-1050 diffractometer equipped with a cobalt anticathode, assisted by computer analysis using Jade (a search and match program) and Siroquant (a quantification and analysis program). Results are expressed in weight percent of dry weight.

4.5 Radiocarbon Dating

During fieldwork an articulated *Anadaria Trapezia* shell was recovered from an outcrop of estuarine mud exposed by erosion of the ocean beach of the spit. The sample was selected for dating in order to provide time constraints on estuarine sedimentation in the study area.

The collected specimen was rinsed in deionised water followed by submersion in a sonic bath for periods of 10 minutes, until the water in the bath remained clear, followed by drying in an oven at 30°C. The sample was submitted to the radiocarbon dating laboratory at Waikato University, New Zealand for dating. The calibrated radiocarbon age obtained from the laboratory was corrected for marine reservoir effect, which is 450 $\pm$ 35 years (Gillespie and Polach, 1979).

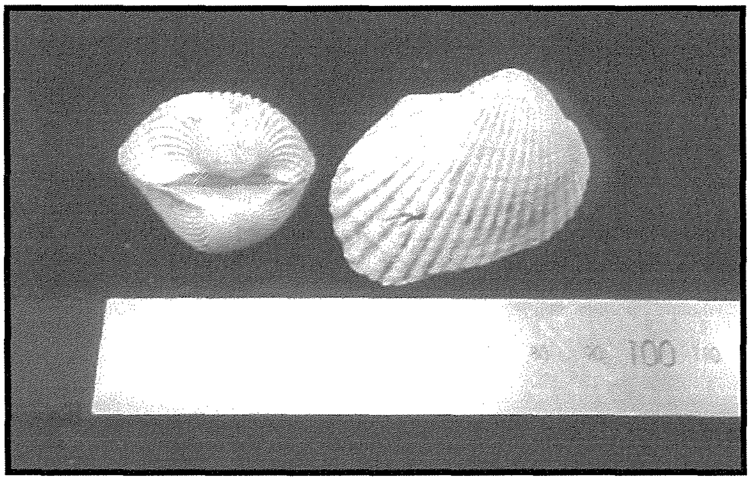


Figure 24. Recovered articulated *Anadara Trapezia* samples. A similar sample was submitted for radiocarbon dating.

4.6 Computerised Modelling

Computerised modelling was undertaken to permit volumetric analysis of sediment movement in the beach zone of the Bribie Island spit as well as adjacent Pumicestone Passage. This is an important step in the calculation of a sediment budget for the study area.

Modelling utilised bathymetric charts that contain sounding depths for the flood tide delta region of the Caloundra inlet for the years 1978 and 1993 respectively (Queensland Transport Maritime Division, 1981 & 1994). The bathymetric data was contained on the respective charts of 1981 and 1994. The chart for 1994 also contains depth contours within Pumicestone Passage. The depth data in Pumicestone Passage were compared to shoreline position changes on the ocean side of the Bribie Island spit. Shoreline positions were obtained from the aerial photographs for 1979 and 1992, up to a contour level of 2 m above the low water mark.

The respective data sets were imported into *Surfer* (Surface Mapping, 1997), a surface-mapping program, for comparison. By overlaying the two different grids (1978 and 1993) it is possible to obtain a volumetric comparison for the two images. The results of the comparisons are output in the form of 'cut and fill' volumes, with the cut volume corresponding to the volume of sediment lost, and the fill volume corresponding with the volume of sediment gained. The cut and fill volumes obtained were used to quantitatively assess changes in sediment volume between the two years to help develop a sediment budget for the study area.

4.6.1 Sources of Potential Error

The use of computerised models may lead to the introduction of error in subsequent sediment budget calculations. In this study, the difference in the number of data points available for the two years may be a source of error as the accuracy of the interpolation is a function of the number of data points. The 1994 map, containing both sounder depths and depth contours, giving 1357 data points, is considered to be sufficiently accurate. However, the 1981 map contains only sounding depths, 822 data points, forcing *Surfer* to interpret contours between considerably less data points.

A lack of elevation data for the sand spit on the 1981 and 1994 maps necessitated that data was obtained from photogrammetric analysis of the 1979 and 1992 aerial photographs (Table 6). This is the only data available close to the time the depth soundings were made and has enabled data corresponding to changes in shoreline position and profile to be used in the modelling. While these photographs are of a different date to the depth data, they are considered to be representative of the position and the profile of the shoreline at the times the depth data was obtained as no significant storms were reported between the dates of the soundings and the aerial photographs. The exact date of the soundings taken in 1993 is unclear, however, the position of the shoreline in 1992 is deemed to be similar to that in 1993 as analysis of shoreline changes between 1992 and 1996 indicates little change in the position of the shoreline over this period.

Table 6. Date of soundings and aerial photographs used in volumetric calculations.

Date of Soundings	Date of Aerial Photographs
September – October 1978	22 May 1979
1993	6 June 1992

4.7 Climatic Data

When considering the role of shoreline processes impacting on beach stability, controlling factors of shoreline processes must be taken into account. To accomplish this, a comprehensive data search of significant meteorological events, such as cyclones and low-pressure systems, affecting the Sunshine Coast was conducted. Additionally, a search for historical Southern Oscillation data was performed, with the assistance of the Bureau of Meteorology, Brisbane.

As storm waves, strong winds and storm tides move significant quantities of sand from the beach and dune (Flood, 1991), the impacts of storms on the study area must be considered in relation to the development of a sediment budget for the study area. For this reason, statistical analysis of the cyclone and east coast low data has also been performed for the period 1958 to 1972, the period for which the sediment budget of the study area was calculated by Jones (1992). The weather data for the periods 1973 to 1977 and 1978 to 1993 have also been analysed for consideration in the development of a sediment budget as part of this study.

Data obtained from the Bureau of Meteorology contained a comprehensive list of cyclones and east coast lows that have impacted on the Queensland coastline between the years 1858 and 2000. The data was assessed for events that have impacted on the study area, that is tracked within 500 km of the study area, as done in Beach Protection Authority studies. Other significant events are those that have occurred outside the 500 km radius but have been reported to have impacted on the Sunshine Coast (Appendix F).

Statistical analysis of storms impacting on the study area involved calculation of the average number of storms per year in 5-year intervals between 1861 and 2000 to permit analysis of the periodicity and cyclicity of storms during that period. A Wilcoxon rank-sum test, as outlined by Newmark (1988), was performed on the data set in the search for any significant variation over time. The Wilcoxon rank-sum test is a non-parametric statistical test used to compare two relatively small data sets. Additionally, a graph of the average number of storms occurring per year over 20 year intervals between 1861 and 2000 was plotted for a broader analysis of storm activity over time.

The frequency of storm events during the periods for which sediment budgets were calculated were also analysed to determine the average number of storms per year impacting on the study area during the two periods. In addition to the storm data, a comprehensive data set of monthly SOI values between 1876 and September 2000 was also obtained (Appendix G). From this data an average annual value of SOI was calculated and plotted on a graph along with annual storm frequencies affecting the study area for the same period. Statistical analysis of the calculated annual average of SOI values was again performed using the Wilcoxon rank-sum test to compare variations in SOI values with variations in storm frequency.

5.0 RESULTS

This chapter presents the results of the field, laboratory and computer based analyses undertaken in this study. Data sets are mostly summarised graphically in the chapter. However, the raw data tables are provided in the appendices.

5.1 Mapping and Monitoring of Sites.

The initial round of erosion site mapping found that the entire eastern side of Bribie Island has experienced severe erosion during the storm swell that occurred between 28 April - 3 May 2000. This is evidenced by an erosion scarp varying between 1 – 3 m high, along the entire ocean beach of Bribie Island (Fig. 25).

Figure 25. The erosion scarp extended along the entire eastern shoreline of the sand spit. The measuring stick is 2 m high. Location of photographs is shown in Appendix A.

From a number of fixed structures existing on the dunes it was possible to make an estimate of the recent erosion. One structure was a beach track (site ODE2, Fig. 26) stabilisation device constructed of wooden slats chained together at 40 cm intervals and anchored to the rear of the foredune. At the time the initial round of mapping was conducted a number of slats were laying stranded on the beach where the foredune had previously been. From the number of slats exposed, and the spacing between them, it was estimated that at least 4 m of beach was lost to erosion in the last storm.

Figure 26. Site ODE2. The slats of this beach track protector were used to estimate the amount of beach recession caused by the April 2000 storm. Photograph was taken three weeks after the storm.

The eroded dune scarp also led to existing dune vegetation, such as Casuarina trees, collapsing onto the beach. Where the erosion extended inland beyond the line of the "pioneer" vegetation along one stretch of the beach, a buried soil profile was exposed. The soil profile is well developed and consists of an organic rich A_1-horizon, a bleached A_2-horizon and dark B-horizon. This soil profile is shown on section B-B' (Fig. 27). A longneck glass beer bottle found in the dune scarp at the top of the A-horizon (Fig. 27) gives the age of burial of the profile as not more than eight years ago.

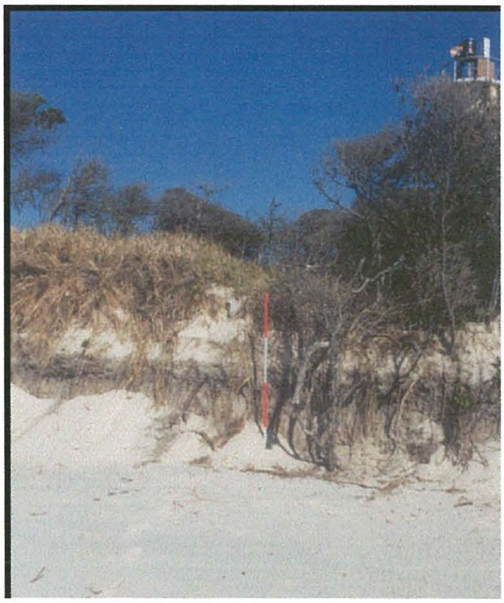


Figure 27.
(Left) Soil profile containing bottle.

(Right) Location of bottle at top of soil profile.

The beach profile had been flattened out by the April storm (Fig. 28) leaving no protection for the exposed dune scarp to succeeding high tides and moderate wave conditions of the following weeks. As a consequence, further undercutting, and slumping of the scarp occurred due to high tides and lack of a built up beach profile (Fig. 29).

Figure 28. Flattened beach profile after the April storm.

Figure 29. Undercutting and slumping of the erosion scarp occurring approximately one month after the flattening of the beach profile by the April storm due to the lack of a built up beach profile.

The storm erosion of the beach also led to the exposure of a number of estuarine mud units in the intertidal zone on the lower shoreface. These units were along a 3 km section of coast, in the lower shoreface, and were often marked by groundwater seeps in the beach above the mud (Fig.30).

Figure 30. Estuarine mud exposed on the eastern shore of the spit in the intertidal zone. The groundwater seeps are evident above the mud.

Mangrove stumps and roots of up to 40 cm diameter were exposed in one particular mud outcrop, approximately 100 m south of Fort Bribie (Fig. 31). Fort Bribie is an old gun emplacement built to protect the Port of Brisbane during World War 2.

Figure 31. Mangrove stumps sticking out of the beach in the intertidal zone (low tide) on the eastern shoreline. The assistant is standing on an outcrop of estuarine mud.

Figure 32. Fort Bribie. Note the flat beach profile and 3 m high dune scarp.

The present position of Fort Bribie, on the upper beachface (Fig. 32), is significant as it was originally built behind the foredune in the 1940's and indicates at least 50 m of erosion.

Figure 33. The second gun emplacement built behind the dunes approximately 3 km south of Fort Bribie. An estuarine shell bed was exposed on the lower beach face at this site after the erosion event in April.

Further south, adjacent to this second gun emplacement, another mud unit was exposed. It contained a shell bed directly below mangrove mud. The shell bed contains a number of estuarine species including gastropods, eugaries, and articulated cockle shells (*Anadara Trapezia,* Fig. 34). Radicarbon dating of an articulated pair of *Anadara Trapezia* extracted from the unit returned an age of 3330 $\pm$ 70 yBP (calibrated and corrected for marine reservoir effect).

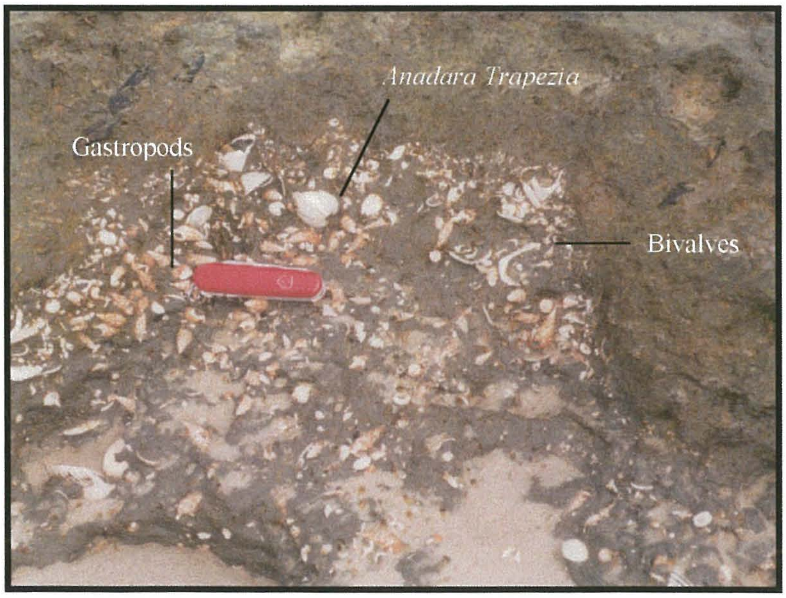


Figure 34. An assortment of shells contained in the unit below mangrove mud. Shells included are gastropods, bivalves, and articulated *Anadara Trapezia.*

A common feature of barrier islands is washover, where storm waves and high tides breach the foredune and wash inland into low-lying areas. This is a common feature in areas of the spit where the dunes are less than 2m high. The rapid influx of saltwater and sand into vegetated areas has left a trail of dead vegetation where this occurred during the April storm (Fig. 36). Areas where washover has occurred on the spit are shown in Figure 35.

Figure 36. Storm washover has dissected the dunes and resulted in the death of the vegetation.

Progressive monitoring of the ocean beach throughout the fieldwork period recorded the gradual return of the beach to a normal profile, although the entire beach face has retreated landwards by up to approximately 5 m.

Changes in the beach profile that were observed during the period of fieldwork are shown on sections A-A', B-B', and C-C' (Figs. 41B, 43B, 44B), which indicates beach profile changes along the lines of the cross sections, as well as general changes in beach morphology. Examples of these changes can be seen in Figures 37 and 38.

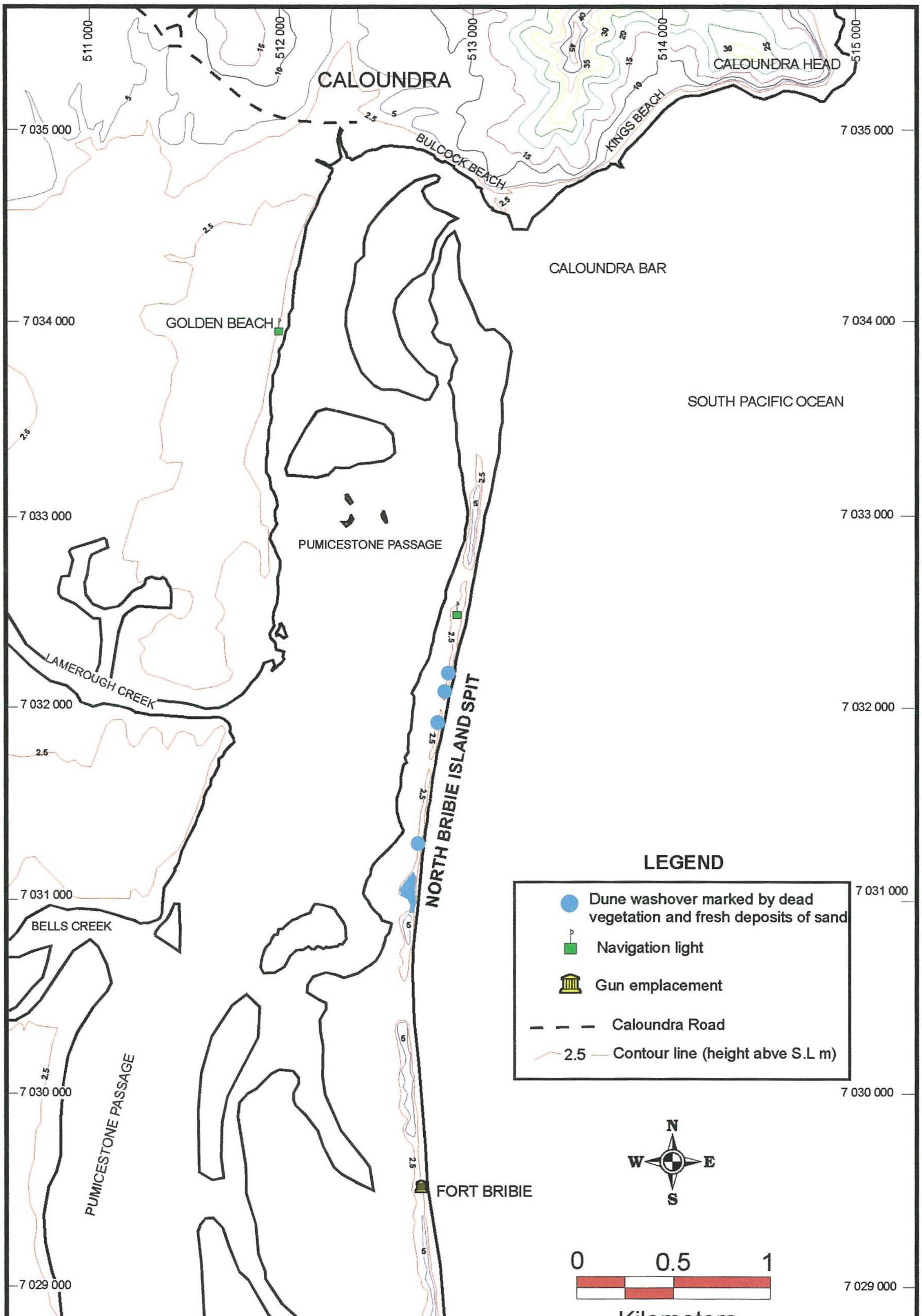


Figure 35. Sites where washover was experienced during the April 2000 storm

Figure 37. Site ODE2 (4/6/2000). Erosion of foredune exposing the buried beach track.

Figure 38. Site ODE2 (7/9/2000). Shoreline processes have built up the beach profile at this site after erosion.

A number of erosion scarps were also observed on the mainland side of the spit (Fig. 39). The base of these scarps was at the high water mark. Undercut and slumped vegetation is a common feature of the scarps. The results of the monitoring at these scarps is shown in Table 7, and indicates a gradual recession of the dunes. Locations of monitoring sites are shown in Figure 40.

Figure 39. Site MDE5. An example of erosion on the mainland side of the sand spit, adjacent to Pumicestone Passage. The scarp is approximately 4 m high, with fallen vegetation at the base. Six monitoring sites were established at this site (sites MS1 – MS6).

Table 7. Location of monitoring sites on the mainland side of the sand spit and measurements from marked sites to the edge of the scarp.

Monitoring Site	Location (GPS)		Date Observed (distances in metres)			
	East	North	28/5/00	6/7/00	24/8/00	7/9/00
MS1	512693	7033169	0.95	0.9	0.85	0.85
MS2	512964	7033193	0.92	0.8	0.75	0.75
MS3	512963	7033223	1.1	1.0	1.0	1.0
MS4	512960	7033235	0.92	0.9	0.9	0.9
MS5	512959	7033256	1.67	1.6	1.25	1.2
MS6	512958	7033266	1.15	1.1	1.1	1.1
MS7	512951	7033360	1.29	1.2	1.2	1.2
MS8	512939	7033468	3.0	3.0	3.0	3.0
MS9	512917	7033636	1.25	0.9	0.7	0.6
MS10	512905	7033694	1.06	1.0	1.0	1.0
MS11	512971	7033165	1.6	1.3	1.2	1.2

5.2 Cross Sections

The cross-sections show the results of the surveying and data obtained by hand augering, vibrocoring, grab sampling, surveying, and geomorphological observation. The spit consists of a relatively shallow sloping beach profile abutted by an erosional scarp cut into a single

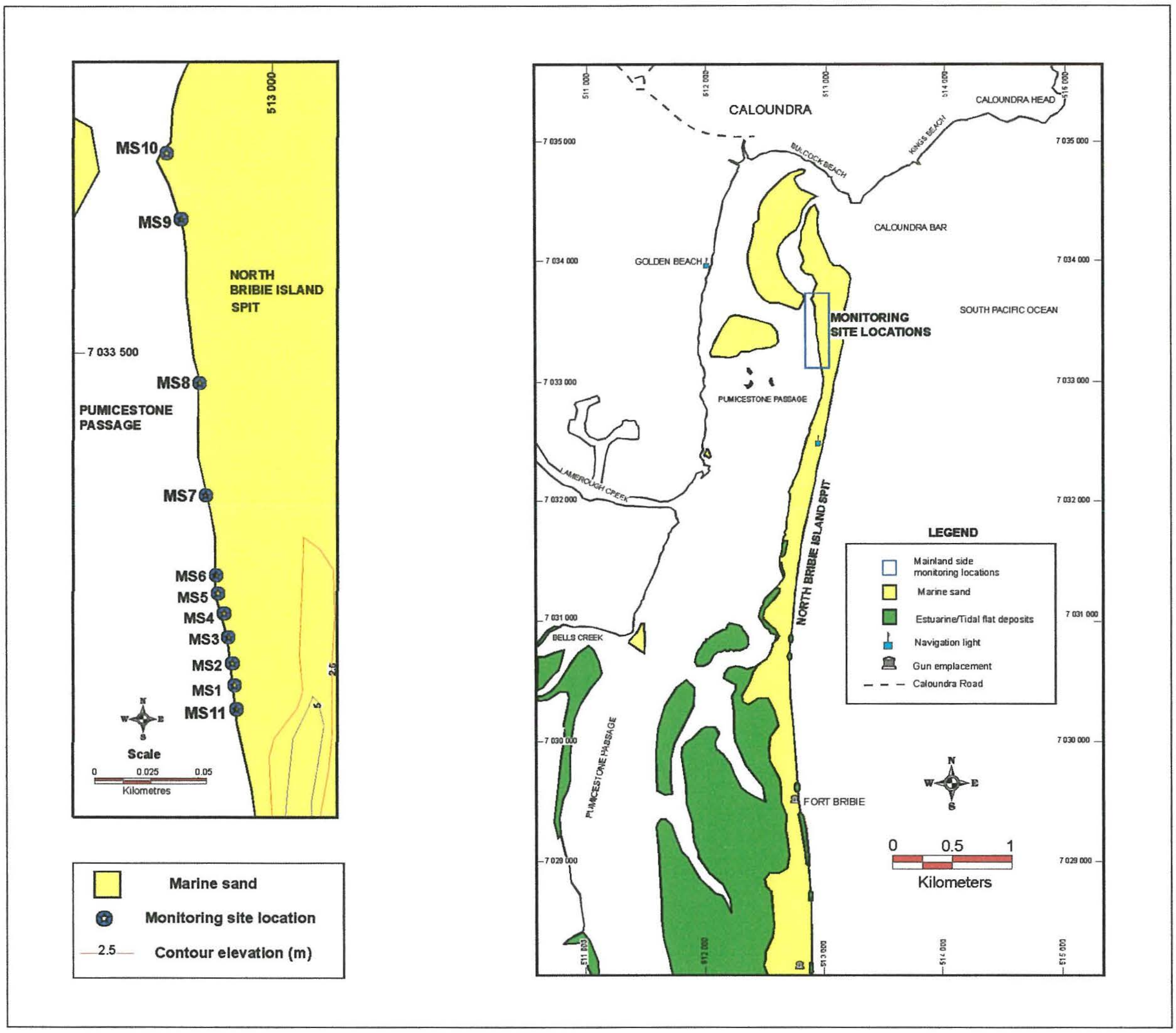


Figure 40. Monitoring site locations.

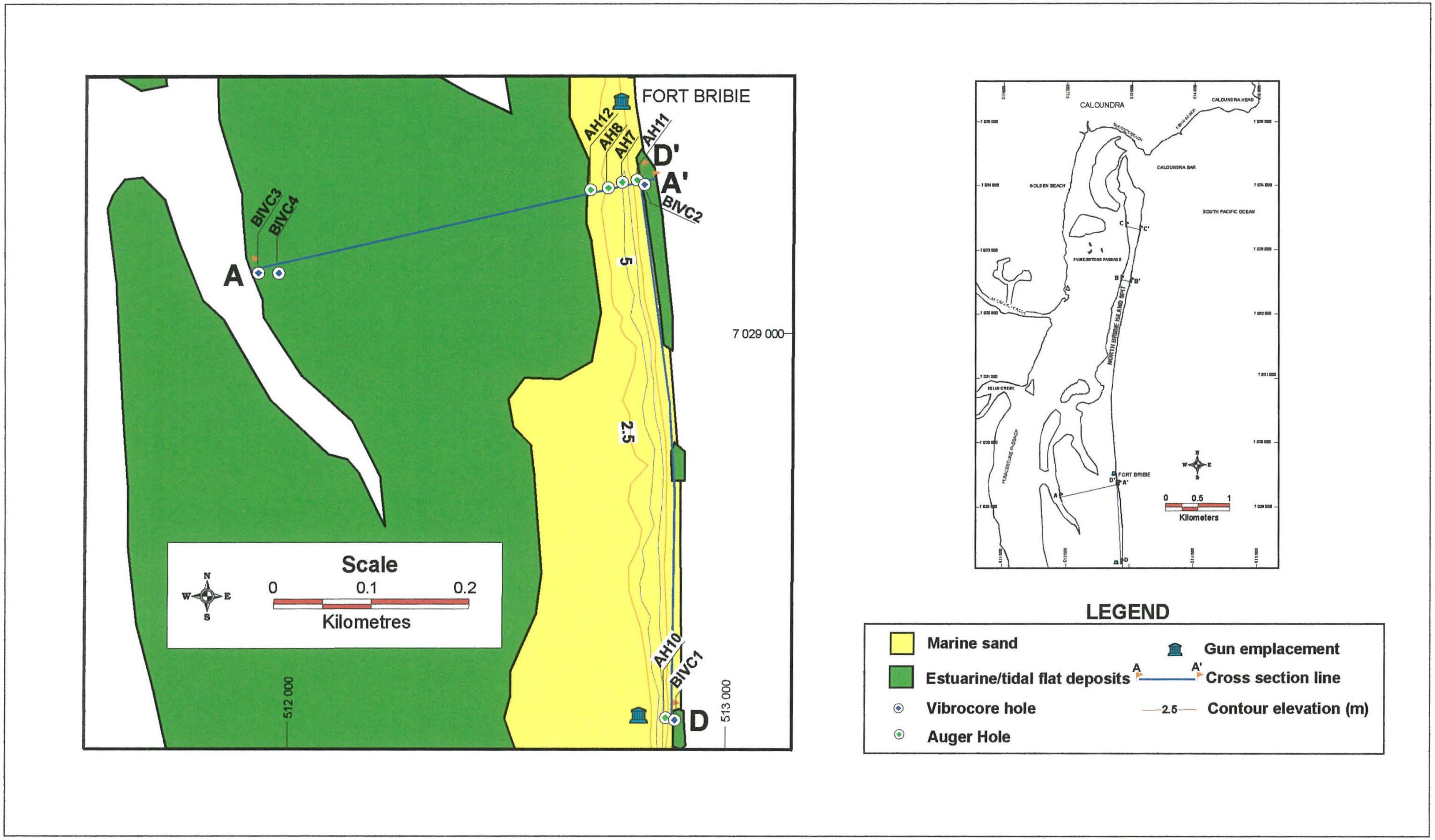
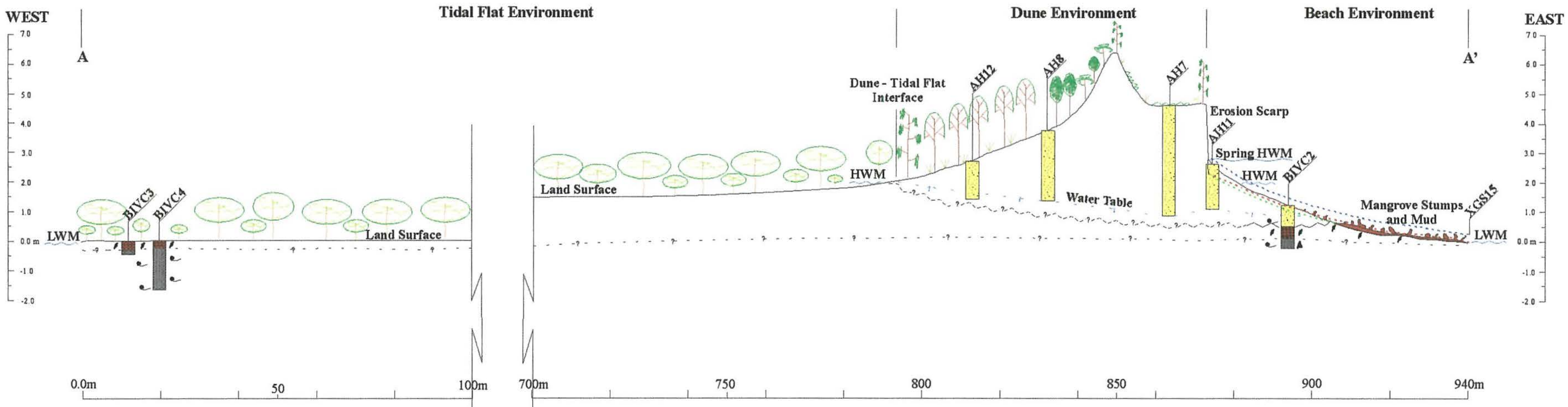


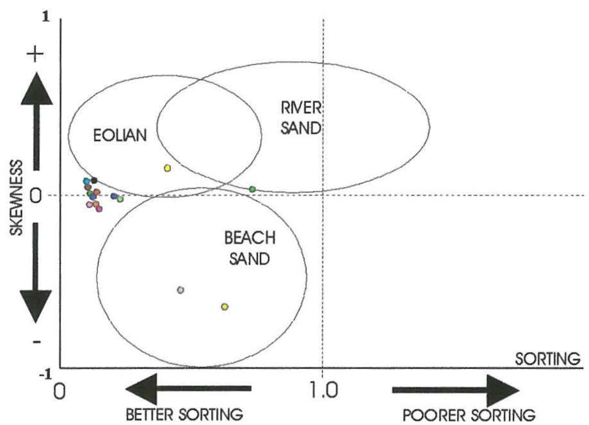
Figure 41A. North Bribie Island Spit - Section A-A' and D-D' Locations

North Bribie Island Spit Section A-A'



Vertical Exaggeration - 75X

ANALYSIS OF GRAINSIZE DISTRIBUTION



KEY			
	HOLE	SAMPLE	DEPTH (m)
(yellow)	BIVC3	BIVC3B	0.36
(green)	BIVC4	BIVC4B	1.0
(grey)	AH8	AH8A	0.2
(black)	AH8	AH8B	0.7
(magenta)	AH8	AH8E	2.0
(pink)	AH7	AH7A	0.45
(green)	AH7	AH7C	1.6
(red)	AH7	AH7D	2.15
(brown)	AH7	AH7E	2.35
(blue)	AH7	AH7F	2.68
(light blue)	AH7	AH7G	3.25
(light green)	AH11	AH11A	0.6
(yellow)	BIVC2	BIVC2A	0.31
(orange)	BIVC2	BIVC2B	0.68
(dark blue)		XGS15	0.0

Indicated depth is below land surface.

After: Bjorlykke (1989)

Figure 41B

NORTH BRIBIE ISLAND SPIT SECTION A-A' LEGEND

GEOLOGICAL SYMBOLS

Beach sand / Dune sand. Buff coloured (5Y 8/4 - 5Y 7/2). Predominantly medium-fine grained, clean, quartzose, very well sorted sands containing minor flecks of shell fragments as well as specks of heavy minerals of a similar grainsize to the quartz throughout.

Estuarine / Intertidal mud. Dark brown (5YR2) mud containing extensive mangrove root material and other fibrous organic matter.

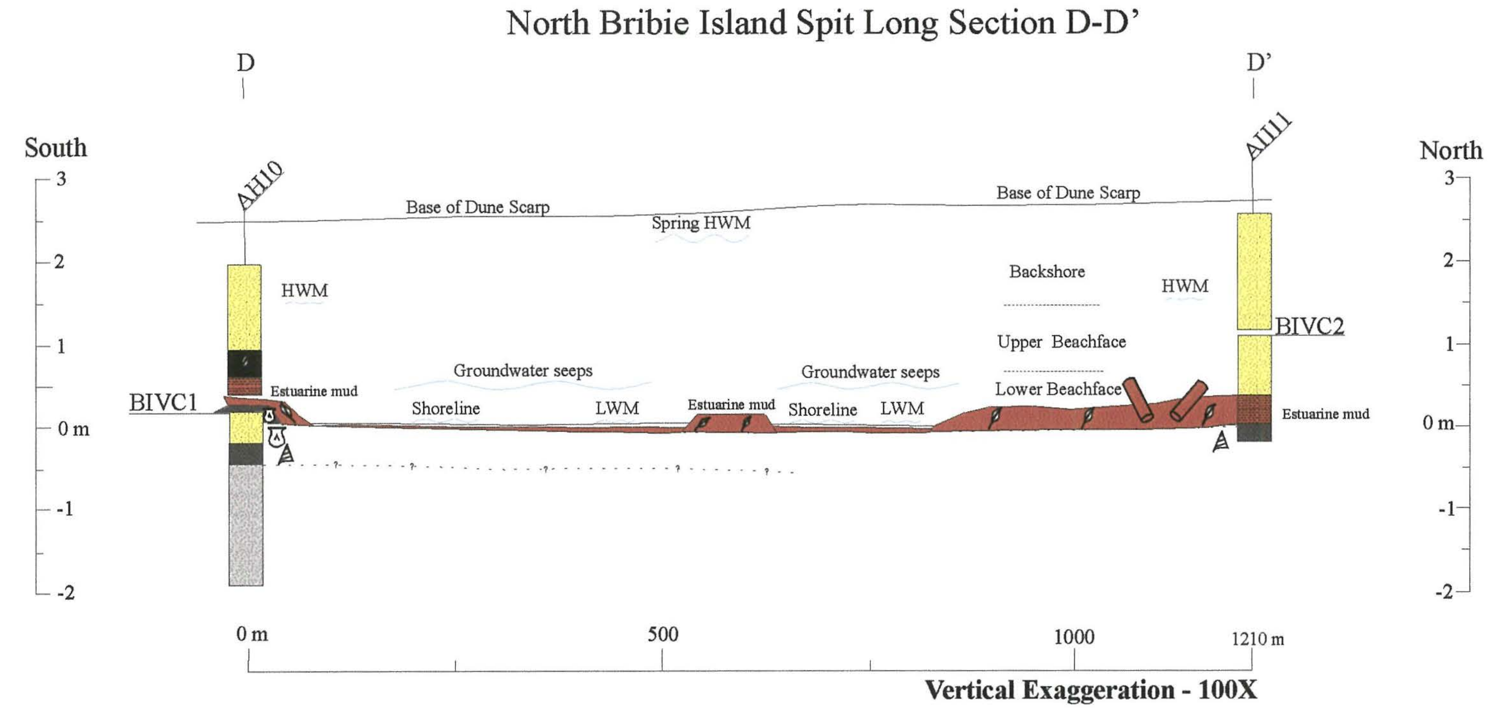
Estuarine sediments. Dark grey (N3) sediments consisting of varying amounts of clay, silt, and fine grained sand. Estuarine shells are common in this layer.

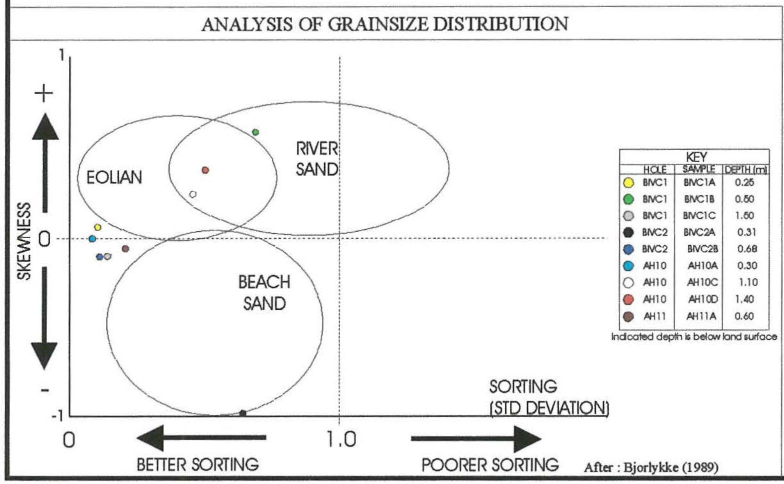
- Inferred geological boundary
- Erosional unconformity
- Inferred erosional unconformity
- Water table
- Gastropod shells
- Undifferentiated shell material
- Organic matter
- BIVC — Vibrocore hole
- AH — Hand auger hole
- XGS — Grab sample
- LWM — Low water mark
- HWM — High water mark
- Observed beach profile 6/6/2000
- Observed beach profile 6/7/2000
- Surveyed beach profile 13/7/2000 (Mud buried, stumps showing)
- Observed beach profile 7/9/2000

VEGETATION TYPES

- GRASSES: Sand Spinifex, Blade Grass
- CREEPERS: Pigface, Goatsfoot, Beach Primrose
- SHRUBS: Monotoca
- TREES: Casuarina, Banksia, Melaleuca
- INTERTIDAL: Mangrove Species

Drawn by Jared Lester 18/9/2000


North Bribie Island Spit Long Section D-D'
D
D'
South
North
AH10
AH11
Base of Dune Scarp
Spring HWM
Base of Dune Scarp
HWM
Backshore
HWM
BIVC2
Upper Beachface
Groundwater seeps
Groundwater seeps
Estuarine mud
Lower Beachface
BIVC1
Shoreline
LWM
Estuarine mud
Shoreline
LWM
Estuarine mud
3
2
1
0 m
-1
-2
0 m
500
1000
1210 m
Vertical Exaggeration - 100X


ANALYSIS OF GRAINSIZE DISTRIBUTION
SKEWNESS
EOLIAN
RIVER SAND
BEACH SAND
SORTING (STD DEVIATION)
BETTER SORTING
POORER SORTING
KEY
HOLE SAMPLE DEPTH (m)
BIVC1 BIVC1A 0.25
BIVC1 BIVC1B 0.50
BIVC1 BIVC1C 1.50
BIVC2 BIVC2A 0.31
BIVC2 BIVC2B 0.68
AH10 AH10A 0.30
AH10 AH10C 1.10
AH10 AH10D 1.40
AH11 AH11A 0.60
Indicated depth is below land surface
After : Bjorlykke (1989)

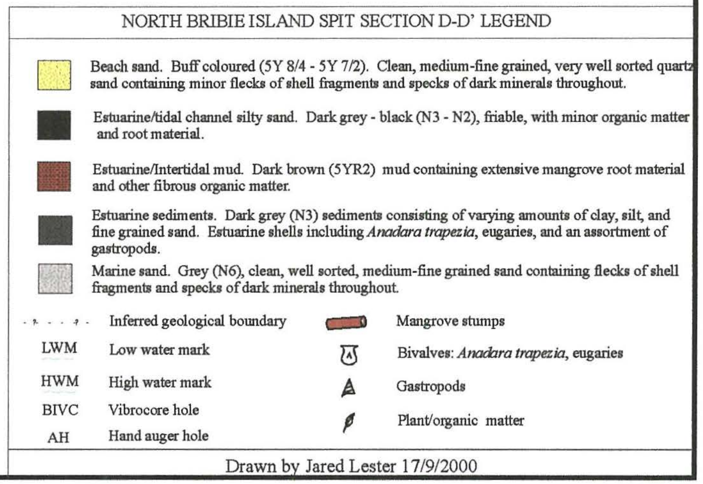

NORTH BRIBIE ISLAND SPIT SECTION D-D' LEGEND
Beach sand. Buff coloured (5Y 8/4 - 5Y 7/2). Clean, medium-fine grained, very well sorted quartz sand containing minor flecks of shell fragments and specks of dark minerals throughout.
Estuarine/tidal channel silty sand. Dark grey - black (N3 - N2), friable, with minor organic matter and root material.
Estuarine/Intertidal mud. Dark brown (5YR2) mud containing extensive mangrove root material and other fibrous organic matter.
Estuarine sediments. Dark grey (N3) sediments consisting of varying amounts of clay, silt, and fine grained sand. Estuarine shells including Anadara trapezia, eugaries, and an assortment of gastropods.
Marine sand. Grey (N6), clean, well sorted, medium-fine grained sand containing flecks of shell fragments and specks of dark minerals throughout.
Inferred geological boundary
Mangrove stumps
LWM Low water mark
Bivalves: Anadara trapezia, eugaries
HWM High water mark
Gastropods
BIVC Vibrocore hole
Plant/organic matter
AH Hand auger hole
Drawn by Jared Lester 17/9/2000

Figure 42.

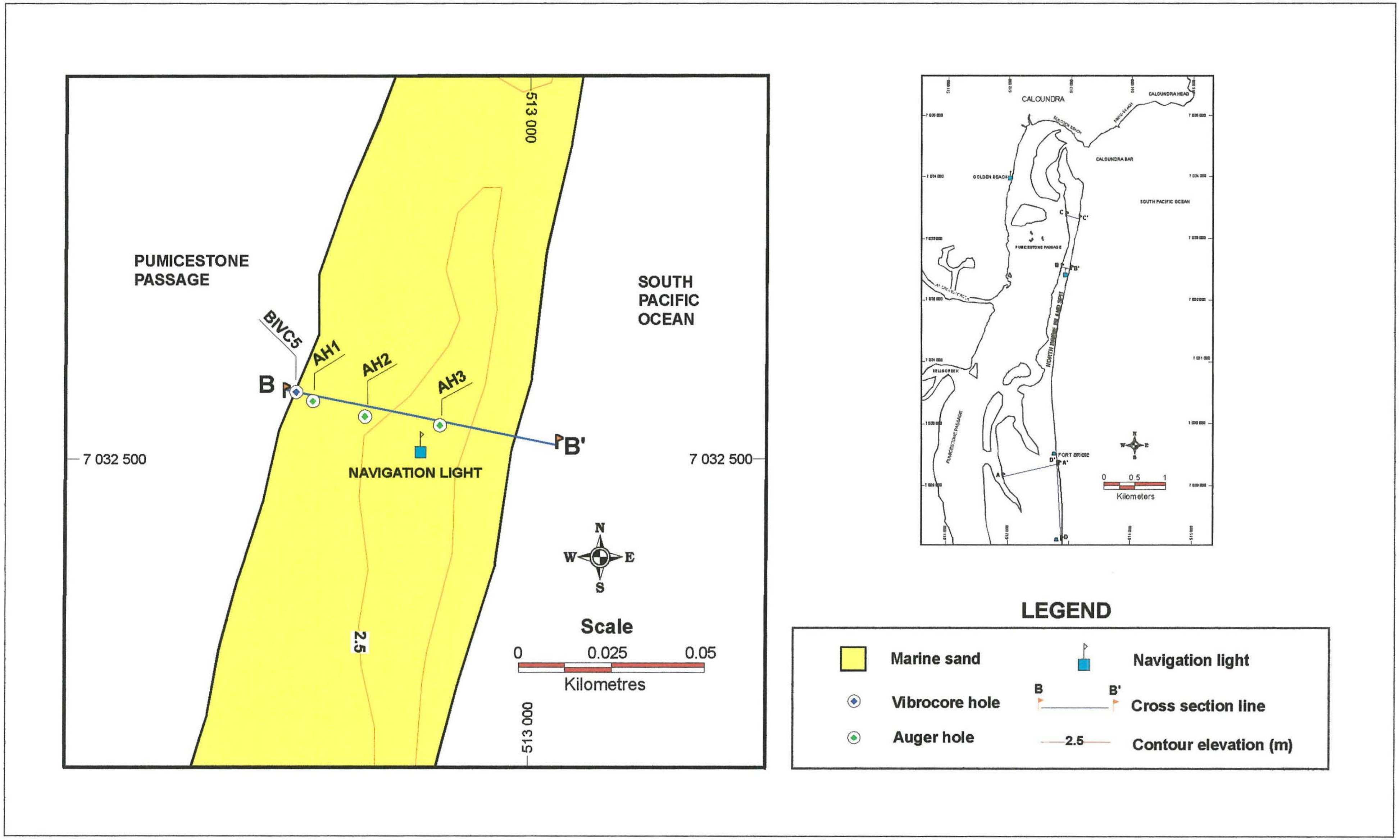
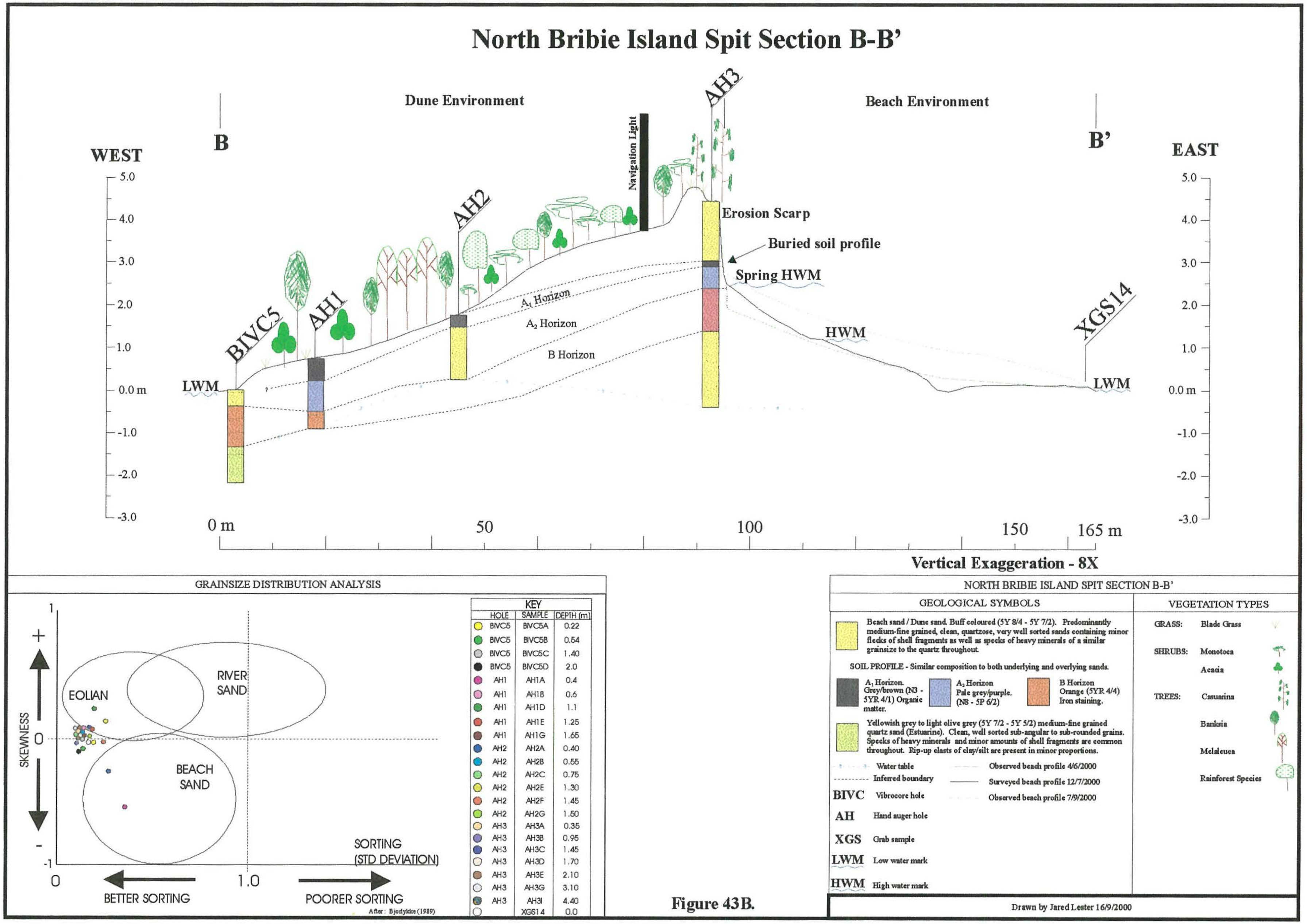


Figure 43A. North Bribie Island Spit - Section B-B' Location



North Bribie Island Spit Section B-B'
Dune Environment
Beach Environment
B
B'
WEST
EAST
Navigation Light
AH3
AH2
AH1
BIVC5
XGS14
Erosion Scarp
Buried soil profile
Spring HWM
HWM
LWM
A1 Horizon
A2 Horizon
B Horizon
5.0
4.0
3.0
2.0
1.0
0.0 m
-1.0
-2.0
-3.0
0 m
50
100
150
165 m
Vertical Exaggeration - 8X
GRAINSIZE DISTRIBUTION ANALYSIS
SKEWNESS
EOLIAN
RIVER SAND
BEACH SAND
SORTING (STD DEVIATION)
BETTER SORTING
POORER SORTING
After: Bjorlykke (1989)
KEY
HOLE | SAMPLE | DEPTH (m)
BIVC5 | BIVC5A | 0.22
BIVC5 | BIVC5B | 0.54
BIVC5 | BIVC5C | 1.40
BIVC5 | BIVC5D | 2.0
AH1 | AH1A | 0.4
AH1 | AH1B | 0.6
AH1 | AH1D | 1.1
AH1 | AH1E | 1.25
AH1 | AH1G | 1.65
AH2 | AH2A | 0.40
AH2 | AH2B | 0.55
AH2 | AH2C | 0.75
AH2 | AH2E | 1.30
AH2 | AH2F | 1.45
AH2 | AH2G | 1.50
AH3 | AH3A | 0.35
AH3 | AH3B | 0.95
AH3 | AH3C | 1.45
AH3 | AH3D | 1.70
AH3 | AH3E | 2.10
AH3 | AH3G | 3.10
AH3 | AH3I | 4.40
XGS14 | 0.0
NORTH BRIBIE ISLAND SPIT SECTION B-B'
GEOLOGICAL SYMBOLS
Beach sand / Dune sand. Buff coloured (5Y 8/4 - 5Y 7/2). Predominantly medium-fine grained, clean, quartzose, very well sorted sands containing minor flecks of shell fragments as well as specks of heavy minerals of a similar grainsize to the quartz throughout.
SOIL PROFILE - Similar composition to both underlying and overlying sands.
A1 Horizon. Grey/brown (N3 - 5YR 4/1) Organic matter.
A2 Horizon Pale grey/purple. (N8 - 5P 6/2)
B Horizon Orange (5YR 4/4) Iron staining.
Yellowish grey to light olive grey (5Y 7/2 - 5Y 5/2) medium-fine grained quartz sand (Estuarine). Clean, well sorted sub-angular to sub-rounded grains. Specks of heavy minerals and minor amounts of shell fragments are common throughout. Rip-up clasts of clay/silt are present in minor proportions.
Water table
Inferred boundary
Observed beach profile 4/6/2000
Surveyed beach profile 12/7/2000
Observed beach profile 7/9/2000
BIVC Vibrocore hole
AH Hand auger hole
XGS Grab sample
LWM Low water mark
HWM High water mark
VEGETATION TYPES
GRASS: Blade Grass
SHRUBS: Monotoca
Acacia
TREES: Casuarina
Banksia
Melaleuca
Rainforest Species
Drawn by Jared Lester 16/9/2000

Figure 43B.

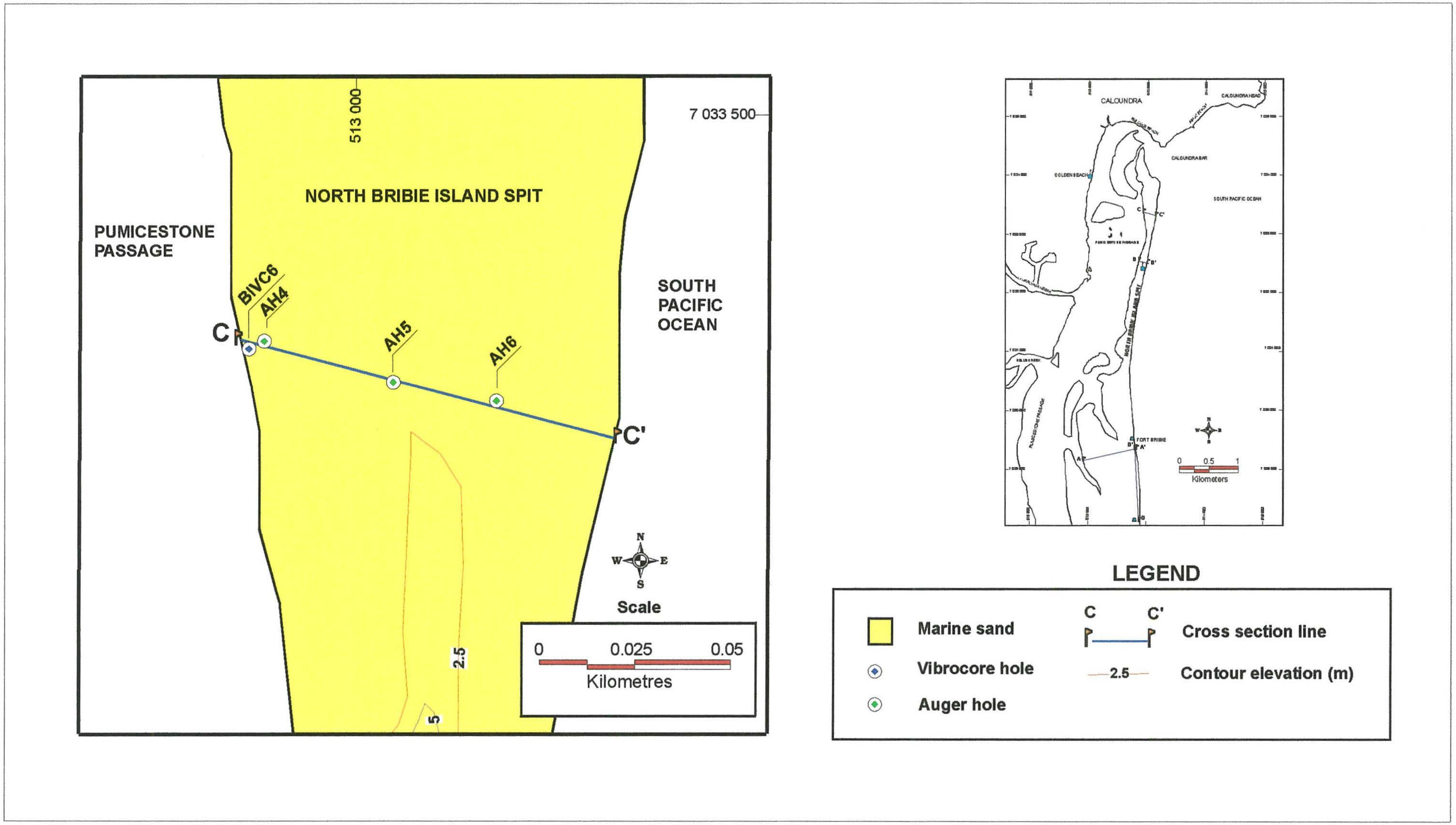
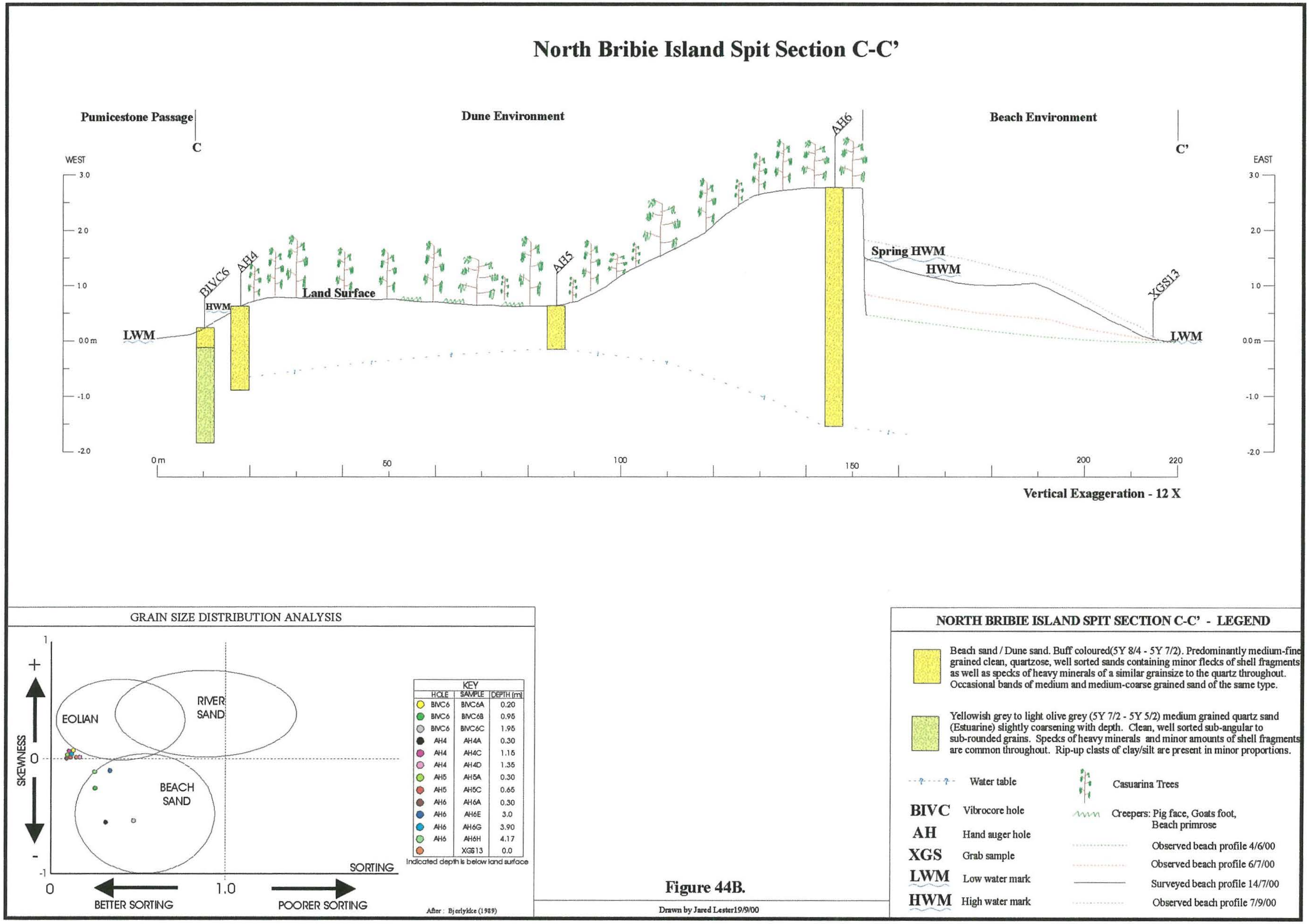


Figure 44A. North Bribie Island Spit - Section C-C' Location



North Bribie Island Spit Section C-C'
Pumicestone Passage
Dune Environment
Beach Environment
C
C'
WEST
EAST
3.0
2.0
1.0
0.0 m
-1.0
-2.0
BIVC6
AH4
AH5
AH6
XGS13
HWM
LWM
Land Surface
Spring HWM
0 m
50
100
150
200
220
Vertical Exaggeration - 12 X
GRAIN SIZE DISTRIBUTION ANALYSIS
SKEWNESS
EOLIAN
RIVER SAND
BEACH SAND
SORTING
BETTER SORTING
POORER SORTING
KEY
HOLE | SAMPLE | DEPTH (m)
BIVC6 | BIVC6A | 0.20
BIVC6 | BIVC6B | 0.95
BIVC6 | BIVC6C | 1.95
AH4 | AH4A | 0.30
AH4 | AH4C | 1.15
AH4 | AH4D | 1.35
AH5 | AH5A | 0.30
AH5 | AH5C | 0.65
AH6 | AH6A | 0.30
AH6 | AH6E | 3.0
AH6 | AH6G | 3.90
AH6 | AH6H | 4.17
XGS13 | 0.0
Indicated depth is below land surface
After: Bjorlykke (1989)
NORTH BRIBIE ISLAND SPIT SECTION C-C' - LEGEND
Beach sand / Dune sand. Buff coloured(5Y 8/4 - 5Y 7/2). Predominantly medium-fine grained clean, quartzose, well sorted sands containing minor flecks of shell fragments as well as specks of heavy minerals of a similar grainsize to the quartz throughout. Occasional bands of medium and medium-coarse grained sand of the same type.
Yellowish grey to light olive grey (5Y 7/2 - 5Y 5/2) medium grained quartz sand (Estuarine) slightly coarsening with depth. Clean, well sorted sub-angular to sub-rounded grains. Specks of heavy minerals and minor amounts of shell fragments are common throughout. Rip-up clasts of clay/silt are present in minor proportions.
Water table
Casuarina Trees
BIVC Vibrocore hole
AH Hand auger hole
XGS Grab sample
LWM Low water mark
HWM High water mark
Creepers: Pig face, Goats foot, Beach primrose
Observed beach profile 4/6/00
Observed beach profile 6/7/00
Surveyed beach profile 14/7/00
Observed beach profile 7/9/00
Drawn by Jared Lester19/9/00

Figure 44B.

dune. The single dune structure of the spit in indicated by the cross section morphology and bedding exposures in the scarp on the bank of Pumicestone Passage.

Changes in the beach profile at each of the section locations were observed throughout the field period and are shown on sections A-A', B-B' and C-C' (Figs. 41B, 43B, 44B). The beach has not been exposed to storms since April and has been accreting during the monitoring period. The beach profile has been raised by approximately 0.5 m on sections A-A' and B-B', covering the mud outcrops exposed on the profile at section A-A', and by approximately 1 m at section C-C'.

The spit varies between 3 to 6 m above LWM in height. The lack of a foredune on each section, and along the entire spit, is a significant feature consistent with severe erosion.
The width of the supra tidal area of the spit varies between approximately 70 to 150 m. A distinct zonation of the major types of dune vegetation is a feature of section A-A'. The vegetation zones are characterised by pioneer plants including creepers, grasses and *Casuarina* trees on the exposed side of the dune. Behind the crest of the dune distinct zones of *Monotoca* shrubs, *Banksia* woodland, *Melaleuca*, and then *Casuarina* forest are present seaward of a tidal flat environment dominated by mangrove species.

The zonation described for section A-A' is less distinct but still evident in section B-B'. In contrast, section C-C' exhibits only "pioneer" vegetation of *Casuarina* trees and various creepers, indicating a much younger age relative to sections A-A' and B-B'. The pioneer zone of vegetation on sections A-A' and B-B' extends to the edge of the existing scarp and its width will steadily decrease as erosion continues. Also notable is the absence on sections B-B' and C-C' of a tidal flat on the passage side of the spit, possibly recording the landward translation of the dune.

5.3 Sedimentology

Through a combination of augering, vibrocoring, grain size analysis and surveying of cross-sections, the sedimentology and stratigraphy of the sand spit has been determined. Detailed descriptions of vibrocore and auger logs are provided in Appendix B, with grainsize data in Appendix C. Binocular microscope analysis of core samples and selected grab samples provided a semi-quantitative assessment of sediments. X-ray diffraction analysis provided a quantitative analysis of fine sediments that could not be analysed under the binocular microscope.

The two main types of sediment within the study area are sand of marine origin and estuarine sediments. The distribution of these sediments is shown in Figure 45.

5.3.1 Sand

The majority of sands in the samples are clean, well sorted, quartz sand and shell fragments along with minor proportions of heavy minerals. Based on binocular microscope analysis the sand fraction in core samples consisted of between 87-96% sub-angular to sub-rounded quartz, 0-10% carbonate (mainly shell fragments), 1-5% lithics (mainly red and grey chert and volcanic rock fragments), 0-2% well rounded K-feldspar grains and 0-10% heavy minerals.

The grain size distribution (Figs. 41B, 42, 43B, 44B, Appendix C) of samples taken from vibrocores, auger holes and grab samples indicate that the majority of sands are well sorted and are medium to fine grained. Exceptions are found in some samples from the lower shoreface of the open beach, high-energy environments in Pumicestone Passage, and samples taken near the surface in vegetated areas. Although these exceptions display a high degree of sorting, they exhibit a larger degree of skewness, largely attributable to inclusions of shells or organic matter. Additionally, sands within areas of relatively high tidal energy in Pumicestone Passage, such as the inlet, display a significantly coarser grain size than that found at the low water mark on the eastern shore of the spit.

The sandbars in Pumicestone Passage, adjacent to the sand spit, are primarily part of the flood tide delta of Caloundra Bar and are therefore confined to the area north of Bells Creek. The grain size characteristics of sands within the flood tidal delta are strongly related the tidal regime in the Passage, with coarser grained sands evident in high-energy areas, and medium sands in lower energy areas. Compositionally, sands in the flood tide delta contain a significant proportion of shell fragments, and in some cases traces of pyrite.

5.3.2 Estuarine Sediments

The estuarine units exposed on the eastern shore of the spit are an important feature of the study area. These sediments consist of varying amounts of clay, silt and fine-grained quartz sand. Additionally, mangrove roots, stumps, organic matter, and estuarine shells are present indicating a previous tidal flat environment. These outcrops occur in the intertidal zone of the open beach and are only exposed during low tides and after an erosional event. Transport of

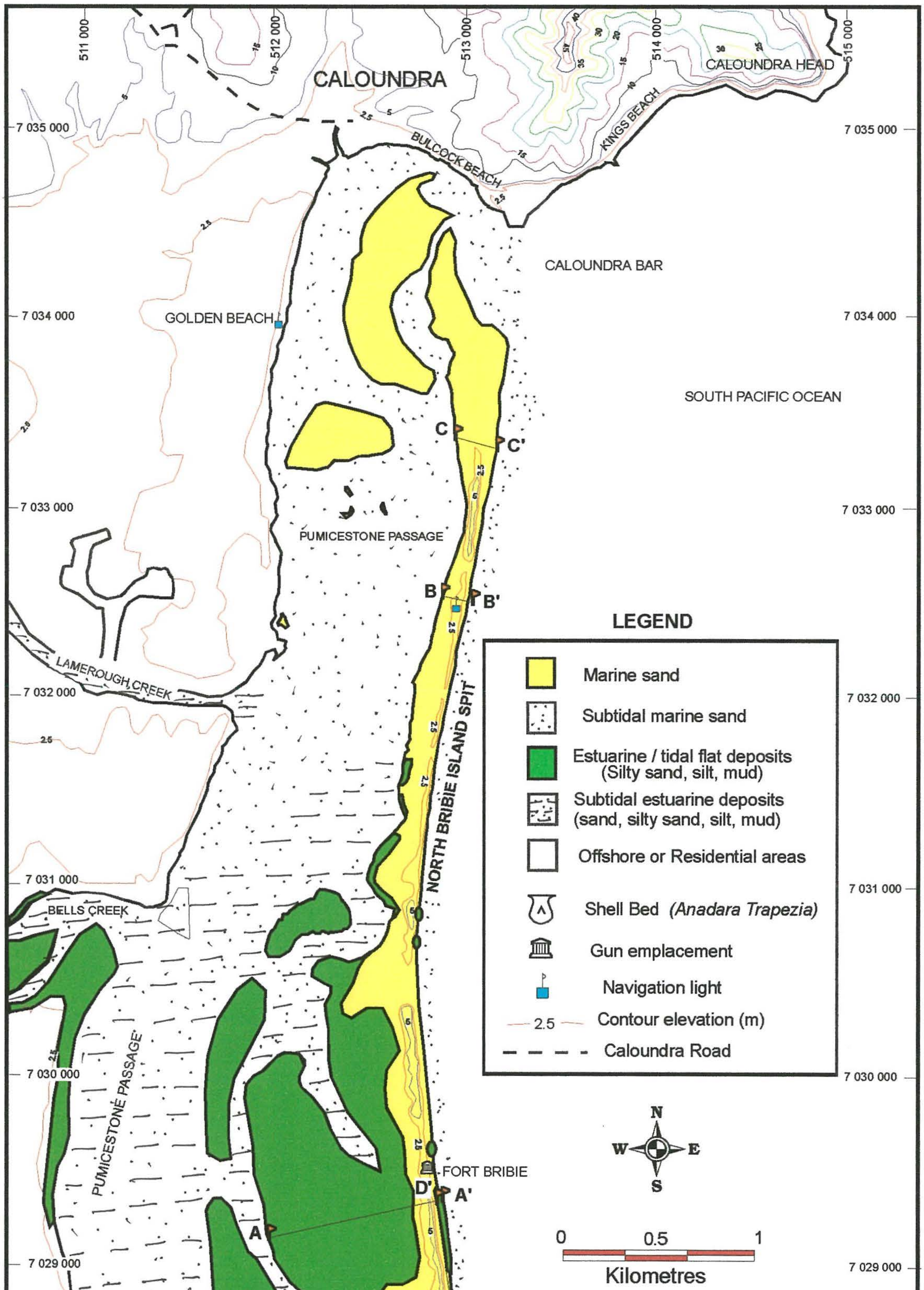


Figure 45. Distribution of sediment types within the study area.

sand onshore after the storm in April completely covered these exposures by up to 0.5 m of sand within four months.

The impermeable nature of the estuarine deposits creates a confining layer, leading to a perched aquifer in areas where they extend under the sand spit. Evidence of the perched aquifers was seen in groundwater seeps on the shoreface above the mud units (Fig. 30) along with the seaward slope of the water table. The presence of a seaward sloping water table is evident in section A-A' (Fig. 41B) by following the depths at which the auger holes were abandoned due to the presence of saturated sand. Due to the confining nature of the mud units, the perched water above it moves laterally following the profile of the low-permeability layer (Fetter, 1994). As the holes were augered at low tide, which is below the upper surface of the mud units, the shape of the perched water table probably reflects the surface profile of the underlying mud unit.

At the location of vibrocore BIVC1 (Fig. 45), a shell bed is exposed below the estuarine mud consisting of shells and varying proportions of clay, silt and fine grained sand. The bed contains a large number of estuarine shells, including articulated *Anadara Trapezia*, and an assortment of gastropods and bivalves.

Estuarine sediments within Pumicestone Passage, beyond the influence of the flood tidal delta, consist largely of tidal channel and flat deposits. Two vibrocores were taken on the tidal flat in this area for comparison with the auger samples and those cores taken on the eastern shore of the sand spit. The sediments in tidal flat environment in Pumicestone Passage are similar in composition to the tidal flat deposits exposed on the eastern shore of the sand spit and it is likely they are part of a single lithostratigraphic unit.

5.4 X-Ray Diffraction Analysis

Graphical results of X-ray diffraction analysis are contained in Appendix E and a tabulated summary of results is contained in Table 9. All samples tested were from estuarine units contained in cores or sampled from augers and outcrops within the study area (Table 8). Samples from Pumicestone Passage were collected in cores, while those taken from the eastern shore of the spit were sampled from vibrocores, augers and outcrops.

Table 8. Location and descriptions of samples tested by X-ray diffraction analysis. See Fig. 46 for map locations of samples.

SAMPLE	LOCATION	DEPTH IN CORE/AUGER	FACIES
VC1B	BIVC1 – Eastern shore of spit	0.50 m	Estuarine sediments
VC4B	BIVC4 – Pumicestone Passage tidal flats	1.0 m	Estuarine sediments
VC4A	BIVC4 – Pumicestone Passage tidal flats	0.12 m	Tidal flat deposits
PSGS4	Grab Sample - Pumicestone Passage	-	Tidal flat deposits
XGS9	Grab Sample - Pumicestone Passage	-	Tidal flat deposits
VC2C	BIVC2 – Eastern shore of spit	1.0 m	Tidal flat deposits
MUD4	Mangrove mud outcrop – eastern shore of spit	Surface	Tidal flat deposits
AH10C	AH10 – Upper beachface eastern shore of spit	1.10 m	Estuarine sediments
AH10D	AH10 – Upper beachface eastern shore of spit	1.40 m	Estuarine sediments
AH9B	AH9 – Upper beachface eastern shore of spit	1.65 m	Estuarine sediments

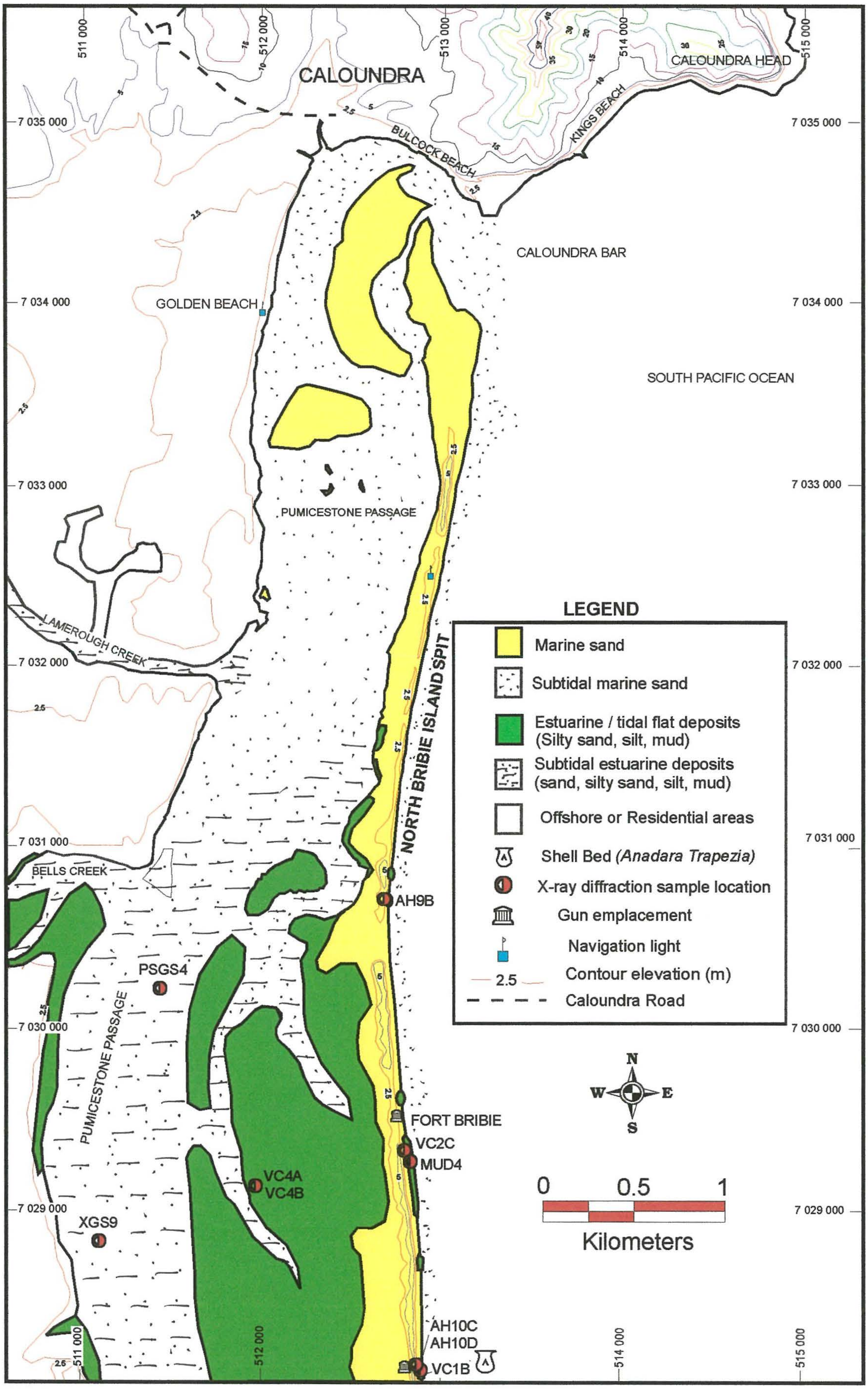


Figure 46. Locations of samples analysed by x-ray diffraction

Table 9. Summary of X-ray diffraction results

Sample	% Mineral Present									
	Quartz	Feldspars	Kaolinite	Smectite/ illite	Illite	Muscovite	Amphibole	Pyrite	Salt	Amorphous (Organic)
Error %	0.9-1.8	0.3-0.9	1.0-1.6	0.5-0.7	0.7-0.9	1.0	0.6	0.2-0.3	0.2-0.3	5.0-8.0
VC1B	80.0	4.4	9.5	2.0	1.9	0.0	0.0	1.3	0.2	0.7
VC4B	84.0	3.4	7.1	3.2	1.5	0.0	0.0	0.6	0.2	0.0
VC4A	76.3	3.4	9.8	0.0	1.0	0.0	0.0	0.7	0.2	8.6
PSGS4	78.6	3.0	11.5	0.0	2.2	0.0	0.0	0.3	0.7	3.7
XGS9	70.8	4.1	12.9	2.5	1.5	0.0	0.0	0.2	0.4	7.6
VC2C	39.4	11.3	18.3	6.5	2.4	4.3	3.5	2.5	0.2	11.6
MUD4	33.8	10.4	24.4	2.7	11.3	0.0	0.0	2.0	0.0	15.4
AH10C	91.8	2.0	4.4	0.0	0.0	0.0	0.0	0.0	0.3	1.5
AH10D	86.8	3.1	8.3	0.0	1.4	0.0	0.0	0.2	0.2	0.0
AH9B	94.7	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	1.7

The data indicate a minor proportion of clay minerals and a large percentage of quartz (70.8 – 94.7%) in the majority of samples tested. Samples VC2C and MUD4 were exceptions, containing 33.8% and 39.4% quartz respectively. These two samples were taken from within 50 m of each other on the eastern shore of the spit and both contain similar significant proportions of albite dominated feldspars. Additionally, both contain varying proportions of kaolinite, a mixed layer of smectite/illite, illite, pyrite and amorphous material (most likely organic compounds). Of these minerals, VC2C contains a greater proportion of a mixed layer of smectite/illite and pyrite, whereas MUD4 contains a greater proportion of kaolinite, illite and amorphous material. VC2C also contains muscovite and amphibole, both of which are not present in sample MUD4.

Samples VC4A was taken from the present tidal flat environment in Pumicestone Passage. Samples PSGS4 and XGS9 were taken from Pumicestone Passage south of the tidal delta area. These three samples are representative of the present estuarine sediments within the north end of Pumicestone Passage. Each of these three samples contain varying proportions of quartz (70.8 – 78.6%), albite dominated feldspars (3 – 4.1%), kaolinite (9.8 – 12.9%), illite (1 – 2.2%), pyrite (0.2 – 0.7%) and amorphous material (3.7 – 8.6%). Also, sample XGS9 contains 2.5% mixed layer smectite/illite while samples PSGS4 and XGS9 contain none.

Samples VC1B and VC4B were obtained from estuarine sediments containing an abundance of shell material. VC4B was sampled 0.75 m below modern estuarine sediments in Pumicestone Passage while VC1B was sampled from within an outcrop of estuarine sediment on the eastern shore of the sand spit. Both samples contain an abundance of quartz (80 – 84%) along with much smaller proportions of clays. The clays in these samples consist of variable amounts of albite dominated feldspars (3.4 – 4.4%), kaolinite (7.1 – 9.5%), mixed layer smectite/illite (2 – 3.2%), illite (1.5 – 1.9%) and pyrite (0.6 – 1.3%). VC1B contains 0.7% amorphous material whereas VC4B contains none.

Samples AH10C and AH10D are augered samples of sand from the upper beach face on the eastern shore of the spit, 30 m shoreward of the exposure of estuarine mud (Fig. 45). Sample AH9B is also an augered sample of sand from the upper beach face 2.6 km north of AH10C and AH10D. The data show that each of these three samples contain an overwhelming abundance of quartz (86.8 – 94.7%) and a minor proportion of clay minerals. The clay minerals include albite dominated feldspars (0 – 3.1%), kaolinite (3.6 – 8.3%), illite (0 – 1.4%) and amorphous material (0 – 1.7%).

5.5 Stratigraphy

The stratigraphy of the sand spit is best shown on sections A-A' and D-D'. A basal unit of grey sand, likely of subtidal origin, is overlain by estuarine sediments, tidal flat deposits, and beach and possibly dune sands.

The estuarine sediments are characterised by a shell bed at the location of BIVC1, dated at 3330 $\pm$ 70 yBP, thus providing a maximum age for overlying deposits. The tidal flat deposits are characterised by dark brown mud containing extensive root material and other fibrous organic matter probably indicative of a mangrove environment. No tidal flat deposits were encountered along sections B-B' and C-C'.

The beach deposits lie non-conformably over the tidal flat deposits and consist primarily of medium-fine grained well-sorted quartz sand containing shell fragments and heavy minerals. Along sections B-B' and C-C' these sand deposits are of a similar character to those along sections A-A' and D-D'. Additionally, a well-developed soil profile is contained within the sand deposits along section B-B'.

5.6 Hydrodynamics Impacting of the North End of Pumicestone Passage

Current velocity measurements and bedform mapping within Pumicestone Passage and along the eastern shore of the sand spit have provided an indication of tidal circulations during the monitoring period (Figs. 47, 48).

Measurements within Pumicestone Passage were similar for both flooding and ebbing tides, with a slightly higher velocity obtained during the flooding tide. In contrast, measurements taken closer to the inlet were found to be almost twice the velocity observed further upstream. This is consistent with a more highly defined and narrower main channel related to the development of large sandbanks inside the inlet.

Current measurements taken along the eastern shore of the sand spit during the flooding tide indicate a southerly-directed current averaging 0.23 m/s, with a steady increase in current velocity with increasing distance from the inlet at Caloundra Bar.

Bedform mapping within the flood tidal delta of Pumicestone Passage also provided an insight into the hydrodynamics of the study area (Fig. 48). The large sandbanks inside the inlet exhibit a number of bedding features consistent with a flood-dominated environment.

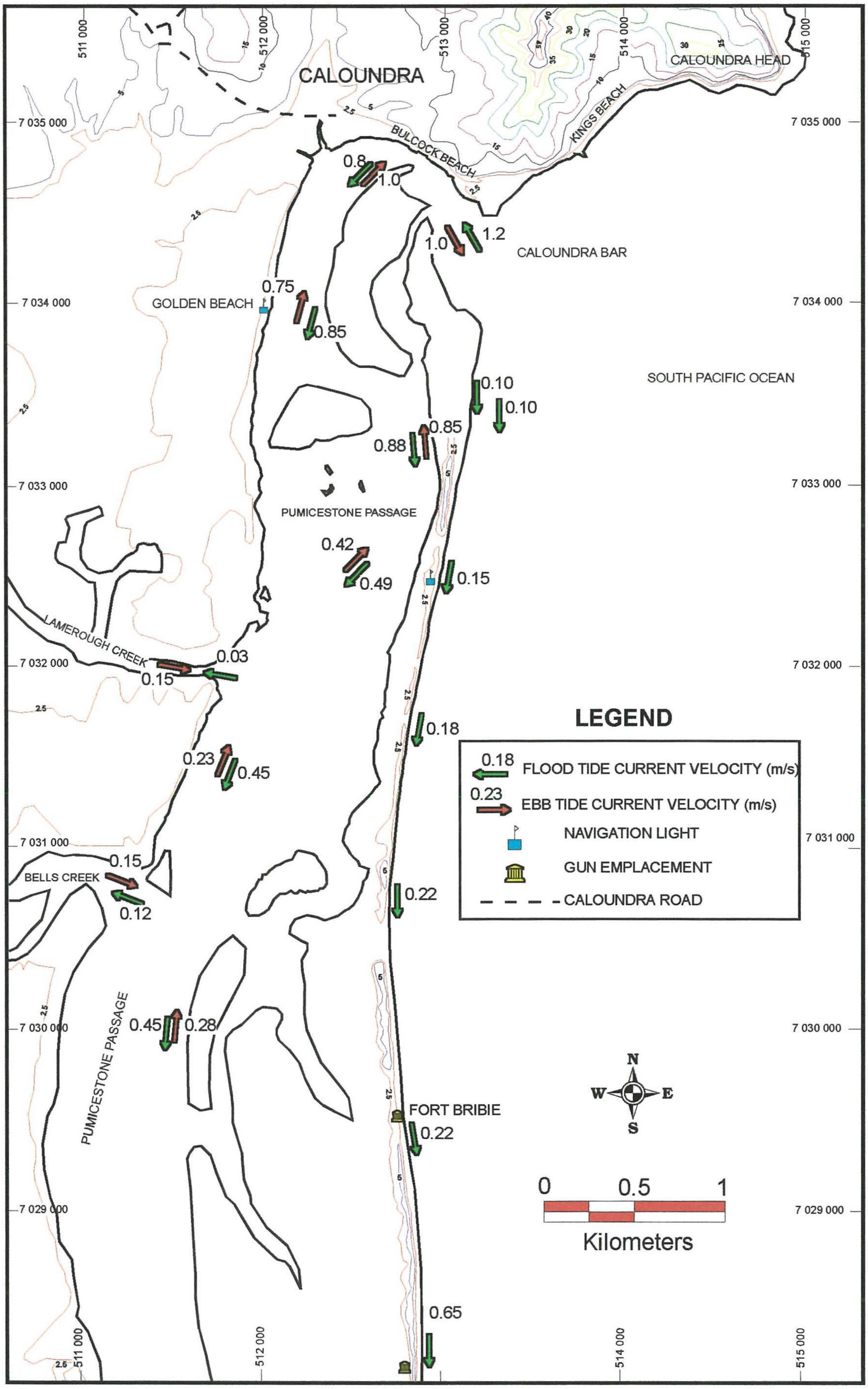


Figure 47. Pumicestone Passage and North Bribie Island Spit current data.

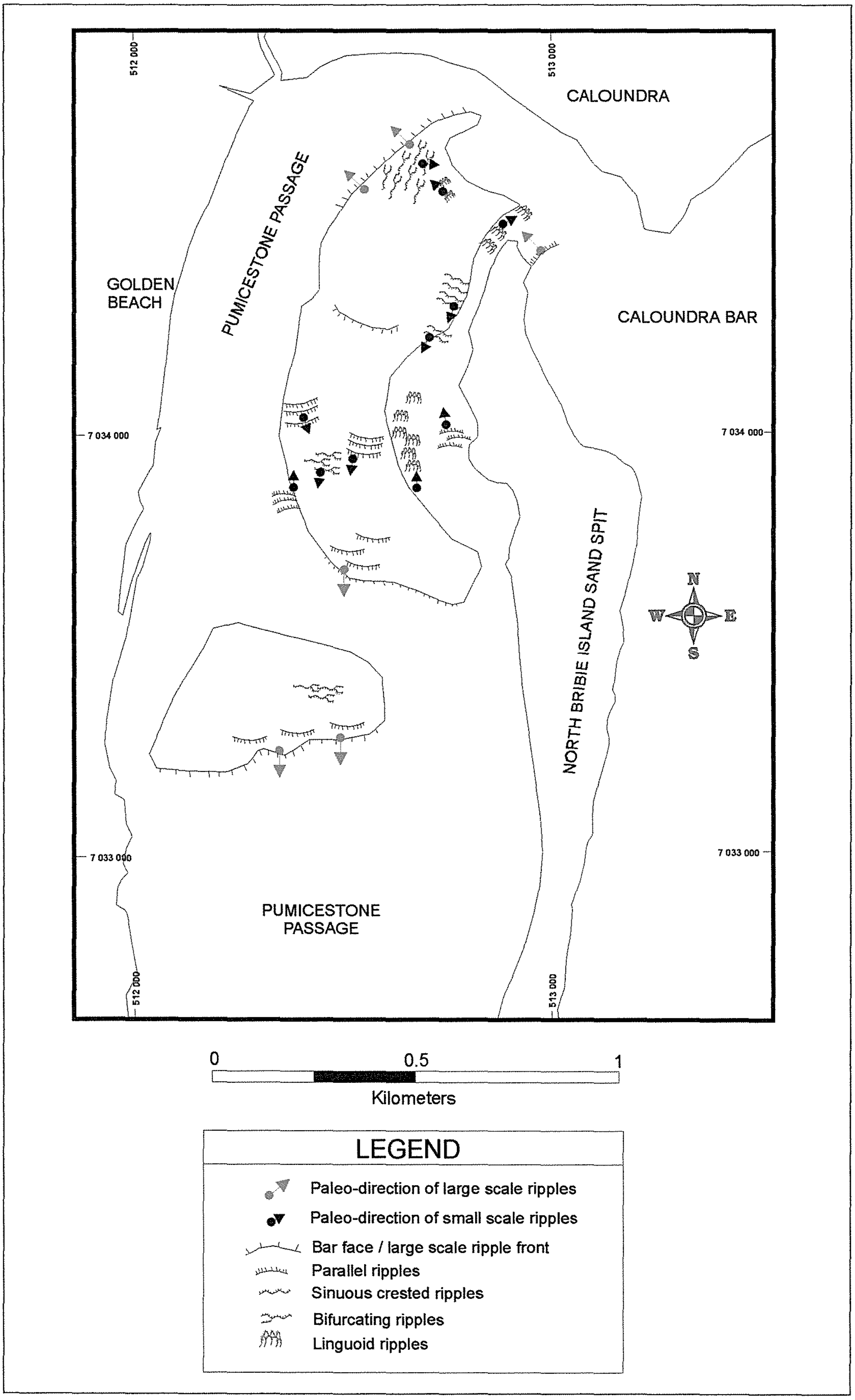


Figure 48. Pumicestone Passage flood tidal delta bedform map.

The surface of the sandbanks have large-scale ripples of 40 cm amplitude and wavelengths of approximately 400 metres. The geometry of these subaqueous dunes indicates deposition by flood tide currents. Small-scale ripples are superimposed on the dunes also indicating flood dominance. Small-scale ebb tide ripples are also present within the flood tide delta, but are mainly confined to channels that appear to take much of the ebb tide flows.

5.7 Shoreline Changes

The eastern shoreline of north Bribie Island spit has receded by at least approximately 60 m between 1940 and 1992. Since 1992, recession of up to 15 metres can be seen in aerial photographs of some areas of the eastern shoreline.

As well as recession of the eastern shoreline of the spit, there have been a number of significant changes in the shape of the northern end of the spit, including shifts in the position and width of the main inlet channel at Caloundra Bar. The pronounced changes in the shape of the sand spit can be seen in maps of the shoreline for the years 1940, 1961 and 1999 (Fig. 49).

In 1940, the main inlet channel lay within 50 m of the Caloundra headland (BPA, 1993). By 1961, a northern segment of the spit had joined to the headland and extended approximately 850 m south to the new inlet. The southward retreat of the spit attached to Bribie Island was accompanied by a loss of approximately 600 m of vegetated dunes. By 1971, the mainland spit retreated approximately 500 m northwards, accompanied by a northward migration of the inlet channel and extension of the Bribie Island spit. Between 1971 and 1972, the mainland spit retreated a further 60 m with the erosion of the vegetated dune deposits.

Erosion of the spit extending from the mainland, accompanied by northward extension of the spit attached to Bribie Island by approximately 600 m, continued until 1982. This resulted in a reduction in the length of the mainland spit to approximately 300 m. Between 1982 and 1992 the Bribie Island spit retreated south by approximately 500 m, with little change in the length of the mainland spit. Between 1992 and 1999, the Bribie Island spit had extended northwards by approximately 550 m concomitantly with a reduction in the width of the inlet and recession of the mainland spit of approximately 100 m.

Between 1940 and 1999 a continuous influx of sand into Pumicestone Passage via the inlet channel at Caloundra accompanied the progressive recession of the eastern shoreline and the

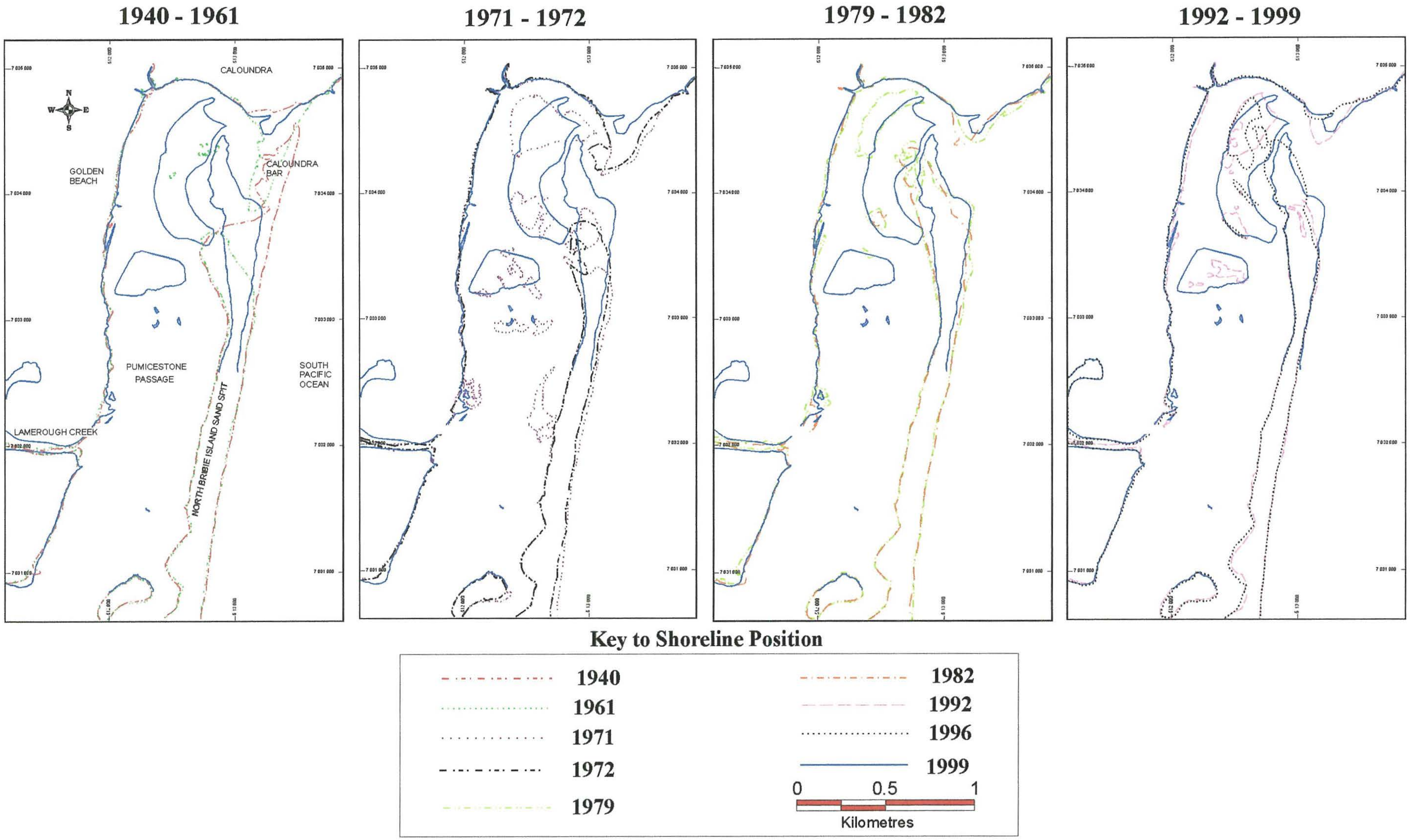


Figure 49. Shoreline changes from 1940 to 1996 in relation to 1999 shoreline position based on aerial photograph interpretation

migrations of the Bribie Island spit and the mainland spit. This influx of sand produced progressively expanding sandbanks in the flood tide delta at the entrance of Pumicestone Passage.

There has been little change in the position of the northern bank of Pumicestone Passage at Caloundra probably due to bedrock outcrops, an example of which is evident on the mainland side of Caloundra Bar (Fig. 50). There have been only small changes along the western bank of the passage during the period 1940 to 1999.

Figure 50. Looking south across Caloundra inlet to spit showing an outcrop of Landsborough Sandstone on the mainland side of the inlet.

5.8 Modelling and Volumetric Analysis of Sediment Movement

The use of computerised modelling has permitted a comparison of sand volume changes in the flood tidal delta at Caloundra with the volume of sand removed from the eastern shore of the Bribie Island spit between 1978 and 1993. This comparison should indicate whether this section of coast is operating as a closed sediment transport system, or an open system with the loss of sand from the Bribie Island spit exceeding the input of sediment to the tidal delta.

Changes in sediment deposits are presented in maps that show bathymetry contours of the flood tidal delta and topography contours of the eastern shore of the spit (Fig. 51A, 51B). As expected, the maps show a large build up of sand in the north end of Pumicestone Passage between 1978 to 1993. In association with the build up of sand in Pumicestone Passage, the eastern shoreline of the spit retreated by up to 50 m between 1979 and 1992 (Fig. 52).

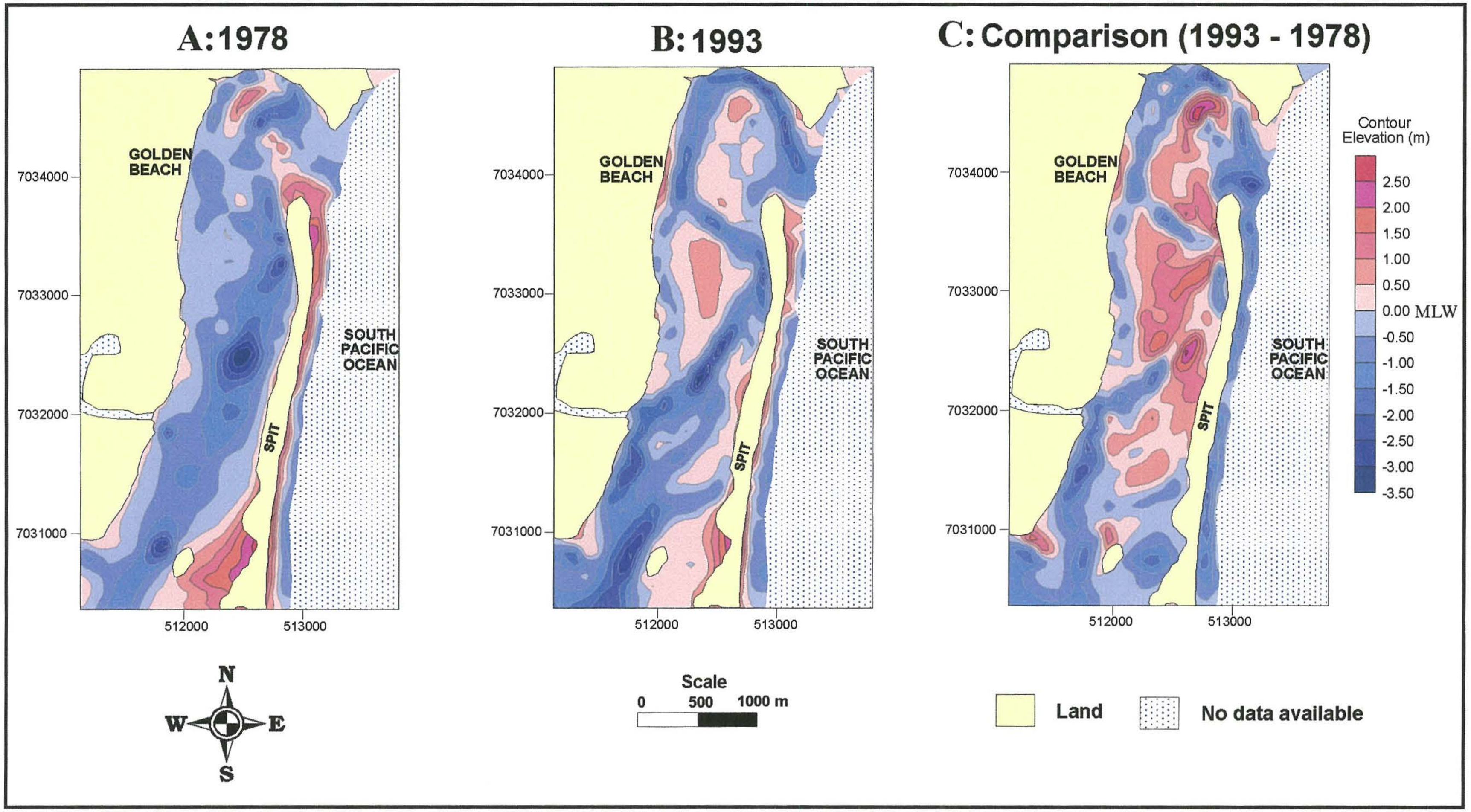


Figure 51. Comparison of bathymetric data for sediment budget calculations. (A) and (B) show sediment distribution in Pumicestone Passage and on the eastern shore of the spit in 1978 and 1993. It is evident that a significant volume of sand has moved into Pumicestone Passage since 1978, shown by the build up of large sand banks in the flood tidal delta (B). A comparison of sediment distribution between 1993 and 1978, (C), shows that a substantial volume of sediment has been removed from the eastern shore of the spit (shown by negative contour elevations), corresponding with the build up of sediment in the flood tidal delta of Pumicestone Passage (shown by positive contour elevations).

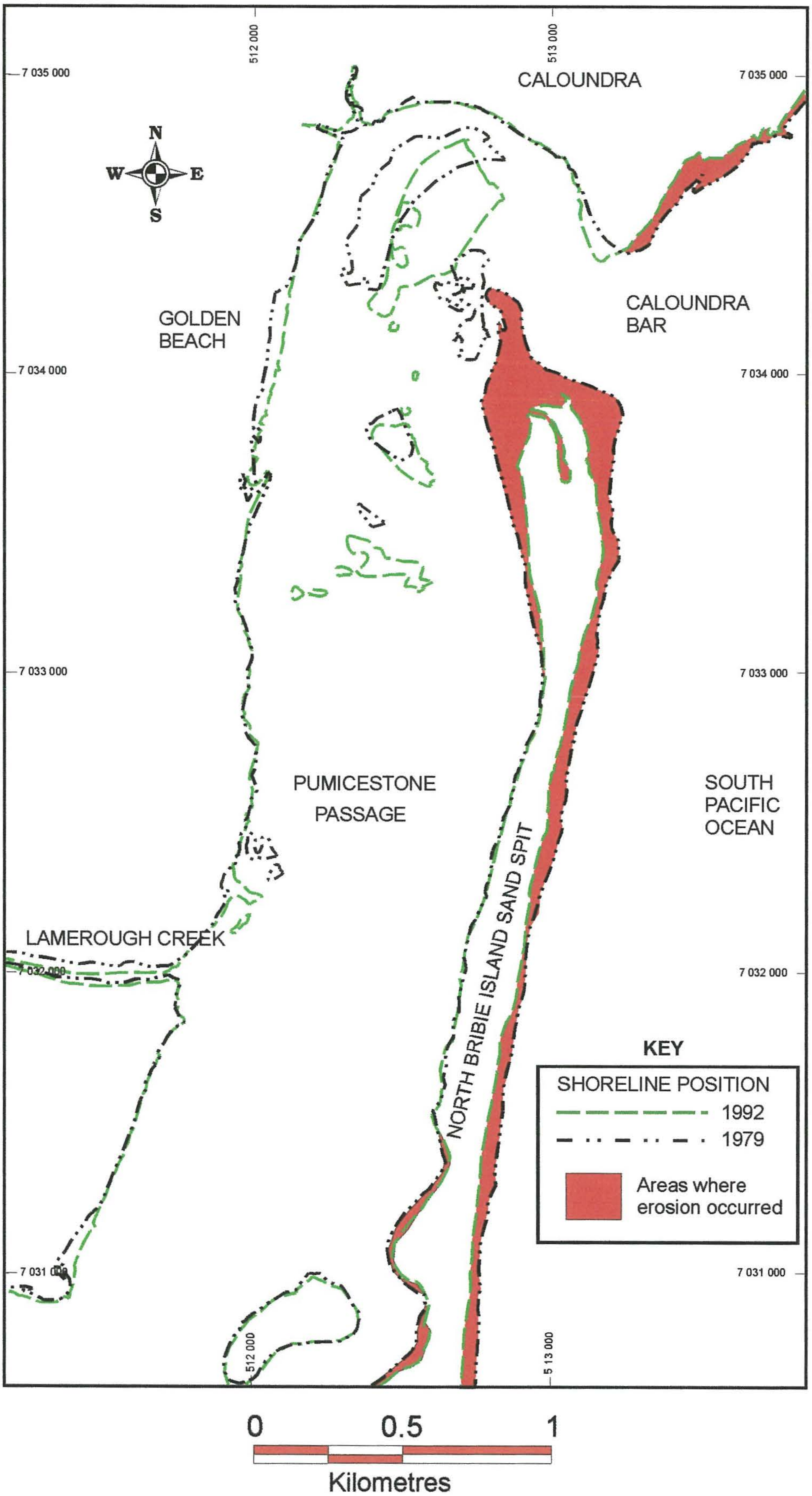


Figure 52. Retreat of the eastern shoreline 1979 to 1992.

A volumetric analysis of the sediment flux has been obtained by overlaying the bathymetric grids of 1978 and 1993 and determining areas of cut (erosion) and fill (deposition); (Fig. 51C). Volumetric calculations using *Surfer* software reveal a cut of approximately 3 600 000 m^3, a fill of approximately 2 900 000 m^3, and a deficit (loss) of approximately 720 000 m^3, between 1978 and 1993. Therefore, the study area has experienced erosion at a rate of approximately 144 000 m^3yr^{-1}, deposition at a rate of approximately 116 000 m^3yr^{-1}, and a loss of sand at a rate of approximately 30 000 m^3yr^{-1}.

5.9 Climatic Data

Data relating to tropical cyclones and low-pressure systems of significant intensity likely to cause coastal erosion on the Queensland coastline reveals that there have been 200 reported tropical cyclones affecting Queensland from April 1858 to April 2000, along with 70 reported 'significant' low-pressure systems from August 1846 to April 2000. Of the tropical cyclones, about 90 (45%) have been reported to have directly impacted on the southeast Queensland beaches between April 1858 to April 2000. Torrential rain, strong winds, widespread flooding, tidal surges and heavy seas caused significant beach erosion in many areas. As expected, the data indicate that tropical cyclones are confined to the summer and autumn months, from December to April.

About 60 (86%) of the low pressure systems have been reported to have directly impacted on southeast Queensland beaches between April 1846 and April 2000. The data indicate that the low-pressure systems have formed during any month of the year, and typically at lower latitudes than tropical cyclones.

Analysis of the data in 1 year intervals between 1861 and 2000 (Fig. 53) has provided a detailed description of storm frequency. The data indicate three levels of storm frequency. These are a period of low storm activity (0-1 storms per year), moderate storm activity (2-3 storms per year) and high storm activity (greater than 3 storms per year). While periods of low annual storm activity are the most common between 1861 and 2000, the data indicate that there has been an increase in the frequency of moderate to high annual storm activity impacting on the study area since 1930.

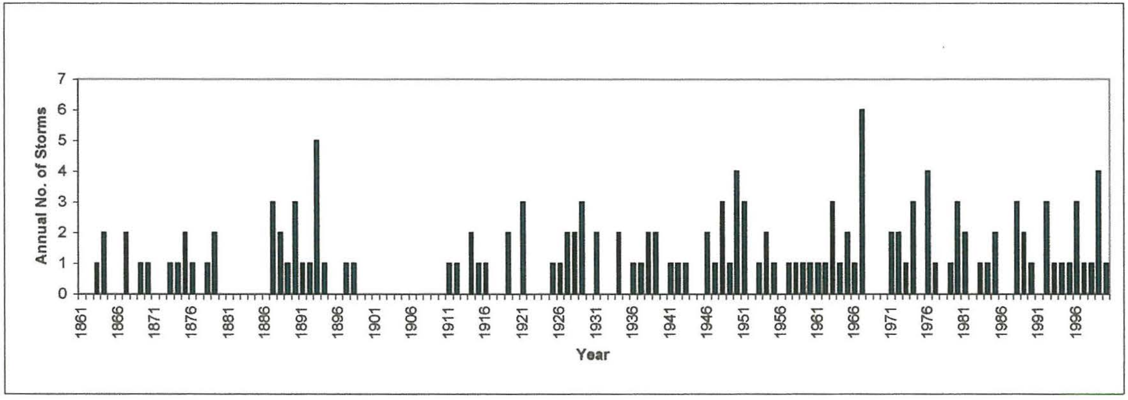


Figure 53. Annual cyclone and low pressure system frequency for the study area (1861 – 2000).

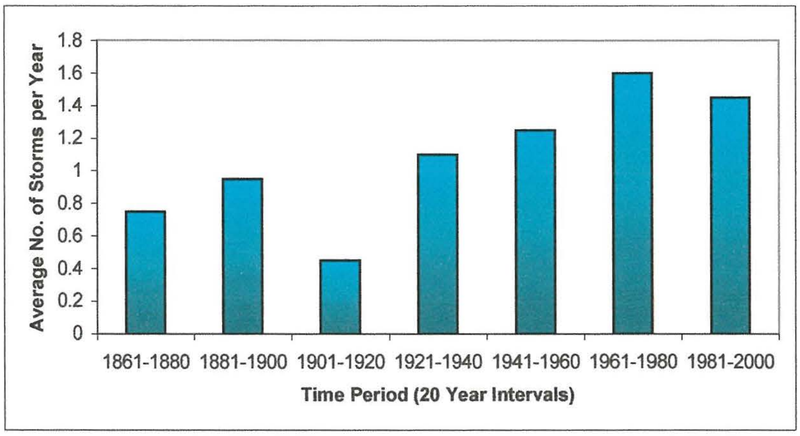


Figure 54. Cyclones and low pressure systems that have been within 500 km of the study area, averaged over 20-year intervals (1861 – 2000).

The data, grouped at 20-year intervals between 1861 and 1920, indicate that the average number of storms per year impacting on the study area (Fig. 54) is less than one severe storm per year. In the ensuing period 1921 to 2000 the frequency of storm activity has increased to greater than 1 severe storm per year. These data point to a progressive increase in storm activity impacting on the study area in the last 80 years.

Confirmation of this apparent increase in storm activity is confirmed by statistical analysis of the storm data (averaged in 5 year intervals, Fig. 55) using a Wilcoxon rank-sum test. The test incorporated a null hypothesis that there has been no change in the frequency of storm activity in the periods 1861 to 1930 and 1931 to 2000. The calculated test statistic falls outside the region for acceptance, thus rejection of the null hypothesis. As expected this indicates a significant increase in the frequency of storm activity affecting the study area since 1930.

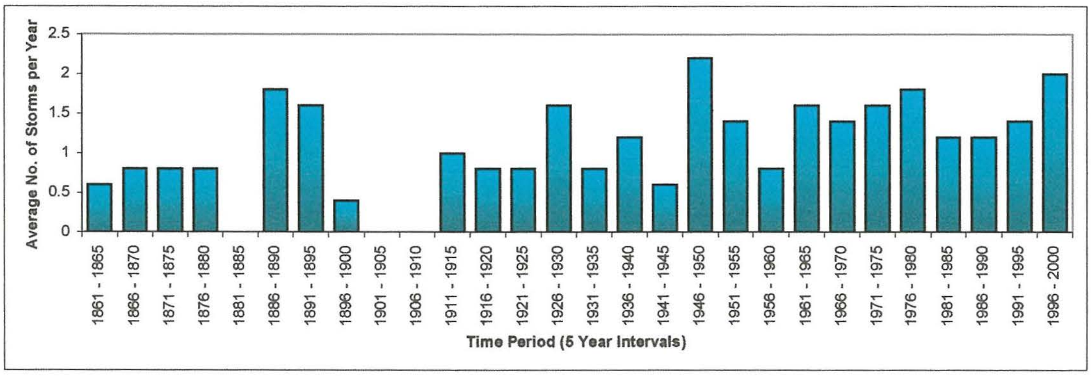


Figure 55. Average number of storms per 5-year interval within 500 km of the study area, 1861 – 2000.

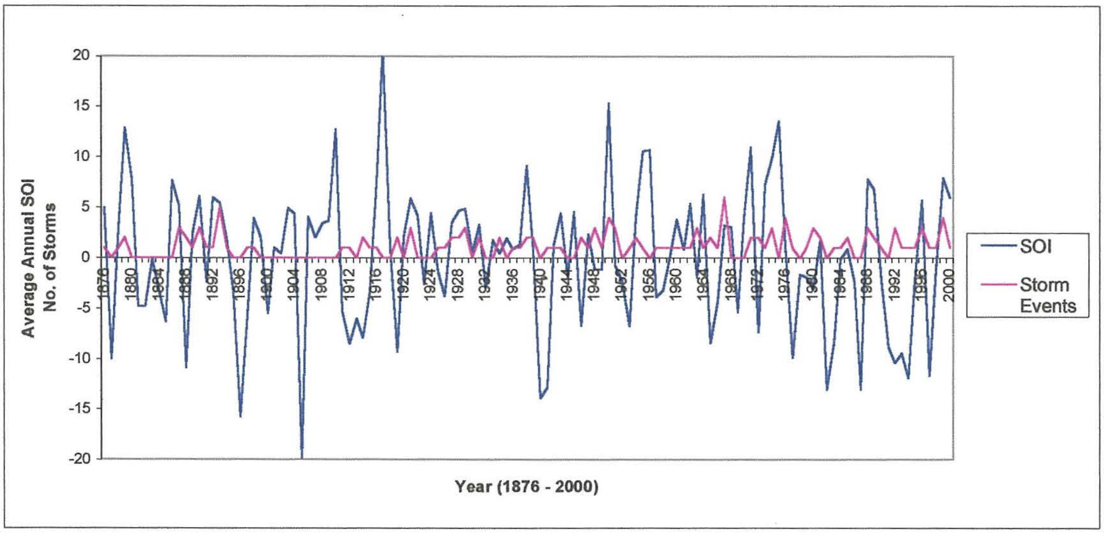


Figure 56. Comparison of average annual Southern Oscillation Index (Australia) and storm frequency impacting 500 km of the study area, 1876 – 2000.

In consideration of controlling factors on meteorological events, analysis of SOI data has indicated a correlation between storm frequency and variations in Southern Oscillation. Analysis of annual averages of SOI between 1876 and 2000 for Australia (Fig. 56), indicates a good correlation between the La Niña cycle (positive SOI) and periods of moderate to high storm activity that have affected the study area. For example, recent La Niña cycles have occurred in 1988/89, 1998/99 and 1999/2000 with the most recent event ending in May 2000. Each of these La Niña cycles has coincided with periods of moderate to high storm activity affecting the study area.

Conversely, there is also a good correlation between El Niño cycles (negative SOI) and periods of low storm activity affecting the study area. For example, the most recent El Niño event occurred in 1997/98 and coincides with a period of low storm activity affecting the study area. Similar patterns exist for previous years, with some minor variations.

Statistical analysis of the SOI data using a Wilcoxon rank-sum test has revealed a slight increase in the frequency of oscillations between El Nino and La Nina cycles since 1938. This is significant as it coincides with the previously mentioned increase in the frequency of storms affecting the study area since 1931.

Sediment budgets for the study area for the period 1958 to 1972 by Jones (1992) and for the period 1978 to 1993 (this study) have been calculated for periods that have experienced an increase in storm activity compared to previous periods (Fig. 54). For the period 1958 to 1972, 22 severe storms were recorded to have impacted on the Sunshine Coast, while for the period 1978 to 1993, 21 severe storms were recorded (Fig. 57). Analysis of SOI averages for the sediment budget timeframes also reveals a slight variation. In the period 1958 to 1972, four La Niña and four El Niño cycles occurred (Fig. 58A) whereas three La Niña and four El Niño cycles occurred in the period 1978 to 1993 (Fig. 58B).

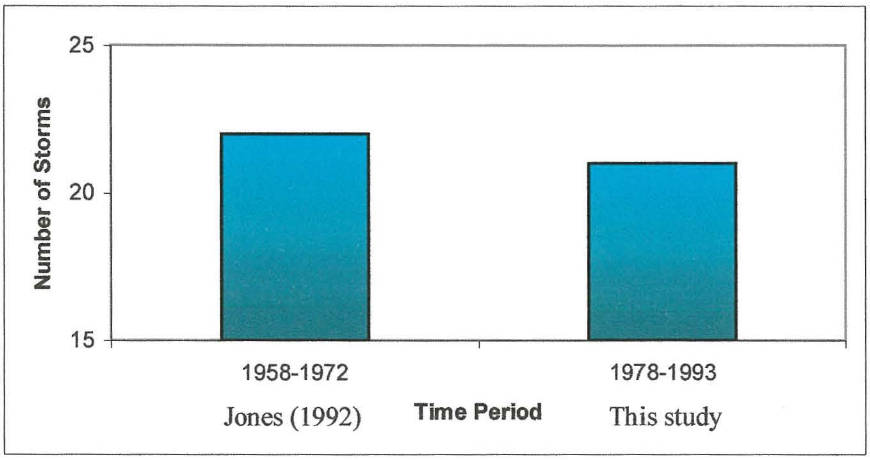
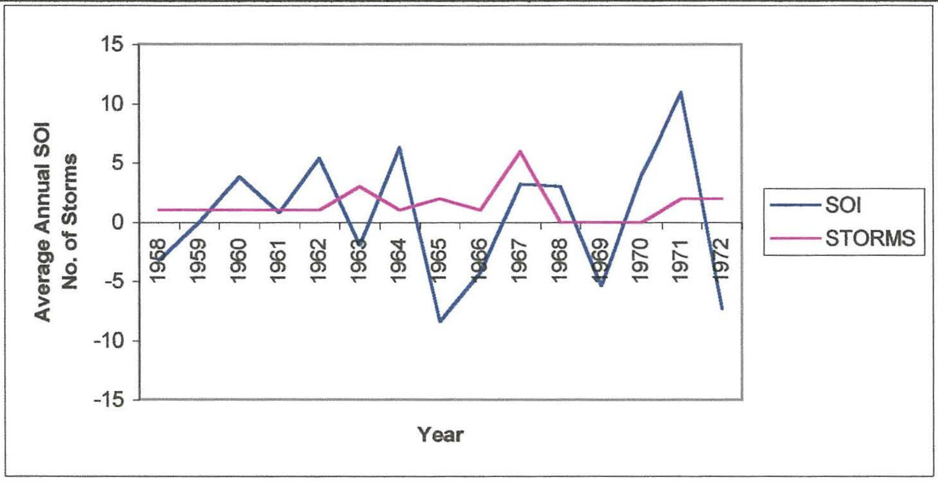
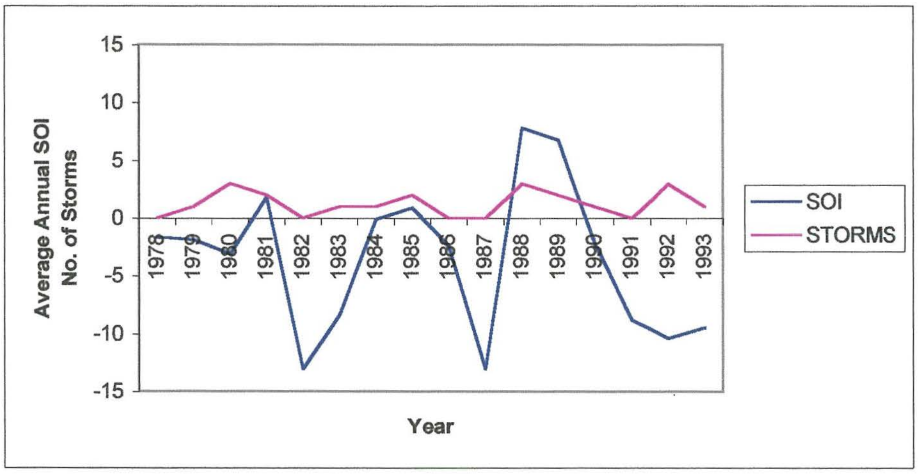


Figure 57. Number of storms impacting within 500 km of the study area during sediment budget calculation periods.

61



A) Average annual SOI compared with the number of storms impacting within 500 km of the study area (1958 – 1972).



B) Average annual SOI compared with the number of storms impacting within 500 km of the study area (1978 – 1993).

Figure 58. Average annual SOI compared with the number of storms within 500 km of the study area for the periods of sediment budget calculations. (A) Jones (1992), (B) this study.

6.0 DISCUSSION

The results contained in the previous section have provided a range of reliable geoscientific data that indicate several major factors are platform for discussion on factors affecting the stability of the Bribie Island spit. Fortunately some results have been able to be compared to an earlier study (Jones, 1992), providing a relatively large temporal scale for the study of the spit, especially in relation to sediment budget calculations. In this chapter a variety of data generated in this study will be incorporated into a comprehensive assessment of the stability of the spit.

6.1 Evidence of Shoreline Changes from Sediments and Stratigraphy

Two potential sources of sand for the Bribie Island east coast (Jones, 1992) are:

1. A supply of sand through erosion of existing onshore deposits;
2. Input from the tidal delta deposits (North Banks) offshore.

The supply of sand from the North Banks during the Holocene transgression may have been a relatively short-lived event, as by the time sea level had stabilised during the Holocene, the North Banks were too far offshore to provide any further contribution of sand to the Bribie Island east coast (Jones, 1992). Additionally, the North West Channel which separates the North Banks from the Bribie Island coast, appears to have prevented sand reaching the island as it is lost in the deeper water of the channel and transported south to Skirmish Point (Jones, 1992). Given that the depth of the North West Channel varies between 11 m and 19 m, and the wave height influencing the Bribie Island spit is approximately 1 m (80% of the time Fig. 17), it is unlikely that sand could be transported across the channel or back onshore from the channel after a storm event.

Analysis of sand samples taken within the study area, specifically sorting versus skewness plots (Figs. 41B, 42, 43B, 44B and App. C), indicates the predominance of well sorted and clean sands, suggesting long residence times between initial erosion and deposition. These sedimentological features imply that no new sand (eg. from a fluvial source) has been supplied to the study area in recent times.

Given that there has been no new influx of sand, evidence for recycling of existing deposits is gained from grainsize data and results of the microscope analysis of sand samples collected from the spit (Appendix C, D). Results indicate sand deposits consist of predominantly sub angular to rounded quartz, minor amounts of lithic fragments and little to no feldspar. These results suggest that shoreline processes have considerably reworked the sands forming the spit, rounding the resistant quartz grains and destroying the weaker feldspar grains. It is possible that the texture of the sand indicates recycling of existing sand deposits, and that recycling may be the main source for sand supplies within the study area. Earlier investigations in the Bribie – Caloundra region have also proposed recycling of existing onshore deposits (Jones, 1992).

As mentioned previously, the estuarine sediments outcropping on the eastern shore of the Bribie Island spit are an important feature of the study area. The relationships between these outcrops and the modern tidal flat deposits of Pumicestone Passage are a key feature in the development of an evolutionary model for the sand spit. Comparisons of cores and x-ray diffraction analysis of estuarine and tidal flat deposits within the study area has permitted mineralogical and stratigraphic correlations to be made (Table 9).

Sample VC1B, taken from the eastern shore of the spit, is similar to sample VC4B, taken from the tidal flat area of Pumicestone Passage, based on a similar chemical composition of clay minerals as well as a lack of amorphous content (organic matter). The relationship of these two samples is shown stratigraphically on sections A-A' and D-D' (Figs.41B and 42). The unit from which both these samples were taken is a typical estuarine deposit that contains a vast number of shells of estuarine species and shell fragments, most of which were uncovered where BIVC1 was recovered. These data suggest that Pumicestone Passage was wider than it is today at around 3330 yBP (^{14}C age of *Anadara Trapezia* sample), and the sand spit lay considerably further east of its present position.

Comparisons of samples VC4A, PSGS4, XGS9, from modern estuarine and tidal flat deposits, and sample VC2C from tidal flat deposits exposed on the eastern shore, reveals a different clay mineralogy between the two groups, with much less quartz and greater concentrations of kaolinite, smectite, and organic content present in VC2C (Table 9). The stratigraphic locations of samples VC4A and VC2C are presented on section A-A' (Fig. 41B). Other notable differences are the presence of muscovite and amphibole in sample VC2C, suggesting a fluvial component in the sediment building the tidal flats at approximately 3330 yBP, the likely provence being the North Arm Volcanics west of the study area. The absence of muscovite and amphibole in samples VC4A, PSGS4 and XGS9 suggests a diminished supply from this source after that time. The presence of feldspars in all samples, with the exception of XGS9 (Table 9), indicates a similar source for a significant component for the estuarine sediments deposited approximately 3330 yBP and those deposited in the present day environment.

The predominance of quartz in samples AH10C, AH10D and AH9B accompanied by a lack of clay minerals may suggest a higher energy depositional environment (Table 9). Alternatively, the mineralogical composition of these samples may be a product of weathering and reworking of tidal flat deposits.

6.2 Geological Records of Erosion

The new geomorphological, sedimentological, stratigraphic and chronological data gained by this study provides the opportunity to propose an evolutionary model of the north Bribie Island spit. This model considerably updates and expands on an earlier study of the Bribie – Caloundra region (Jones, 1992).

The evolution of the Bribie Island spit is closely related to Holocene sea level fluctuations and sediment supply and loss. Since the Last Interglacial highstand (~120 000 yBP) there have been a number of episodes of sea level rise and fall. During the Post Glacial Marine Transgression (~18 000 – 6 500 yBP) it has been proposed that substantial deposition of sand occurred in the former embayment inland from Golden Beach (Jones, 1992), although there is no geochronological data to support this morphostratigraphic interpretation. Probable infilling of the embayment during the early stillstand led to the development of a foredune ridge succession inland of Golden Beach, as suggested by aerial photographs of the area prior to urbanisation (Appendix H); (Beach Protection Authority, 1993; Jones, 1992).

The beach ridge succession inland of Golden Beach indicates that the Bribie Island spit probably formed later in the Holocene. This interpretation was also proposed by Jones (1992) who reports that a humic sand rock layer underlying a section of the spit provided a radiocarbon age of 3440 $\pm$ 105 years (corrected for marine reservoir effect). As part of the present study, a radiocarbon age of 3330 $\pm$ 70 yBP was obtained for shell recovered from the estuarine deposits outcropping on the eastern shore of the sand spit. The data indicates that by 3330 yBP sea level was similar to the present level as the estuarine and tidal flat deposits crop out in the intertidal zone.

A slight fall in sea level and shoreline progradation after 3330 yBP has been proposed by Flood (1981), and that may have led to the formation of a much wider spit eastward of its present position in response to the mobilisation onshore of sand deposits in the nearshore zone. As the nearshore profile slopes gently to a maximum water depth of 16 m over 1 km from the present location of the spit (Fig. 10), the mobilisation of stored sand deposits at a slightly lower sea level is quite feasible. Erosion and redeposition of sections of the

Pleistocene deposits of Bribie Island, south of the spit, may also have provided sand for accretion of the spit. Much of the shoreline progradation in the Golden Beach area was also related to infilling of intertidal and sub tidal areas with tidal delta and estuarine channel deposits, filling in the paleo estuary between the mainland and the spit (Jones, 1992).

In studies on both the southern and northern Great Barrier Reef, a slight fall in sea level at approximately 3000 yBP may have been responsible for a major phase of island development and accretion (Flood et al., 1979). Additionally, paleotemperature data obtained by Flood (1981); (unpublished data) for radiocarbon dated shells from Lady Elliot Reef indicates that a fall in sea level occurred between approximately 3050 and 2750 yBP at this location. However, the record of Holocene sea level for different regions of the east coast of Australia may vary by a few metres, and the eustatic record indicates stable sea level since approximately 6000 yBP (Fig. 7); (Flemming et al., 1998).

The possible rise of sea level to its present position since ~3330 yBP at Bribie Island may be a factor in the landward retreat of the Bribie Island spit and its translation over the top of estuarine and tidal flat deposits, resulting in their exposure on the eastern shore of the spit after storm conditions. These exposures and the new radiocarbon age provide additional strong evidence of long term erosion of the spit throughout the late Holocene.

6.3 Observations of Modern Processes and Their Implications

Field observations of the north Bribie Island spit indicate that erosion in recent years is a major feature of this barrier. Recent erosion is evidenced by the extent of the erosional scarp stretching along the eastern shore, accompanied by a retreat of some parts of the mainland side of the spit, and the erosion of dunes that appear to have advanced into Pumicestone Passage as evidenced by monitoring (Fig. 39, Table 7). Erosion of these dunes is probably caused by draw down effects due to tidal fluctuations and natural tidal channelling processes.
Fallen vegetation and bank slumping are evident on the passage side of the spit where erosion has occurred. Although the east and west shore have experienced erosion, the northern tip of the spit has accreted since about 1992. This has been is response to the northward migration of the entrance to Pumicestone Passage (Fig. 59A, 59B).

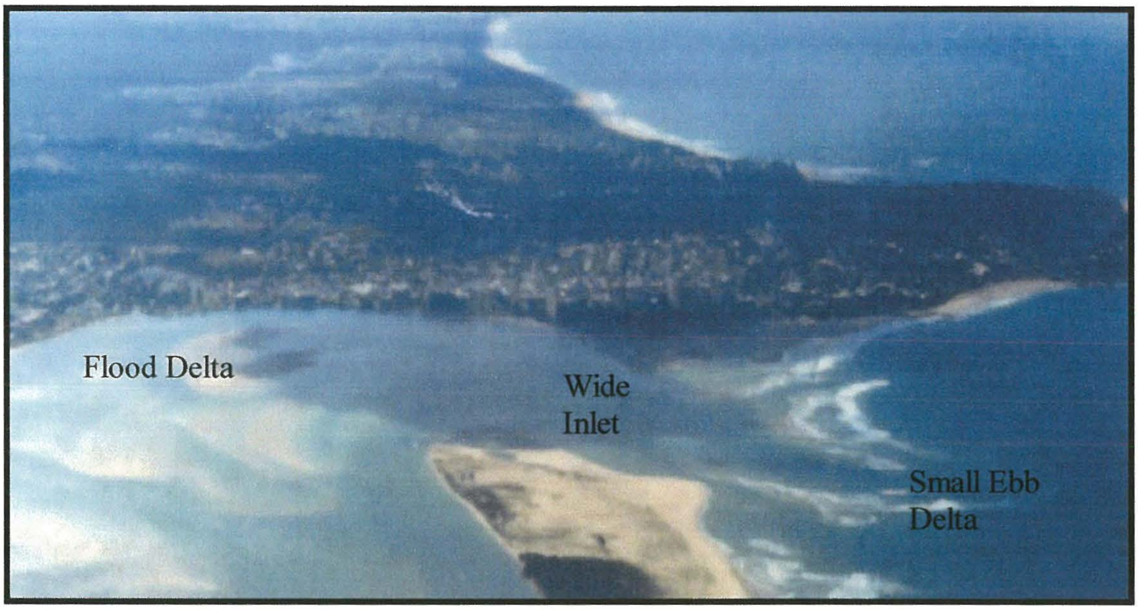


Figure 59A. Northern tip of Bribie Island spit and inlet (near low tide, 4/5/1989). Note the lack of a well-developed ebb delta and the broad inlet. Also, there is a large volume of sand moving into the flood delta evidenced by sandbanks in the Passage (Lang et al., 1989).

Figure 59B. Northern tip of Bribie Island spit and inlet (low tide, 25/5/2000). Beach ridge progradation has led to the northward accretion of the spit and subsequent narrowing of the inlet. The well-developed ebb delta is visible in Figure 60B. The accretion of the spit is accompanied by the growth of pioneer dune vegetation (*Casuarina* trees and creepers).

The relative age of the accretion at the north end of the spit can be viewed on the cross sections (Figs.41B, 43B, 44B), as indicated by the zonation of existing vegetation. Young *Casuarina* trees and creepers dominated the newly accreted area whereas distinct zones of heath vegetation along with incipent soil profiles can be discerned on older, presently eroding areas. Additionally, much of the sand spit comprises a single dune while the most recently accreted area, north of section C-C', consists of multiple beach ridges. This recently accreted area is in the most dynamic part of the spit, fluctuating between erosional and accretional regimes, as observed in aerial photographs of the spit (Fig. 49).

Time-series analysis of aerial photographs has revealed that the eastern shoreline of the Bribie Island spit has progressively retreated landward by at least 75 m since 1940 (Fig.49). Additionally, the mainland side of the spit has either retreated slightly in some areas or remained stationary. In this period the tidal inlet at Caloundra Bar has shifted both northward and southward associated with the accretion and recession of both the north end of the Bribie Island spit and the sand spit attached to the mainland at Caloundra. This indicates the highly dynamic nature of this environment, where associated changes in the tidal inlet morphology and spit landforms represent one sediment system.

In a barrier system tidal energy has an important impact on the overall morphology of the barrier inlet complex (Davis, 1994). Although the Bribie Island spit is predominantly a mixed energy to wave dominated system at the north end of the spit, tidal influences dominate during fair weather conditions, hence the morphology of the inlet may vary during periods of low wave energy. An example of this is shown in Figure 60 where there is little evidence of an ebb delta in 1987 (60A) compared with a well-developed ebb delta in 2000 (60B). A well-developed ebb delta has a profound impact on adjacent sand spit: waves are refracted around the ebb delta creating a local reversal of longshore current on the southern side of the tidal delta, as shown in Figure 3, which directs sediment into the flood dominated inlet (Fig 60A).

The newly accreted northern tip of the Bribie Island spit consists of multiple low beach ridges shaped by aeolian processes (Fig. 61). The accretion of this portion of the spit since 1989 in association with a well-developed ebb delta, can be seen in Figure 60. The diversion of longshore currents created by a prominent ebb delta has created a sediment sink, with the trapped sediment moving onshore to nourish the beach at the northern tip of the spit or into Pumicestone Passage in the form of large sand banks in the flood tidal delta region. The onshore movement of sand at the northern tip of the spit has created a wide backshore area subject to aeolian processes. The widening of the north end of the Bribie Island spit is similar to the development of 'drumstick' barriers described by Davis (1994; Section 2.2.1).

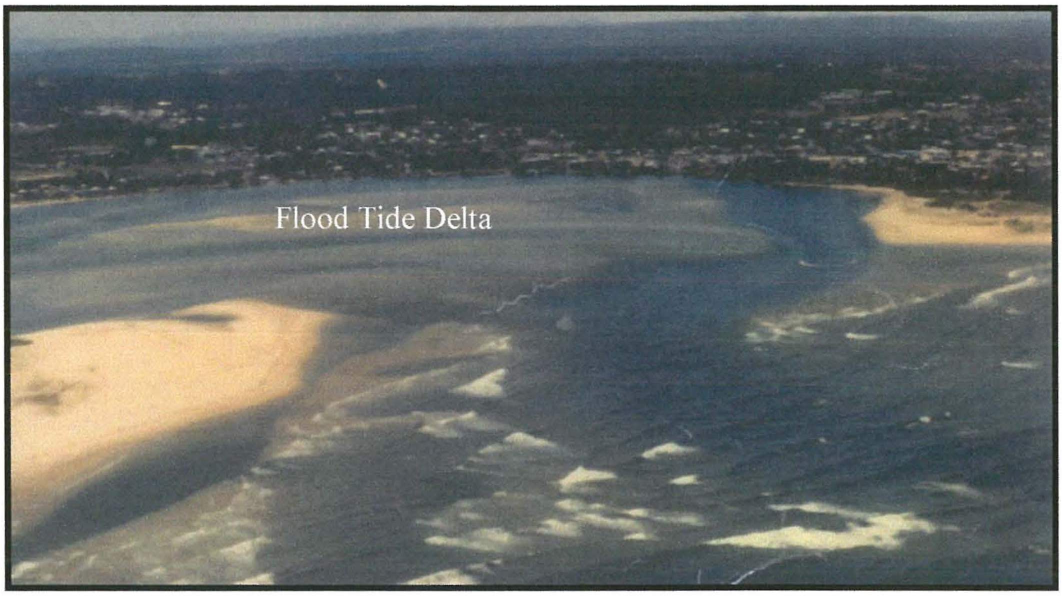


Figure 60A. Flood tide delta (Near low tide 14/3/1997). Looking west at Caloundra inlet showing lack of ebb tide delta and a flood-tide delta. Note the great width of the inlet at this time.

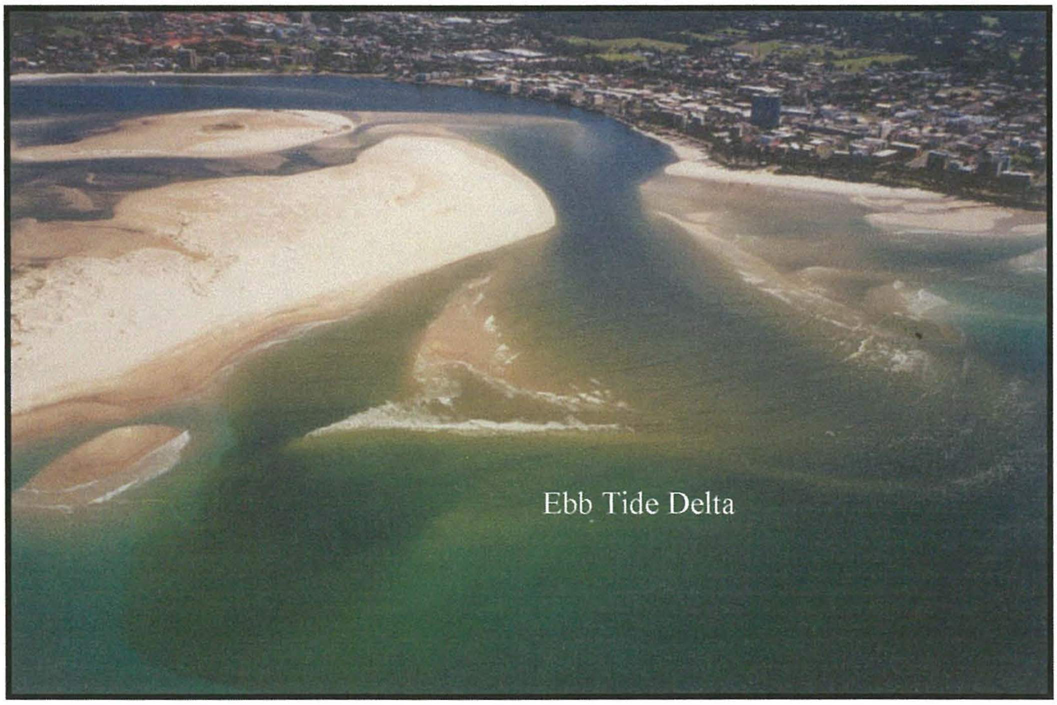


Figure 60B. Ebb tide delta (Low tide 25/5/2000). Looking west at Caloundra inlet, showing both the flood-tide delta and a well-developed ebb-tide delta after the April storm. The narrow width of the inlet channel is due to northward accretion of the spit. Sandbanks are exposed above low tide in the flood-tide delta.

Figure 61. Position of multiple beach ridges oriented north-south on the newly accreted northern tip of the spit (Low tide 25/5/2000).

The build up of sand at the northern end of the spit can also be seen in Figures 37 and 38 where the previously exposed beach track is almost buried with sand. This contrasts with the beach further south at Fort Bribie, which is being starved of sand. This is consistent with the drumstick barrier model described by Davis (1994) where prograding characteristics are observed adjacent to the inlet and recession occurs further alongshore, exposing older back-barrier sediments. The combination of progradation at one end of the barrier and recession at the other end can result in a change in the orientation of the barrier. This may happen with the Bribie Island spit as accretion at the northern end may lead to closure of the present inlet and the opening of an inlet further south. Alternatively, erosion at the southern end of the spit may create a new opening and lead to closure of the present inlet.

Intense storms may partly control large-scale, long-term mobility of sandy shores by transporting large volumes of sand in short periods (Moreton et al., 1995). The effects of such storms have been observed within the period of this study. The east coast low impacting on the study area in April 2000 resulted in a large volume of sand being eroded from the eastern shoreline. Similar types of erosional events have occurred over the last century, as described in Section 5.9 and detailed in Appendix F.

While the erosion of sand from the foreshore, backshore and shoreface is the dominant mode of sediment transport during storm conditions, the rebuilding of eroded beach profile occurs during fair-weather conditions. The results of the beach monitoring program after the April storm indicate approximately 0.75 m of sand moved back onto the beach around section A-A', in the southern part of the study area (Fig. 41B). In comparison, section C-C' (Fig. 44B), in the northern part of the study area, shows approximately 1.5 m of sand moving back onto the middle to upper beach face. Under fair-weather conditions, following the April storm, sand has moved back onto the eastern shoreface aided by spring high tides and small waves. The recent development of a significant ebb delta at the inlet (Fig. 60B) has led to the more rapid recovery of the northern section (section C-C') of the spit compared to the section further south (section A-A').

Littoral drift from north to south along the eastern shore of the spit is a likely method of sediment transport under fair-weather conditions as indicated by current velocity measurements along the eastern shore of the spit (Fig. 47). Additionally, the build up of sand on the northern side and exposure of bedrock on the southern side of the Kings Beach groyne is in agreement with southward littoral drift along this section of coast (Fig. 62). This has also been observed in a previous study (Jones, 1992). The combination of southward transport along the eastern shore and littoral current reversals in the lee of the inlet, produce the sediment transport pathways within the study area under fair-weather conditions (Fig. 18).

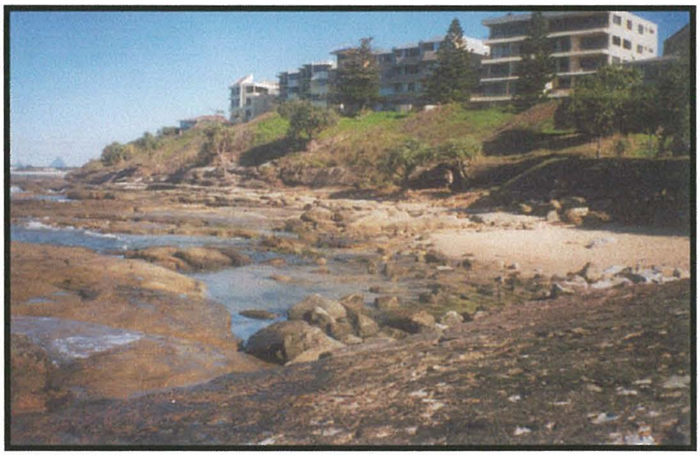


Figure 62. Bedrock (Landsborough sandstone) exposed on the southern side of Kings Beach groyne.

Based on the field measurements, analysis of aerial photographs, and a previous sedimentological study (Jones, 1992), summaries of the processes influencing sediment transport on the eastern shore of the spit before (A), during (B), and after (C & D) storms conditions are presented in Figure 63.

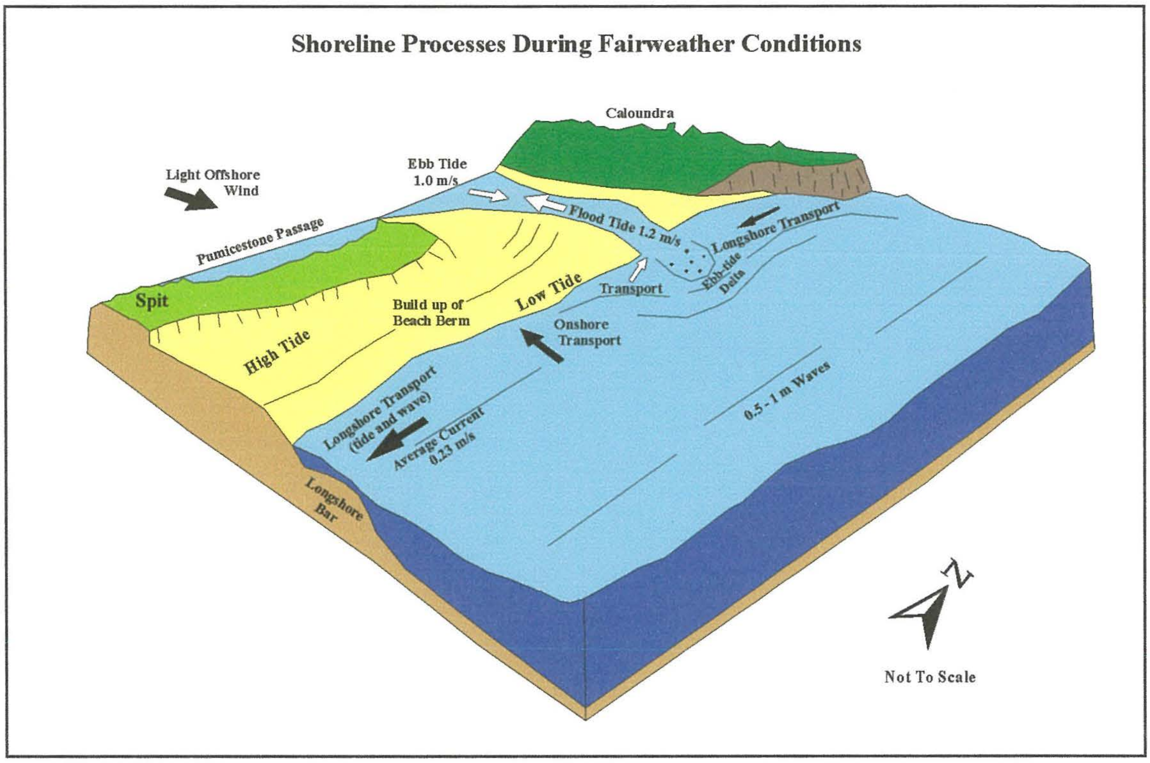


Figure 63 (A). Shoreline processes and sediment transport pathways affecting the north Bribie Island spit under fair-weather conditions include light wind from variable directions, waves mostly from easterly, south-easterly, and north-easterly directions, tidal currents and longshore currents. These processes control sediment transport on the beach, in Pumicestone Passage and out of the study area. Three major processes summarised in the diagram are:

1. Wave refraction around the ebb delta inducing sediment transport into the estuary, enhanced by a slightly higher flood tide velocity than ebb tide velocity.
2. Onshore transport of sand under low waves leading to the raising of the beach profile, following erosion after a storm. Wave direction is mostly from easterly to south-easterly directions due to refraction of southerly swells around Moreton Island. North-easterly swells may occur at times depending on seasonal weather patterns.
3. A steady southward directed longshore current influenced by a combination of wave alignment to the shore and flood tide currents entering the North Entrance Tidal Delta.

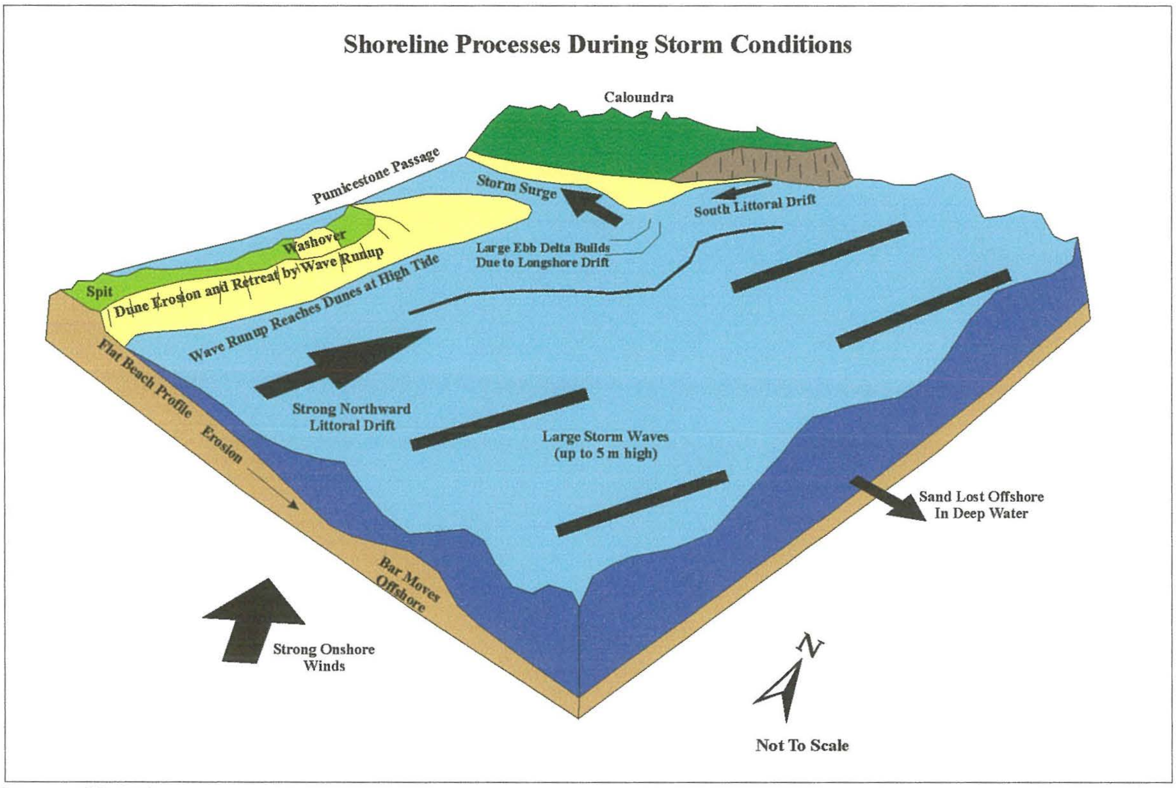


Figure 63 (B). Shoreline processes affecting the spit under storm conditions. These processes result in rapid removal of large volumes of sand from the spit and re-deposition in the inlet and outside the spit system. There are five main processes indicated:

1. Large waves (deepwater heights up to 5 m) that reach the shore with predominantly a southeast or easterly orientation, due to refraction of swell and protection by Moreton Island, induce a strong northerly longshore current. Cyclone generated northerly swells may be refracted around Caloundra Head and off the North Banks before approaching the shore from a more easterly direction. This may create a net northerly littoral transport at times in areas protected from direct swell impacts such as the northern tip of the spit (Fig. 19). However, it is important to note that most storms tracing within 500 km of the study area will produce easterly to south-easterly swells (eg. Fig. 14). The northerly current transports sand eroded from the beach and foredune of the spit towards the tidal inlet.
2. The beach profile is flattened and the longshore bar, originally close to the shoreline, has moved offshore due to shoreface erosion by the large waves.
3. Some sand moving offshore in rip currents is lost offshore below the storm wave base into the North West Channel then transported south by the dominant tidal current.
4. The building of a prominent ebb delta in response to longshore transport of sediment released from the spit by erosion.
5. On the beach, the foredune retreats as it is eroded by wave run up, while washover is a feature in areas with low dune topography.
6. A storm surge in response to strong onshore winds, low pressure and large waves creates a higher than normal high tide increasing the area exposed to erosion. The storm surge may also impact on the mainland side of the spit and Golden Beach as it pushes into the estuary creating strong tidal currents and elevated

high tides. Draw down effects (erosion and bank slumping) as the tide returns to normal may also impact on the mainland side of the spit and the bank along Golden Beach.

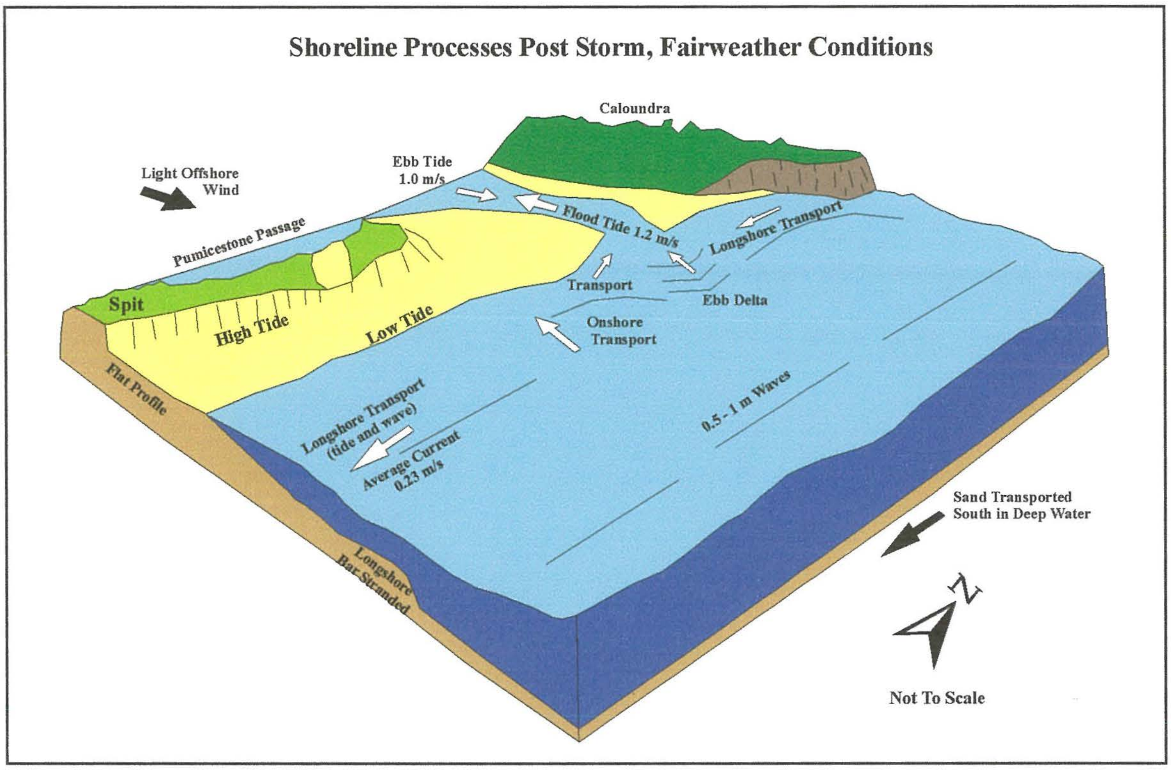


Figure 63 (C). Shoreline processes affecting spit immediately post storm, with fairweather conditions. Six major processes are shown:

1. Flat beach profile and prominent dune scarp due to erosion by storm waves.
2. Longshore bars begin to be reworked back onshore.
3. Onshore transport of sediment that moved offshore onto the shallow shelf and into the large ebb delta.
4. Prominent ebb delta formed during the storm refracts waves and draws sediment transported from north and sediment moving back onshore into the inlet with flood tide currents.
5. Sediment lost offshore in the North West Channel during the storm is transported south by tidal currents.
6. Longshore transport is southerly.

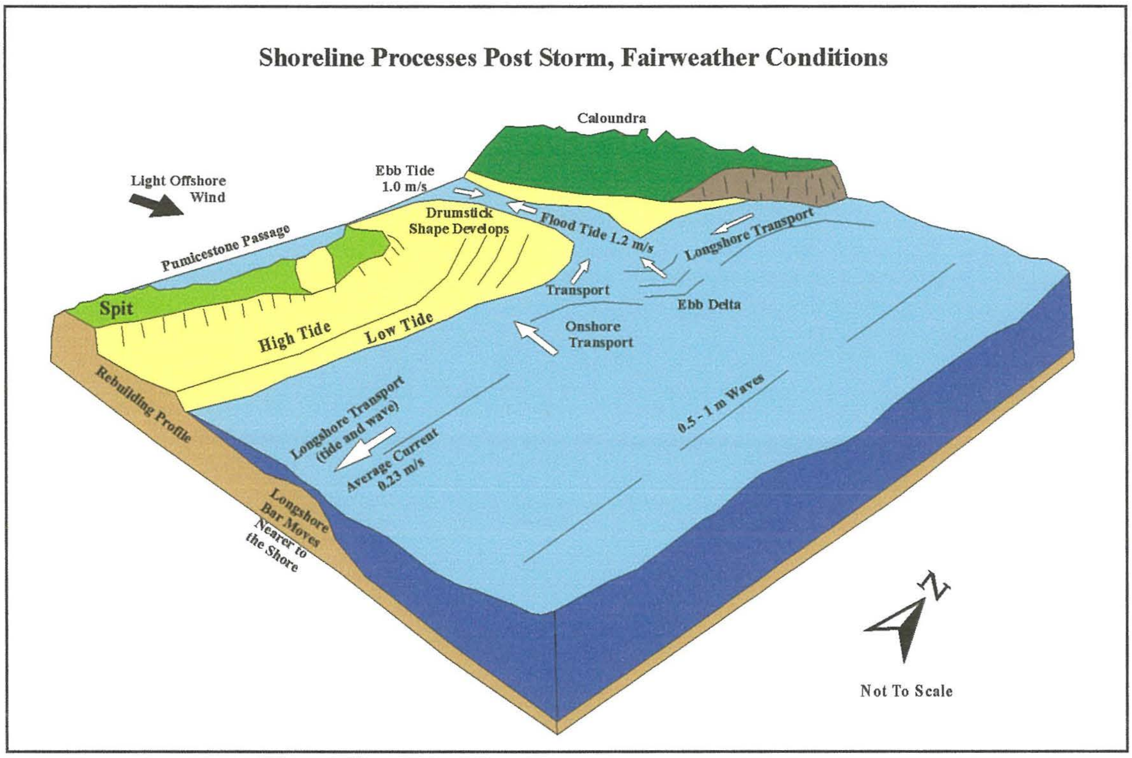


Figure 63 (D). Shoreline processes affecting the spit after a period of fairweather conditions. Four major processes are:

1. The beach profile builds up and progrades at a greater rate adjacent to the inlet compared to further south.
2. Sand moves into the inlet forming a large flood delta.
3. The longshore bar moves closer to the shore with onshore movement of sand, forming the typical fairweather profile.

6.4 Tidal Delta and Sediment Budget

Although sediment budgets are site specific, they constitute one of the most important design elements for erosion control strategies and beach stabilisation plans (Kana, 1995). In this study, the development of a sediment budget provides an insight into the relative importance of shoreline processes on the stability of the barrier system. The factors considered when developing a sediment budget for the study area are summarised in Table 10.

Table 10. Factors considered in developing a sediment budget for the Bribie Island spit.

Sediment Gains	Sediment Losses
Dune erosion	Deposition in flood tidal delta
Longshore transport into area	Longshore transport out of area
Onshore transport after storms	Offshore loss during storms
Fluvial input	Wind transport into dunes
Headland erosion	Wave washover

This study has calculated a sediment budget for the period 1978 to 1993, which reveals changes in the volume of sediment in the spit system during this period. It also indicates the trend in barrier evolution over this period, as barrier morphology is also examined. Fortunately there exists an earlier study in which a sediment budget was calculated for the spit (Jones, 1992). As similar methods were used in both studies, it is feasible to compare the budgets and look at changes in the spit over the period between the two studies.

Results of sediment budget calculations indicate that since 1972 there has been a net increase in the rate of erosion of the eastern shore of the spit, accompanied by doubling in the rate of sediment lost from the study area, a loss of 30 000 m^3yr^{-1}. The sediment lost from the system is transported out of the study area into the North West Channel and the tidal delta of Moreton Bay. The significant loss of sand is further evidence of continued recession of the spit.

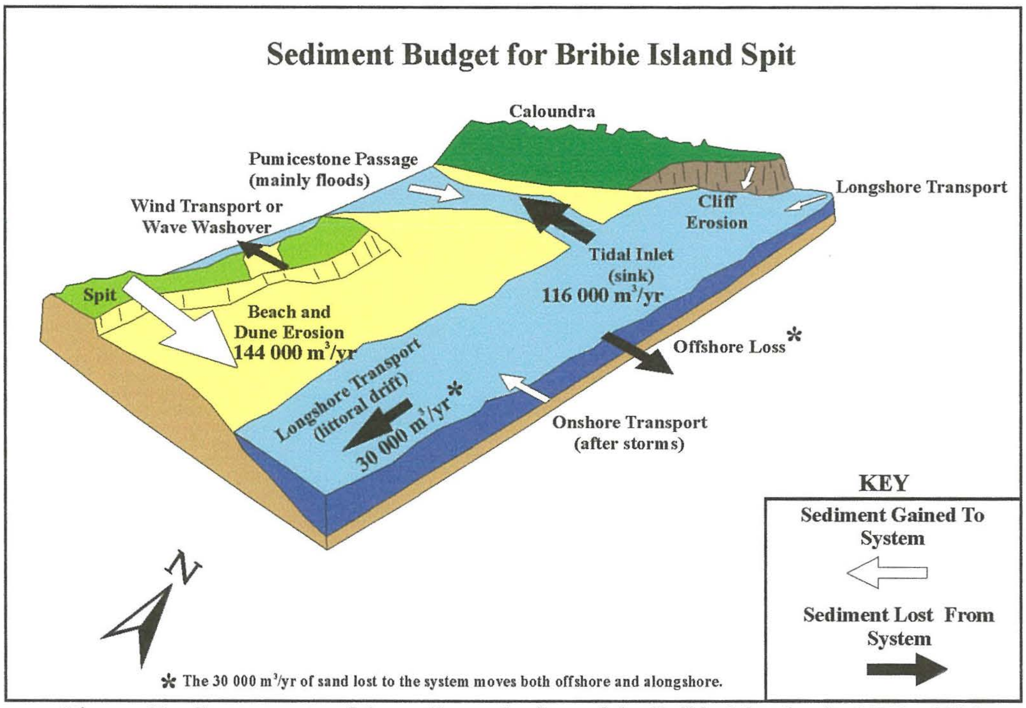


Figure 64. Components of the sediment budget of the Bribie Island spit, 1978 - 1993.

Additionally, 144 000 $m^3yr^{-1}$of sand was eroded from the eastern shore of the spit accompanied by the deposition of 116 000 $m^3yr^{-1}$of sand in the flood tidal delta of the inlet adjacent to the spit between 1978 and 1993. This indicates that approximately 80% of sand eroded from the eastern shore of the spit is deposited in Pumicestone Passage. An earlier study has calculated that approximately 32% of sand eroded from the eastern shore of the spit was deposited in Pumicestone Passage for the period 1958 to 1972 (Jones, 1992). The new figures highlight a substantial increase in the amount of sand being eroded from the eastern shore of the spit and deposited in Pumicestone Passage, effectively starving the coastline further south of sand required for nourishment.

In recognition of the role that severe storms have in transporting large volumes of sediment in short time periods, the sediment budgets calculated in this study and by Jones (1992) have been compared to storm frequency for the same periods. The results reveal that the study area has experienced a similar number of severe storms during both periods (Fig. 57). As the rate of erosion of the spit has increased since 1972 without a commensurate increase in storm frequency, processes other than storm erosion may be contributing to the instability and erosion of the spit.

In light of the relationship between Southern Oscillation and storm frequency (described in Section 5.9) gained from this study it is possible to make some short-term predictions of storm-induced erosion affecting the study area. The last La Niña cycle affecting the study area ended in May 2000, coinciding with the severe storm occurring on 28 April – 3 May. A forecast of SOI, valid for May 2000 to June 2001, predicts an El Niño cycle from May 2000 to February 2001. As El Niño cycles correlate with periods of low storm activity (Fig. 56), it is possible that the beach on the eastern shore of the Bribie Island spit may rebuild its profile during this period. With the onset of a new La Niña phase, forecast for February 2001 (Fig. 65), a period of erosion of the eastern shore of the spit might be expected during that phase.

The apparent relationship between storm cyclicity, SOI variability and beach erosion and accretion outlined in this study could provide a useful predictive tool for coastal planning and management bodies. While some studies have associated wave energy with SOI variations (Phinn and Hastings, 1992,1995), little work has been done on incorporating SOI variations into coastal planning strategies. Such investigations should form a part of future coastal research programs.

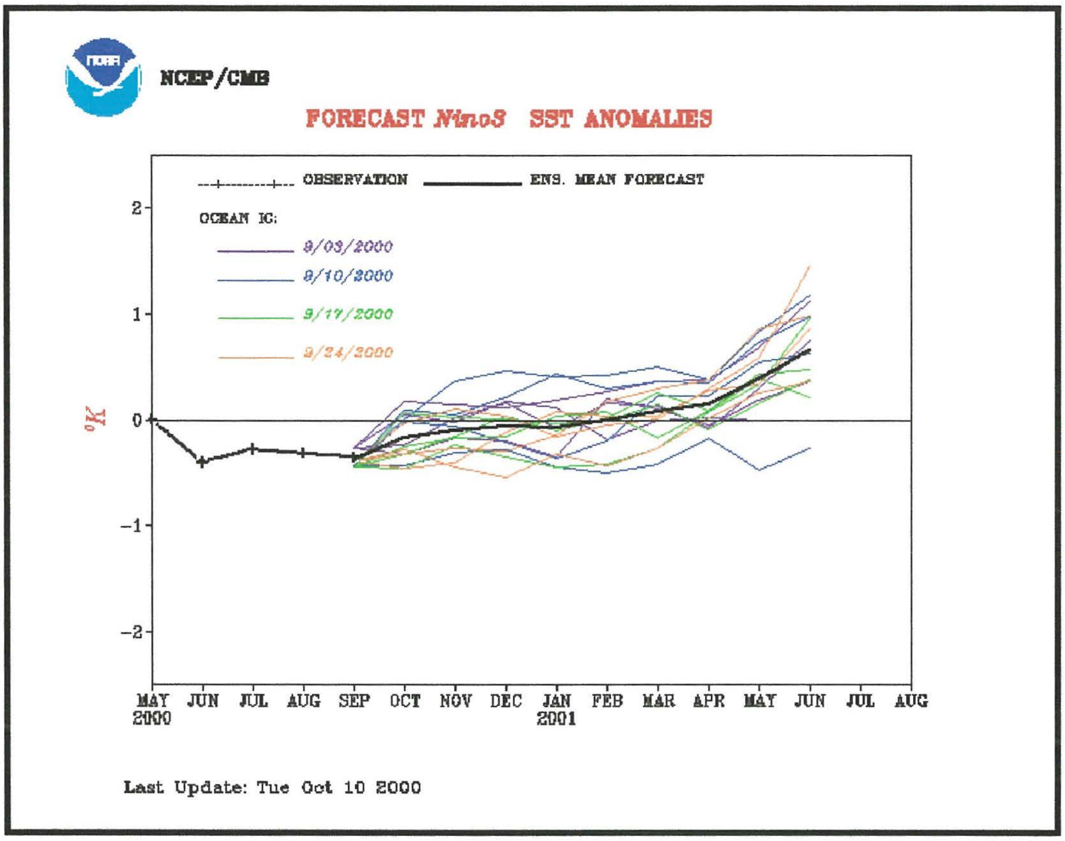


Figure 65. Forecast SOI (SST anomalies; higher SST = more storms) between May 2000 and June 2001 (NOAA, 2000).

6.5 Human Impacts

The history of coastal evolution is linked with the evolution of coastal catchments and drainage basins, and their ability to deliver sediment to the shoreline (Carter and Woodroffe, 1994). Construction of dams and weirs, as well as dredging sediments for extractive resources can seriously restrict sediment supplies to the coast and in turn unbalance the sediment budget (Carter and Woodroffe, 1994). Human impacts on the Southeast Queensland coastline have been the subject of much debate in recent years, especially in relation to urbanisation of coastal areas (Neil, 1998).

The modern sediments comprising the Bribie Island spit are principally well-worked marine sand, based on grainsize and microscope analysis, with an absence of fluvial inputs. The presence of small concentrations of albite dominated feldspars (0-11.3%) and muscovite in sample MUD4 (Table 9) in the estuarine sediments indicate a small input of fluvial sediments, probably from the local catchment. Therefore it is unlikely that the spit has been affected by human impacts further south, such as dredging and damming of rivers since European settlement (~200 yBP).

Due to the physical setting of the Bribie Island spit under the present high sea level conditions, it is cut off from offshore sediment supplies by the deep tidal channel (North West Channel) east of the Bribie Island coast. Also, the North Entrance Tidal Delta as a whole has transgressed into Moreton Bay (Stephens, 1978), indicating a flood dominance which suggests sediment from the Brisbane River, the major fluvial sediment source in Moreton Bay, has not reached the study area.

The Caloundra region has experienced enormous population growth in the last decade, with Golden Beach becoming a major residential and tourist area. Recreational pursuits in Pumicestone Passage, including boating, appear to have little overall impact on the stability of the spit. However, in an attempt to maintain the foreshores of Golden Beach for recreational users, dredging of the sandbanks in the flood tide delta was conducted in 1991 and 1999 for beach nourishment (Caloundra City Council, 2000). The dredging program in 1991 saw approximately 40 000 m^3 of sand removed from the flood tide delta in Pumicestone Passage while the program in 1999 saw approximately 25 000 m^3 of sand removed from the flood tide delta. While these volumes are approximately an order of magnitude less than the annual deposition in the passage (approximately 116 000 m^3yr^{-1}), it serves to create more accommodation space in the flood delta, thereby increasing the amount of sand removed from the spit and deposited in the estuary.

Sandbanks built up around a remnant oyster farm (just north of Lamerough Creek) may exert some control on the formation of sandbanks in that area and influencing the orientation of the main tidal channel in the passage by deflecting tidal flows around it. The meandering morphology of the channel may exacerbate erosion of adjacent Bribie Island dunes where the dunes form the outer bank of the channel. This is consistent with monitoring site observations (Table 7), which indicate some recession (averaging 0.14 m over 2.5 months) of the dunes under fair-weather conditions most likely due to bank slumping resulting from tidal channel processes. However, this would be most likely to occur around the lower states of the tidal prism when most of the water entering or leaving the channel is deflected around the exposed sandbanks.

6.6 Summary

The major findings in this section can be summarised in the following points:

1. Pumicestone Passage was wider than it is today at around 3330 yBP, and the spit lay considerably further east of its present position. The far wider spit may have formed in response to a slight fall in sea level.
2. The main source of sand in the sediment system of the Bribie Island spit is the erosion and recycling of existing deposits, with little new sediment input from outside the system.
3. The eastern shoreline of the Bribie Island spit has progressively retreated landward by at least 75 m since 1940. Erosion is evident along the entire east coast and mainland side of the spit.
4. The tidal inlet has shifted both northward and southward with the accretion and recession of both the Bribie Island spit and the spit attached to the mainland at Caloundra. At present the Bribie Island spit is accreting northwards.
5. Shoreline retreat of the southern section of the spit may create a new inlet and lead to the closure of the present inlet.
6. Since 1972 there has been a net increase in the rate of erosion of the eastern shore of the spit, accompanied by a doubling in the rate of sediment lost from the study area, to 30 000 m^3yr^{-1}. Approximately 80% of sand eroded from the eastern shore of the spit is deposited in the flood tidal delta in Pumicestone Passage.
7. As the rate of erosion of the spit has increased since 1972 without a commensurate increase in storm frequency, processes other than storm erosion alone, such as a slight rise in sea level and a loss of sediment supply from offshore, may be contributing to the instability and erosion of the spit.
8. Based on SOI, further erosion of the eastern shore of the spit is predicted.
9. Human impacts contributing to the instability and erosion of the spit are considered to be confined to anthropogenic activities, namely dredging of sand from the flood tidal delta.

7.0 CONCLUSIONS

From the review of earlier research, field studies, examination of photographic records, laboratory analyses of sediments and analysis of climatic data presented in this study, it has been possible to reveal a number of important insights into the evolution and stability of the Bribie Island spit.

The morphology and stratigraphy of spits usually reflects prograded, stationary, or receding systems. The type of spit system evident depends on the balance between onshore and along shore sediment supply and sediment loss (Roy et al., 1994). The Bribie Island spit currently exhibits a number of features consistent with an eroding or receding barrier, as evidenced by exposures of estuarine and tidal flat deposits in the intertidal zone of the eastern open beach. Those exposures reflect long-term erosion of the spit.

The age of the estuarine unit outcropping on the beach is approximately 3330 years, based on the radiocarbon age of an articulated *Anadara Trapezia* shell recovered from the unit. This is consistent with dating results of similar deposits in southeast Australia by Thom (1978), which indicated that numerous barriers in that region have been receding over the last 3000 years (Roy et al., 1994).

Barrier recession also includes the slow encroachment of the foredune into the estuary or lagoon systems behind the barrier (Roy et al., 1994). This can be observed on the mainland side of the Bribie Island spit, adjacent to Pumicestone Passage. There, dunes form the shore of Pumicestone Passage and are being eroded by tidal currents (Fig 39), and dune sands extend into the passage as revealed in core (Fig 43B, 44B).

Sediment budget calculations determined as part of this study indicate a negative imbalance in the sediment budget of the spit, where approximately 30 000 m^3 of sand per year is lost from the system. Most of this sand is lost as littoral drift to the south, probably contributing to the prograding beach ridge succession at Skirmish Point, at the southern end of Bribie Island (Jones, 1992). A component of the sand lost from the spit may also be lost offshore in the North West Channel.

The sediment budget calculations also show that the eastern shore of the spit experiences erosion at a rate of approximately 144 000 m^3yr^{-1} accompanied by approximately 116 000 m^3yr^{-1} of deposition in the flood tide delta of Caloundra inlet. These figures indicate that approximately 80% of the sand eroded from the eastern shore of the spit is deposited in Caloundra inlet. The sand deposited in the flood tide delta is lost from the littoral system of the open coast. Additionally, comparisons with a previous study (Jones, 1992) have indicated that the rate of erosion of the spit has increased markedly since 1972.

The close relationship between erosion of the spit and deposition in Pumicestone Passage indicates the spit and northern end of the passage are part of the same sediment system. Additionally, the relatively small volume of littoral drift moving along the spit and the grainsize and mineralogical data indicate a lack of external sediment inputs to the system. The lack of external sediment supply is mostly due to the natural physical setting of the region. Most significantly, the 11-19 m deep North West Channel and the flood dominated North Entrance Tidal Delta create a barrier to potential sediment supplies from the North Banks and Brisbane River delta respectively. Due to the lack of external sediment supplies, erosion and recycling of existing sand deposits is the dominant source of sediment for the study area.

Accretion and recession of both the north end of the Bribie Island spit and the spit attached to the mainland at Caloundra leads to a shift in the position of the tidal inlet. At present the northern tip of the Bribie Island spit is accreting northwards due to input of sand from the south by localised, storm-induced longshore drift.

The continued northward accretion of the spit and erosion of the southern section may lead to creation of an inlet further south and the closure of the present inlet. The new inlet is most likely to form in the vicinity of Fort Bribie or nearby lowlying areas that are prone to washover during storm events, or where the mainland side of the spit is narrowed by tidal channel processes in conjunction with retreat of the eastern shoreline (Fig 66).

At present, the spit is approximately 70 m wide just south of Fort Bribie. Given the dynamic nature of the spit environment and the current mean annual rate of retreat of the eastern coast of approximately 1.5 my^{-1}, a breakthrough in this section of the spit is likely in approximately 50 years. If the rate of erosion continues to increase as it has since 1972, breakthrough of the spit may occur in that area in around 20 years.

Severe storms have the potential to erode large volumes of sediment from the eastern shore of the spit in a short period of time and constitute the main erosional events impacting on the

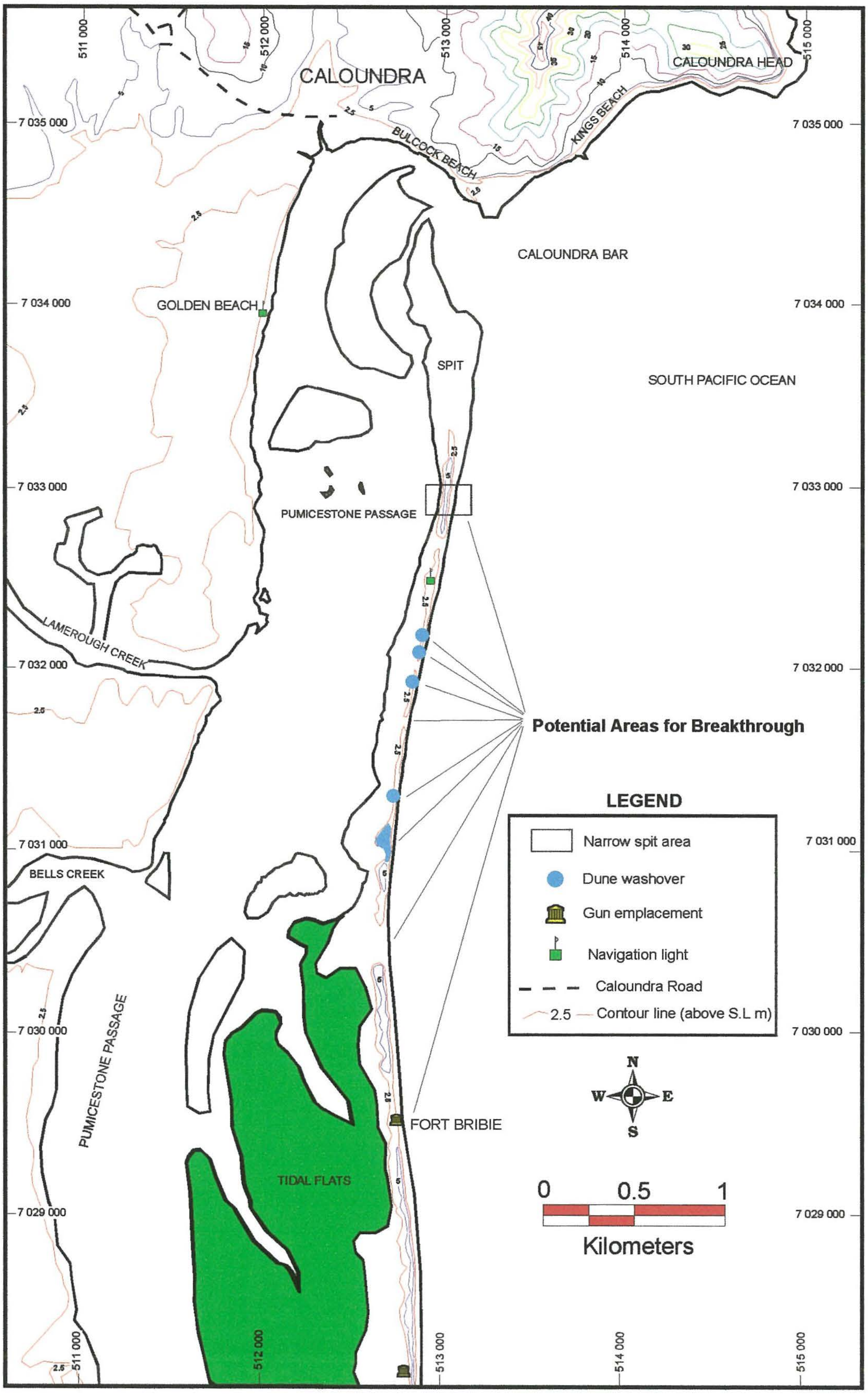


Figure 66. Potential areas for spit breakthrough.

spit. However, as the rate of erosion of the spit has increased since 1972 without a commensurate increase in storm frequency, it is suggested that processes other than storm erosion may be contributing to the instability of the spit. Studies by Flood (1981) have raised the possibility of a slight relative rise in sea level in the order of 1 mm per year in the Moreton Bay region since about 1940. That rate is similar to the proposed eustatic rate of sea level rise of 1-3 mm per year (Williams et al., 1998). When a rise of sea level is combined with storm impacts, they may account for the increase in the rate of erosion of the spit since 1972. A eustatic rise in sea level is likely to continue (Williams et al., 1998), indicating the present high rates of erosion are likely to persist.

The most significant anthropogenic impacts on the Bribie Island spit are related to past dredging of sand from the flood tide delta of the northern inlet of Pumicestone Passage. Dredging of the flood tide delta in the future increased the rate of erosion of the spit by creating additional accommodation space for the deposition of sand eroded from the eastern shore of the spit. Deposition in the tidal delta removes littoral sand from the spit system.

A close correlation was found between storm frequency in the study area and SOI values. Based on SOI variability and storm frequency data presented in this study, it is predicted that the beach profile of the spit will trend towards recovery during the present El Niño cycle. With the predicted onset of the next La Niña cycle in February 2001, a period of increased storm activity and beach erosion is likely until the beginning of the next El Niño cycle.

The findings presented in this study have support a combination of two of the three working hypotheses proposed in Section 2.2. The stability of the Bribie Island spit is primarily influenced by geologic and geomorphologic factors in the context of Holocene sea level fluctuations, however, rates of retreat are affected by severe weather events related to climatic variations. While anthropogenic activities appear to have had relatively minor impacts on the stability of the spit in the past, dredging of the inlet channel should be avoided in the future.

7.1 RECOMMENDATIONS

The results of this study provide a solid platform upon which further research can continue to reveal details of the evolution of the complex barrier system at the north end of Bribie Island. Further research should include:

(i) additional coring of the spit to provide more details of its stratigraphic architecture and thereby the sequence of depositional environments and erosional events which have formed this barrier deposit.

(ii) radiocarbon dating of sand rock offshore from the spit, and shell material and mangrove sediments from estuarine units in the spit, and

(iii) thermoluminescence and luminescence dating of dune units on the spit, which can provide a chronology for the spit succession and insights into past and likely future tempos of change.

Regular and continued monitoring of the spit will provide a greater understanding of modern processes controlling spit evolution over seasonal to decadal temporal scales. This can be done by:

(i) Establishing permanent monitoring sites on or behind the foredune on the eastern shore of the spit. Measuring from the monitoring site to the erosion scarp on a regular basis would allow accurate measurements of the effects of storms and the recovery interval for the beach.

(ii) Establishing measuring staffs in the beach profile, similar to COPE poles used in Beach Protection Authority studies, to help determine changes in beach profiles and shoreline positions on a regular basis.

(iii) Conducting regular depth soundings in the flood tidal delta region of Pumicestone Passage and just offshore from the spit to evaluate changes in the sediment budget over short and long intervals.

(iv) Further research on the effects of SOI (ENSO) variations and their relationship to and implications for coastal erosion.

Finally, given the close relationship between the tidal delta system and the spit, serious consideration should be given to the potential for increased erosional effects on the spit due to dredging of the flood tide delta.

REFERENCES

Aharon, P. and Chappell, J., 1986. Oxygen isotopes, sea-level changes and the temperature history of a coral reef environment in New Guinea over the last 10^5 years. *Paleogeography, Paleoclimatology, Paleoecology* 56, 337-339. **In**: Williams, M., Dunkerley, D., De Deckker, P., Kershaw, P. and Chappell, J., 1998. Quaternary Environments, 2nd Edition. Arnold, London, pp 107-125.

Allen, J.R.L., 1982. *Spits*. In: The encyclopedia of beaches and coastal environments, ed. M.L. Schwartz, pp.789-92. Stroudsberg, PA: Hutchinson Ross Publishing. **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics*. Cambridge University Press, Great Britain, p158.

Armstrong, K.J., 1990. Holocene coastal evolution of southern Bribie Island. Queensland Department of Resource Industries. *Marine and Coastal Investigation Project report MA49/1 (unpublished).* **In**: Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment*. School of Marine Science, The University of Queensland, Brisbane. pp. 81-92.

Batianoff, G.N. and Elsol, J.A., (1989). *Vegetation of the Sunshine Coast*. Queensland Botany Bulletin No.7, Queensland Department of Primary Industries, Brisbane. pp

Beach Protection Authority Queensland, 1981. *Coastal Dune Management – Their Vegetation and Management*. Beach Protection Authority Queensland Report.

Beach Protection Authority Queensland, 1988. Coastal Observation Programme (COPE) – Kings Beach – City of Caloundra. *Beach Protection Authority Queensland Report No. C24.1.*

Beach Protection Authority Queensland, 1988. Wave Data Recording Programme – Moreton Island Region (North East Shipping Channel). *Beach Protection Authority Queensland Report No. W11.1.*

Beach Protection Authority Queensland, 1993. *Northern Bribie Island and Pumicestone Passage Photogrammetry 1940-1992*. Qld Dept. of Env. And Heritage.

BjØrlykke, K., 1989. *Sedimentology and Petroleum Geology*. Springer-Verlag, Berlin, p13.

Brisbane River and Moreton Bay Wastewater Management Study, 1997. *Information sheet: Water Movement and Pollution Processes in Moreton Bay*. Brisbane. **In**: Musk, M., 1998. *Sedimentology, seismic stratigraphy and sand resources of the Northern Entrance tidal delta, Moreton Bay, Queensland, Australia*. Masters Thesis, School of Geology, Queensland University of Technology. (Unpublished).

Bryant, E., 1983. Regional sea level, Southern Oscillation and beach change, New South Wales, Australia. *Nature*, **305**: 213-216.

Bureau of Meteorology Australia website, (20/4/2000). *Cyclone.* http://www.bom.gov.au/climate/c20thc/cyclone.shtml.

Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p3.

Caloundra City Council (CCC) website, (5/10/2000). http://www.caloundra.qld.gov.au.

Chappell, J., 1983. A revised sea level record for the last 300,000 years from Papua New Guinea. *Search* Vol 14, No. 3-4, pp99-101.

Davis, R.A., 1994. *Geology of Holocene Barrier Island Systems.* Springer-Verlag, Berlin.

Evans, K.G., Stephens, A.W. and Shorten, G.G., 1992. Quaternary sequence stratigraphy of the Brisbane River delta, Moreton Bay, Australia. *Marine Geology,* **107**:61-79.

Fetter, C.W., 1994. *Applied Hydrogeology, 3rd Edition.* Prentice Hall Inc. New Jersey.

Fleming, K., Johnstone, P., Zwartz, D., Yokoyama, Y., Lambeck, K. and Chappell, J., 1998. Refining the eustatic sea level curve since the Last Glacial Maximum using far- and intermediate-field sites. *Earth and Planetary Science Letters,* **163**: 327-342.

Flood, P.G., 1980. Tidal-flat sedimentation along the shores of Deception Bay, southeastern Queensland – a preliminary account. *Proc. R. Soc. Qld* **91**:77-84.

Flood, P.G., 1981. Carbon-14 dates from the coastal plains of Deception Bay, southeastern Queensland. *Queensland Government Mining Journal.* Vol. 82 pp19-23.

Flood, P.G., 1991. *Coastal processes, an annotated brief review.* **In**: Workshop on Coastal Processes in the South Pacific Island Nations, Lae, Papua New Guinea, 1-8 October 1987. SOPAC Technical Bulletin 7: 27-35.

Galloway, R.W., 1978. *Landforms.* **In**: Batianoff, G.N. and Elsol, J.A., (1989). *Vegetation of the Sunshine Coast.* Queensland Botany Bulletin No.7, Queensland Department of Primary Industries, Brisbane.

Gillespie, R. and Polach, H.A., 1979. *The Suitability of Marine Shells for Radiocarbon Dating of Australian Prehistory.* **In**: Berger, R. and Suess, H.E., 1979 (eds). Radiocarbon Dating. Proceedings of the Ninth International Conference Los Angeles and La Jolla, 1976, pp 405-419.

Glaeser, J.D., 1978. *Global distribution of barrier islands in terms of tectonic setting.* Journal of Geology. 86:283-297. **In**: Davis, R.A., 1994. *Geology of Holocene Barrier Island Systems.* Springer-Verlag, Berlin.

Gornitz, V., 1993. Mean sea level changes in the recent past. **In**: Williams, M., Dunkerley, D., De Deckker, P., Kershaw, P. and Chappell, J., 1998. *Quaternary Environments, 2nd Edition.* Arnold, London. P 124.

Gornitz, V., Lebedeff, S. and Hansen, J. 1982. Global sea level trend in the past century. **In**: Williams, M., Dunkerley, D., De Deckker, P., Kershaw, P. and Chappell, J., 1998. *Quaternary Environments, 2nd Edition.* Arnold, London. P 124.

Harbison, J.E., 1998. *The occurrence and chemistry of groundwater on Bribie Island, a large barrier island in Moreton Bay, Southeast Queensland.* Masters Thesis. School of Geology, Queensland University of Technology. Brisbane (unpublished). pp 10-23.

Harbison, J.E., and Cox, M.E. *General features of the occurrence of groundwater on Bribie Island, Moreton Bay.* **In**: Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment.* School of Marine Science, The University of Queensland, Brisbane. pp. 111-124.

Harwood, G., 1988. *Microscope techniques: II. Principles of sedimentary petrography.* **In**: Tucker, M. (ed), 1988. Techniques in Sedimentology. Blackwell Scientific Publications, London.

Hayes, M.O., 1979. *Barrier island morphology as a function of tidal and wave regime.* In: Barrier Islands: from the Gulf of St. Lawrence to the Gulf of Mexico, ed. S.P. Leatherman, pp 1-27. New York, Academic Press. **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p155.

Hekel, H. & Day, R.W., 1976. Quaternary geology of the Sunshine Coast, Southeast Queensland. *Geological Survey of Queensland Record 1976/16. (Unpublished)* **In**: Jones, M.R., 1992a. Quaternary Evolution of the Woorim-Point Cartwright Coastline, Volume 1. *Department of Minerals & Energy Project Report MA49/2* (unpublished).

Hekel, H., Ward, W.T., Jones, M. and Searle, D.E., 1979. Geological development of northern Moreton Bay, **In** A. Bailey, and N.C. Stevens (eds.) *Northern Moreton Bay Symposium, Royal Society of Queensland*, 7-18.

Hesp, P.A., 1984. Foredune formation in southeast Australia. In: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p 152.

Jones, M.R., 1992. Quaternary Evolution of the Woorim-Point Cartwright Coastline, Volume 1. *Department of Minerals & Energy Project Report MA49/2* (unpublished).

Kana, T.W., 1995. A mesoscale sediment budget for Long Island, New York. *Marine Geology*, 126: 87-110.

Komar, P.D., 1998. *Beach Processes and Sedimentation 2nd Edition.* Prentice-Hall Inc. New Jersey.

Kraft, J.C. & John, C.J., 1979. Lateral and vertical facies relations of transgressive barriers. *American Association of Petroleum Geologists Bulletin*, **82**, 2131-58. In: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p155.

Lambeck, K., 1993. Glacial rebound and sea level change: an example of a relationship between mantle and surface processes. *Tectonophysics*, **223**: 15-37.

Lang, S.C., McClure, S.T., Grosser, M., Lawless, M. and Herdy, T. *Sedimentation and coastal evolution, Northern Moreton Bay.* **In**: Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment.* School of Marine Science, The University of Queensland, Brisbane. pp. 81-92.

Lockhart, D.A., Lang, S.C. and Allen, G.P., 1998. *Sedimentation and Coastal Evolution of Southern Moreton Bay.* **In**: Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment.* School of Marine Science, The University of Queensland, Brisbane. pp. 93-106.

Marshall, J.F. & Thom, B.G., 1976. The sea level in the last interglacial. Nature, 263, pp120-1. **In**: Roy, P.S. & Thom, B.G., 1981. *Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model.* Journal of the Geological Society of Australia, 28, pp 471-489.

McManus, J., 1988. *Grainsize determination and interpretation.* In: Tucker, M. (ed), 1988. Techniques in Sedimentology. Blackwell Scientific Publications, London.

Moreton, R.A., Gibeaut, J.C., and Paine, J.G. 1995. Meso-scale transfer of sand during and after storms: implications for prediction of shoreline movement. *Marine Geology*, **126**, pp 161-179.

Musk, M., 1998. *Sedimentology, seismic stratigraphy and sand resources of the Northern Entrance tidal delta, Moreton Bay, Queensland, Australia.* Masters Thesis, School of Geology, Queensland University of Technology. (Unpublished).

Neil, D.T., 1998. *Moreton Bay and its Catchment: Seascape and Landscape Development and Degradation.* **In:** Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment.* School of Marine Science, The University of Queensland, Brisbane. pp. 3-54.

Newmark, J. 1988. *Statistics and Probability in Modern Life, 4th Edition.* W.B. Saunders. Rinehart, pp 621-628.

NOAA, 2000. Australian Bureau of Meteorology Website. *Forecast SST Anomalies.* http://www.emc.ncep.noaa.gov/research/cmb/sst_forecast/images/cmb.SSTfcst_nino3.gif

Phinn, S.R. and Hastings, P.A., 1992. Southern Oscillation influences on the wave climate of south-eastern Australia. *Journal of Coastal Research*, Vol: 8, No. 3, pp 579-592.

Phinn, S.R. and Hastings, P.A., 1995. Southern Oscillation influences on the Gold Coast's Summer wave climate. *Journal of Coastal Research*, Vol: 11, No. 3, pp 946-958.

Queensland Department of Environment and Heritage website, (20/4/2000). *Storm tides.* http://www.env.qld.gov.au/environment/coast/tides/st.html.

Queensland Transport, Maritime Division, 1981. *Pumicestone Passage Boating Safety Chart.*

Queensland Transport, Maritime Division, 1994. *Pumicestone Passage Boating Safety Chart.*

Roy, P.S. & Stephens, A.W., 1980. Regional geological studies of the N.S.W. inner continental shelf. *Summary results. Geological Survey of N.S.W., Report No. GS 1980/028* (unpublished). **In**: Stephens, A.W., 1986. *Geological Approaches to Beach Management.* Geological Survey of Queensland Record Series, Report No. 1986/13 (unpublished).

Roy, P.S., Thom, B.G. & Wright, L.D., 1980. Holocene sequences on an embayed High-energy coast. *Sedimentary geology.* **In**: Roy, P.S. & Thom, B.G., 1981. *Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model.* Journal of the Geological Society of Australia, 28, pp 471-489.

Roy, P.S. & Thom, B.G., 1981. Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model. *Journal of the Geological Society of Australia*, 28, pp 471-489.

Roy, P.S., 1984. *New South Wales estuaries: their origin and evolution.* **In:** Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p 139-140.

Roy, P.S., Cowell, P.J., Ferland, M.A. and Thom, B.G., 1994. *Wave-dominated coasts.* **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p121-178.

Shepherd, M.J., 1991. *Relict contemporary foredunes as indicators of coastal processes.* In: Applied Quaternary studies, ed. G. Brierley & J. Chappell, pp. 17-24. Canberra Department of Biogeography and Geomorphology, Australian National University. **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics.* Cambridge University Press, Great Britain, p156.

Silvester, R., (1959). *Journal of Waterways and Harbours Div.*, Proc. Am. Soc. Civil Eng., **85** WW3 11. **In**: Thom, B.G., (1974). *Coastal Erosion in Eastern Australia.* Search Vol.5, No.5, pp198-209.

Silvester, R., (1970). *Journal of Waterways and Harbours Div.*, Proc. Am. Soc. Civil Eng., **96** WW2 275. **In**: Thom, B.G., (1974). *Coastal Erosion in Eastern Australia.* Search Vol.5, No.5, pp198-209.

Skinner, J.L., Gillam, E., Rohlin, C.J. 1998. *The demographic future of the Moreton region.* **In**: Tibbetts, I.R., Hall, N.J. & Dennison, W.C. eds (1998) *Moreton Bay and Catchment.* School of Marine Science, The University of Queensland, Brisbane. pp. 67-78.

Stephens, A.W., 1978. The northern entrance to Moreton Bay. *University of Queensland Papers*, Department of Geology, vol. 2, pp25-43.

Stephens, A.W. 1992. Geological evolution and earth resources of Moreton Bay. **In**: Crimp, O.N. (ed). Moreton Bay in the Balance, *Australian Littoral Society Inc.*, Moorooka, pp 3-23.

Stephens, A.W., Searle, D, E., & Holmes, K.H., 1983. Dredgeability of the North East Channel, Moreton Bay. *Geological Survey of Queensland Record 1983/69.* (Unpublished). **In**: Jones, M.R., 1992a. Quaternary Evolution of the Woorim-Point Cartwright Coastline, Volume 1. *Department of Minerals & Energy Project Report MA49/2* (unpublished).

Stowe, K., 1996. *Exploring Ocean Science, 2nd Edition.* John Wiley & Sons, United States.

Surfer, 1997. *Surface Mapping System Version 6.04 – Feb 24 1997.* Golden Software, Inc. Colorado.

Thom, B.G., McLean, R.F., Langford-Smith, T. and Elliot, I., (1973). *Institute of Engineers Australia, National Conference Publication*, (73/1), p 35. **In**: Thom, B.G., (1974). *Coastal erosion in Eastern Australia.* Search Vol. 5, No. 5, pp 198-209.

Thom, B.G., 1974. Coastal erosion in Eastern Australia. *Search* Vol. 5, No. 5, pp 198-209.

Thom, B.G., 1978. *Coastal sand deposition in southeast Australia during the Holocene.* In: Davies, J.L. & Williams, M. A.G. (eds). Landform evolution in Australasia, 197-214. A.N.U. Press, Canberra. **In**: Roy, P.S. & Thom, B.G., 1981. Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model. *Journal of the Geological Society of Australia*, 28, pp 471-489.

Thom, B.G., Polach, H.A. & Bowman, G.M., 1978. Holocene age structure of coastal sand barriers in New South Wales, Australia. *Geog. Dep., Fac. Mil. Stud. Univ. N.S.W.*, 86. **In**: Roy, P.S. & Thom, B.G., 1981. *Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model.* Journal of the Geological Society of Australia, 28, pp 471-489.

Thom, B.G., 1984. Transgressive and regressive stratigraphies of coastal sand barriers in eastern Australia. *Marine Geology*, 7, 161-8. **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics*. Cambridge University Press, Great Britain, p150-160.

Tucker, M. (ed), 1988. *Techniques in Sedimentology*. Blackwell Scientific Publications, London.

Ward, W.T., Stephens, A.W., & Mc Intyre, N., 1977. *Brisbane's north coast and Fraser Island from the air*. In Day, R.W. (ed), 1977. Field Conference, Lady Elliot Island – Fraser Island – Gayndah – Biggenden. Geological Society of Australia Inc., Queensland Division, 14-30. **In**: Jones, M.R., 1992a. Quaternary Evolution of the Woorim-Point Cartwright Coastline, Volume 1. *Department of Minerals & Energy Project Report MA49/2* (unpublished).

Williams, M., Dunkerley, D., De Deckker, P., Kershaw, P. and Chappell, J., 1998. *Quaternary Environments, 2nd Edition*. Arnold, London.

Woodroffe, C.D. & Grindrod, J., 1991. *Mangrove biogeography: the role of Quaternary environmental and sea level change*. Journal of Biogeography, 18, 479-492. **In**: Carter, R.W.G. & Woodroffe, C.D. (eds), 1994. *Coastal Evolution: Late Quaternary shoreline morphodynamics*. Cambridge University Press, Great Britain, p 4.

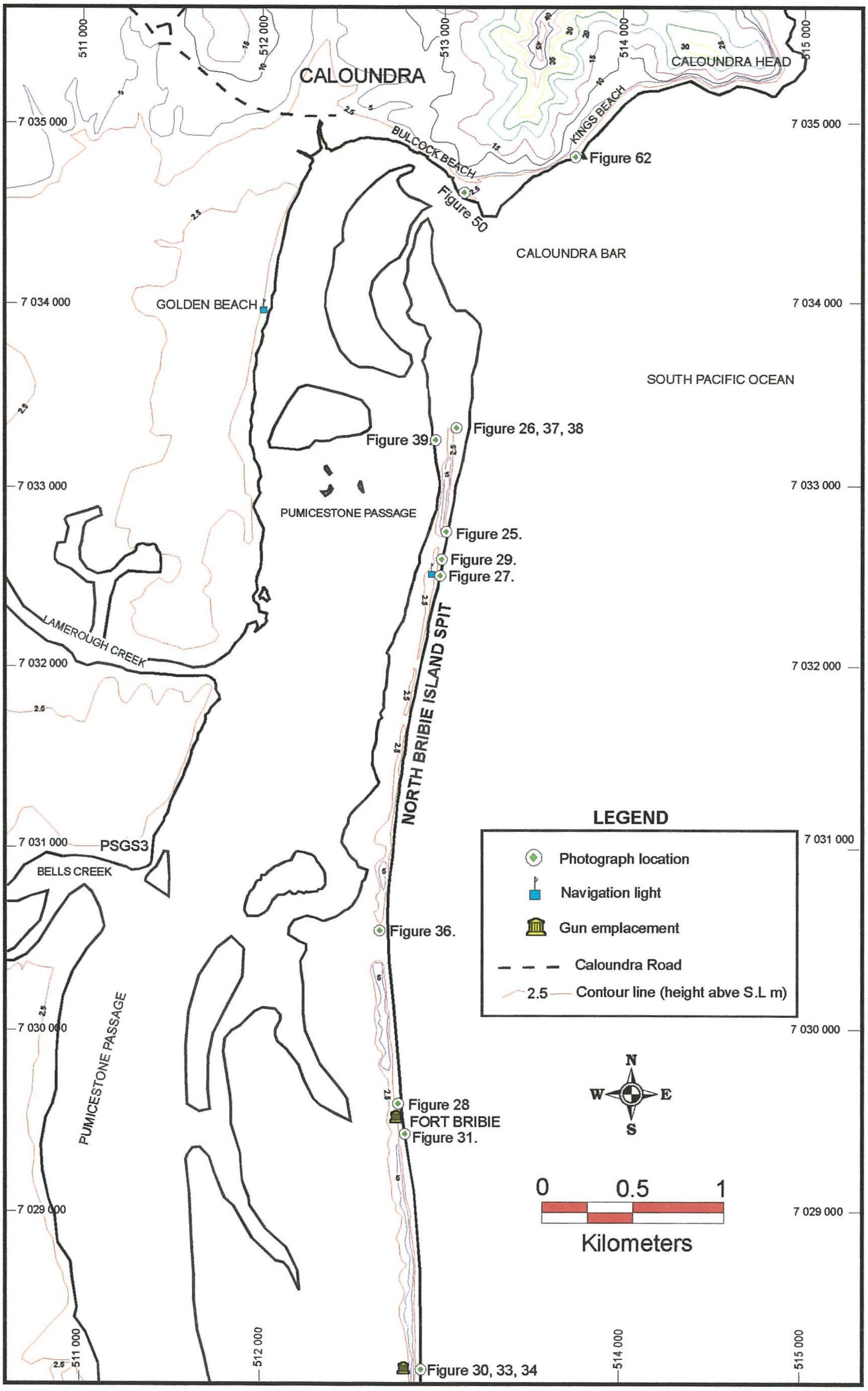
Sample	Location East	Location North	Depth (m)	% Sand (S) % Mud (M)	Mean Grain Size (ϕ) Eqn1	Sorting Eqn 2.	Skewness Eqn 3.	Kurtosis Eqn 4.
VC1A	512864	7028133	0.25	100 (S)	1.88	0.11	0.02	0.09
VC1B			0.5	24 (M)	1.94	0.68	0.75	3.46
VC1C				100 (S)	1.83	0.14	-0.03	0.23
VC2A	512790	7029339	0.31	100 (S)	1.47	0.62	-1.37	5.68
VC2B			0.68		1.84	0.13	-0.03	0.16
VC3B	511933	7029140	0.36		1.81	0.54	-0.28	3.79
VC4B	511941	7029136	1	19 (M)	2.16	0.7	0.17	3.06
VC5A	512861	7032539	0.22	100 (S)	1.76	0.19	-0.01	0.25
VC5B			0.54	100 (S)	1.56	0.14	-0.05	0.21
VC5C			1.4	100 (S)	1.94	0.14	0	0.14
VC5D			2	100 (S)	1.67	0.13	-0.06	0.21
VC6A	512943	7033363	0.2	100 (S)	1.86	0.13	0.05	0.14
VC6B			0.95	100 (S)	1.56	0.25	-0.24	1.16
VC6C			1.95	100 (S)	1.28	0.48	-0.61	2.23
AH1A	512871	7032534	0.4	100 (S)	1.9	0.37	-0.66	3.25
AH1B			0.6	100 (S)	1.97	0.14	0.06	0.25
AH1D			1.1	100 (S)	1.49	0.18	0.21	0.61
AH1E			1.25	100 (S)	1.65	0.18	0.08	0.34
AH1G			1.65	100 (S)	1.91	0.11	0.04	0.1
AH2A	512899	7032519	0.4	100 (S)	1.81	0.26	-0.21	1.63
AH2B			0.55	100 (S)	1.84	0.12	0.03	0.1
AH2C			0.75	100 (S)	1.98	0.11	0.02	0.1
AH2E			1.3	100 (S)	1.64	0.25	0.11	0.47
AH2F			1.45	100 (S)	1.4	0.24	-0.02	0.36
AH2G			1.5	100 (S)	1.59	0.16	0.02	0.2
AH3A	512947	7032518	0.35	100 (S)	1.89	0.1	0.04	0.08
AH3B			0.95	100 (S)	1.87	0.13	-0.01	0.1
AH3C			1.45	100 (S)	1.92	0.15	0.07	0.32
AH3D			1.7	100 (S)	2	0.13	0.01	0.12
AH3E			2.1	100 (S)	1.88	0.13	0.04	0.13
AH3G			3.1	100 (S)	1.97	0.1	0.04	0.09
AH3I			4.4	100 (S)	1.94	0.11	0.01	0.13
AH4A	512951	7033370	0.3	100 (S)	1.24	-0.65	0.3	2.56
AH4C			1.15	100 (S)	1.81	0.12	0.05	0.13
AH4D			1.35	100 (S)	1.87	0.15	0.02	0.1
AH5A	513022	7033367	0.3	100 (S)	1.81	0.1	0.02	0.09
AH5C			0.65	100 (S)	1.82	0.11	0.01	0.07
AH6A	513084	7033346	0.3	100 (S)	1.88	0.1	0.02	0.06
AH6E			3	100 (S)	1.03	0.33	-0.11	0.7
AH6G			3.9	100 (S)	1.58	0.11	0.02	0.08
AH6H			4.17	100 (S)	1.63	0.23	-0.11	0.62
AH7A	512760	7029344	0.45	100 (S)	1.85	0.1	-0.04	0.33
AH7C			1.6	100 (S)	1.9	0.11	0.04	0.08
AH7D			2.15	100 (S)	2.07	0.13	0.02	0.08
AH7E			2.35	100 (S)	1.94	0.12	0.06	0.11
AH7F			2.68	100 (S)	1.96	0.12	0	0.07
AH7G			3.25	100 (S)	1.92	0.1	0.04	0.07
AH8A	512728	7029330	0.2	100 (S)	1.76	0.45	-1.13	4.99
AH8B			0.7	100 (S)	1.93	0.12	0.04	0.14
AH8E			2	100 (S)	2	0.14	-0.05	0.3

AH9A	512667	7030722	0.8	100 (S)	1.95	0.13	0.05	0.09
AH9B			1.35	100 (S)	1.9	0.17	0.15	0.37
AH9C			1.65	100 (S)	2.08	0.26	0.22	0.77
AH10A	512832	7028140	0.3	100 (S)	1.68	0.09	0	0.07
AH10C			1.1	7 (M)	1.87	0.44	0.38	1.57
AH10D			1.4	15 (M)	1.93	0.49	0.51	2.08
AH11A	512768	7029339	0.6	100 (S)	2.52	0.21	-0.02	0.13
BIMDE1	512908	7033720	1	100 (S)	1.71	0.11	0.02	0.07
BIMDE2	512915	7033628	1	100 (S)	1.78	0.09	0.01	0.06
BIMDE3	512935	7033469	1	100 (S)	1.68	0.09	0.01	0.05
BIMDE4	512947	7033350	1	100 (S)	1.71	0.12	-0.01	0.06
BIMDE5	512955	7033249	2	100 (S)	1.87	0.12	0.02	0.09
BIMDE6	512974	7033161	1.5	100 (S)	1.79	0.1	0.03	0.08
BIMDE6A	512966	7033188	1.5	100 (S)	1.8	0.09	0.02	0.05
BIGS1	512977	7033926		100 (S)	1.9	0.09	0.02	0.04
BIGS2	513091	7033322		100 (S)	1.7	0.12	0.01	0.06
BIGS3	513093	7033189		100 (S)	2.19	0.22	0.03	0.1
BIGS4	513010	7032754	1	100 (S)	1.81	0.06	0.02	0.03
BIGS5	512759	7029529		100 (S)	1.79	0.09	0.02	0.06
BIGS6	512759	7029529		100 (S)	1.93	0.08	0.02	0.04
BIGS7	WIND TRANSPORT			100 (S)	1.71	0.11	0.01	0.06
BIGS8	WIND TRANSPORT			100 (S)	2.02	0.1	0	0.04
BIGS9	512974	7033161	2.5	100 (S)	1.13	0.37	-0.16	1.32
KBS1	513809	7034940		100 (S)	1.7	0.12	0.01	0.06
OSGS1	513923	7033386		100 (S)	1.76	0.26	-0.09	0.37
PSGS1	511460	7030776		100 (S)	1.91	0.13	0.01	0.08
PSGS3	511160	7030918			1.79	0.19	-0.02	0.2
PSGS4	511439	7030225		21 (M)	1.79	0.47	0.49	1.66
PSGS7	512136	7031466			1.86	0.14	-0.01	0.12
PSGS9	511845	7031956			1.99	0.28	0.23	0.85
PSGS10	511968	7031963			1.67	0.17	-0.03	0.32
PSGS11	512627	7034734			1.39	0.24	-0.21	0.86
PSGS12	512382	7034133			1.55	0.17	-0.02	0.12
PSGS13	512557	7034076			1.61	0.15	-0.06	0.21
PSGS14	510865	7030828			1.88	0.14	0.03	0.14
PSGS15	513079	7034351		100 (S)	0.96	0.51	-0.76	2.7
XGS1	512721	7032566			1.94	0.19	-0.07	0.26
XGS2	512549	7032663			1.83	0.16	-0.03	0.2
XGS3	512209	7032763			1.9	0.21	-0.1	0.44
XGS4	512863	7033367			1.75	0.1	-0.02	0.16
XGS5	512563	7033410			1.75	0.15	-0.02	0.21
XGS6	512168	7033446			1.9	0.21	-0.09	0.27
XGS7	512012	7033371			1.64	0.22	-0.39	1.56
XGS8	512048	7032760			2.15	0.22	-0.21	0.32
XGS11	511604	7030119			1.93	0.17	-0.03	0.19
XGS12	511601	7029263			1.87	0.16	-0.05	0.18
XGS13	513081	7032501		100 (S)	1.7	0.19	-0.02	0.16
XGS14	513145	7029349		100 (S)	1.55	0.21	0	0.15
XGS15	513145	7033313		100 (S)	1.78	0.14	0.01	0.07

APPENDIX A

Location of photographs used in text.

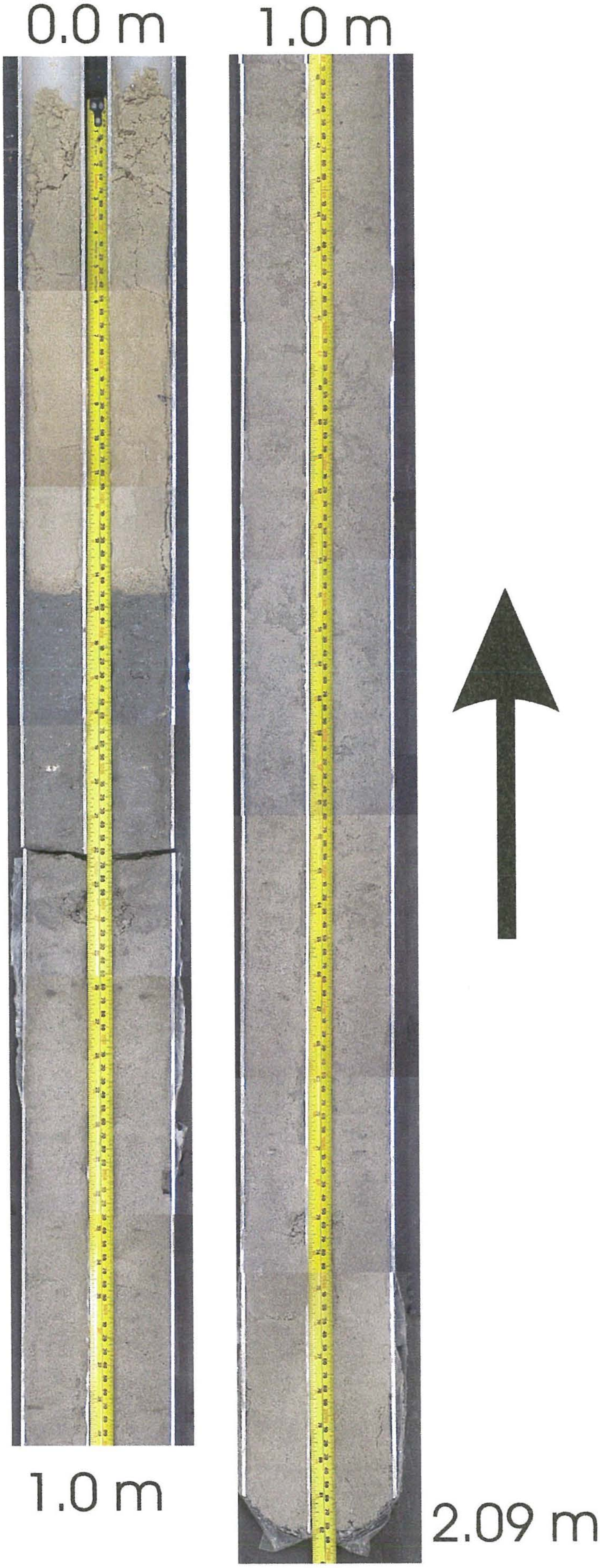
Location of photographs used in text.



APPENDIX B

Core photographs, vibrocore logs and auger logs.

BIVC1



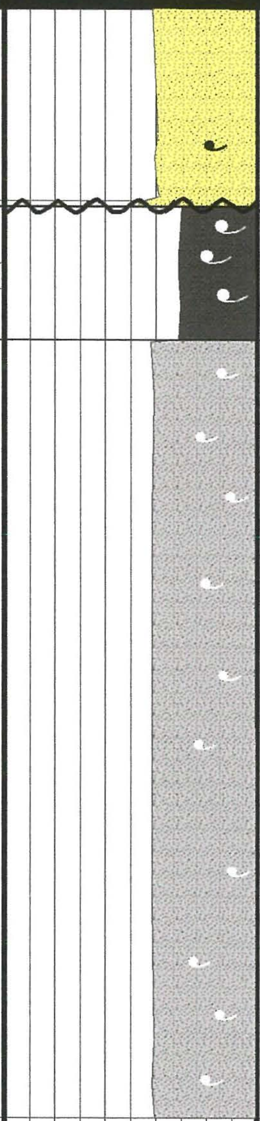
QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Core Compaction: 18%

Project	North Bribie Island Spit Stability Study				
Hole No.	BIVC1	**Co-ordinates**	512864 **E**	**Angle**	-
R.L			7028133 **N**	**Bearing**	-
Date	26/6/2000	**Started** 10:30 AM	**Finished** 11:30 AM	**Method**	Vibrocore

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 0.37	VC1A			Beach sand : Quartz sand. Buff coloured (5Y 8/4). Clean, medium grained. Well sorted sub-angular to sub-rounded grains. Flecks of dark minerals throughout.
	0.37 – 0.38				Very clean, well sorted, sub-angular to sub-rounded, coarse beach sand containing a shell fragment of 5mm size.
	0.38 – 0.63 (0.5)	VC1B	VC1B		Silty/Clayey fine grained Sand (Estuarine). Dark grey (N3). Low to medium plasticity in clayey patches. Coarse shell fragments 5-10 mm throughout.
	0.63 – 2.09 (1, 1.5, 2)	VC1C			Subtidal beach sand: Grey Quartz Sand (N6). Clean, well sorted, sub angular to sub rounded, medium sized grains. Minor flecks of dark minerals and shell fragments throughout.
	2.09				End of Hole.
	2.5				



Notes

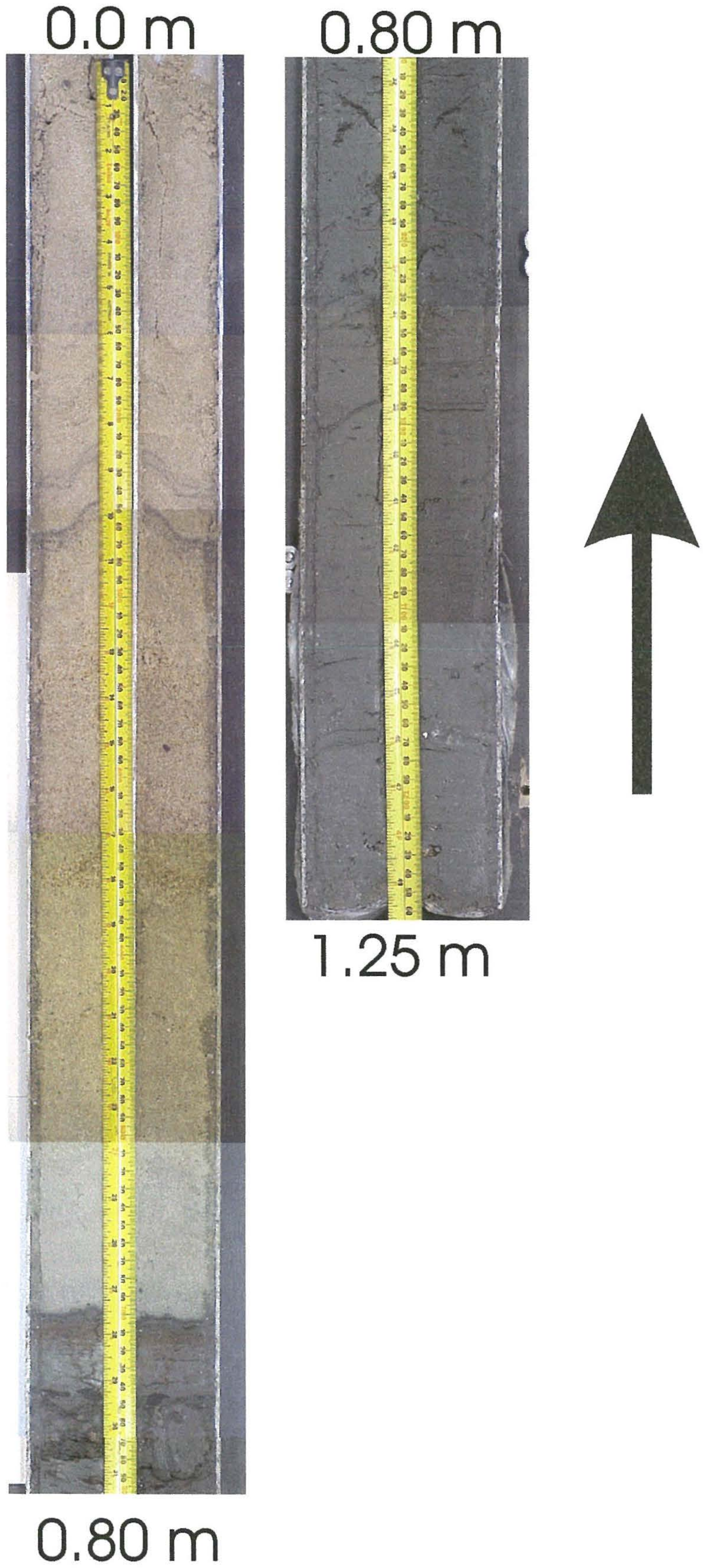
●	Undifferentiated shell fragments
5YR	Munsell Rock Colour
∿	Unconformity
G.S	Grainsize analysis
XRD	X-Ray diffraction analysis

Logged Jared Lester

Date 8/8/2000

Checked

BIVC2



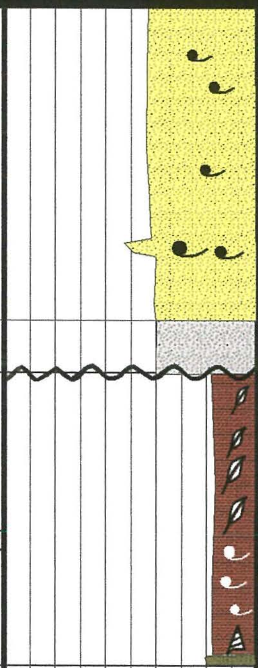
QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Core Compaction: 44%	**Project**	North Bribie Island Spit Stability Study			
	Hole No. BIVC2	**Co-ordinates** 512790 E		**Angle** -	
	R.L	7029339 N		**Bearing** -	
	Date 27/6/2000	**Started** 12:00	**Finished** 13:00	**Method** Vibrocore	

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 0.6	VC2A			Beach sand : Quartz Sand. Buff coloured (5Y 8/4), medium grained, well sorted, sub-angular to sub-rounded quartz sand containing shell fragments and specks of dark minerals. -Between 0.21 to 0.25 m the sand contains grey laminations up to 3 mm thick due to concentration of dark minerals. -Between 0.43 to 0.45 m exists a coarse sand/shell lag containing shell fragments up to 4 mm.
	0.6 – 0.69	VC2B			Quartz sand (Beach). Light grey (bleached)(N6), clean, medium grained. Well sorted sub-angular to sub-rounded grains.
	0.69 – 1.25		VC2C		Clay/Silt (Estuarine mud). Dark brown-grey (5YR2), sticky, high plasticity containing fossilised organic matter and shell material. -Between 0.695 to 0.71 m brown fibrous organic matter. -Between 0.735 to 0.77 m an organic root. -Between 0.77 to 0.95 m inclusions of fibrous organic matter of varying orientations and size. -Between 1.1 to 1.235 inclusions of carbonate shells up to 3 mm diameter. -At 1.22 m a whole Gastropod shell, 20 mm diameter. -Between 1.235 to 1.25 m exists dark grey (N3) very fine grained silty/clayey sand of very low plasticity (Estuarine sediments).
	1.25				End of Hole

Depth scale: 0, 0.5, 0.6, 0.69, 1, 1.25, 1.5, 2, 2.5



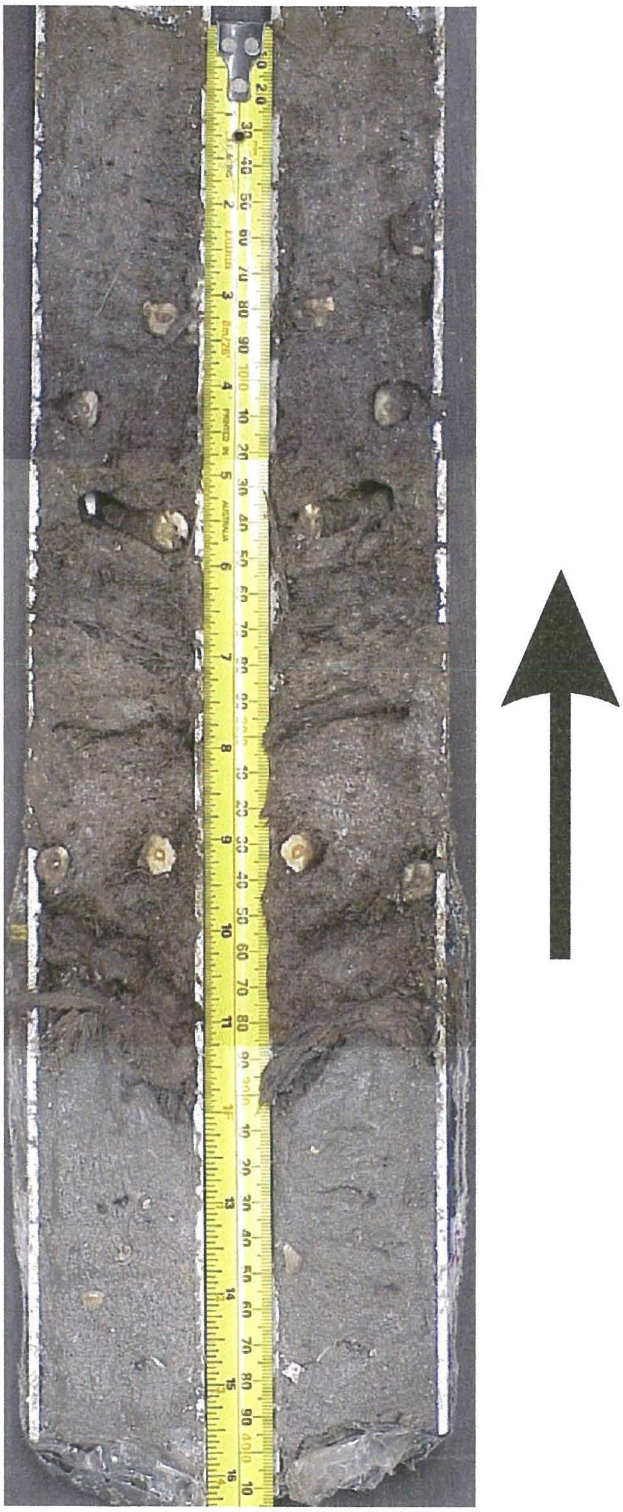
Notes

- Undifferentiated shell fragments
- Gastropod Shell
- Organic matter
- Unconformity
- 5YR — Munsell Rock Colour
- G.S — Grainsize analysis
- XRD — X-Ray diffraction analysis

Logged	Jared Lester
Date	8/8/2000
Checked	

BIVC3

0.0 m

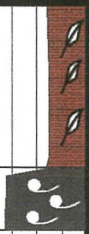


0.42 m

QUEENSLAND UNIVERSITY OF TECHNOLOGY
LOG SHEET

Core compaction uncertain due to core blockage. May be similar to BIVC4.

Project	North Bribie Island Spit Stability Study				
Hole No.	BIVC3	**Co-ordinates**	511933 **E**	**Angle**	-
R.L			7029140 **N**	**Bearing**	-
Date	4/7/2000	**Started** 10:30 AM	**Finished** 10:35 AM	**Method**	Push

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 0.30				Estuarine Mud. Dusky brown - grey (5YR2), containing abundant mangrove roots (10 mmϕ) as well as fibrous roots and organic matter. The mud gives off a faint organic smell. Sharp contact.
	0.30 – 0.42	VC3B			Estuarine sediments. Very fine to fine grained quartz sand with approximately 20% clay/silt matrix. This unit is dark grey (N3) and contains abundant shell fragments (2 to 8 mm). End of Hole.

Depth scale: 0, 0.5, 1, 1.5, 2, 2.5

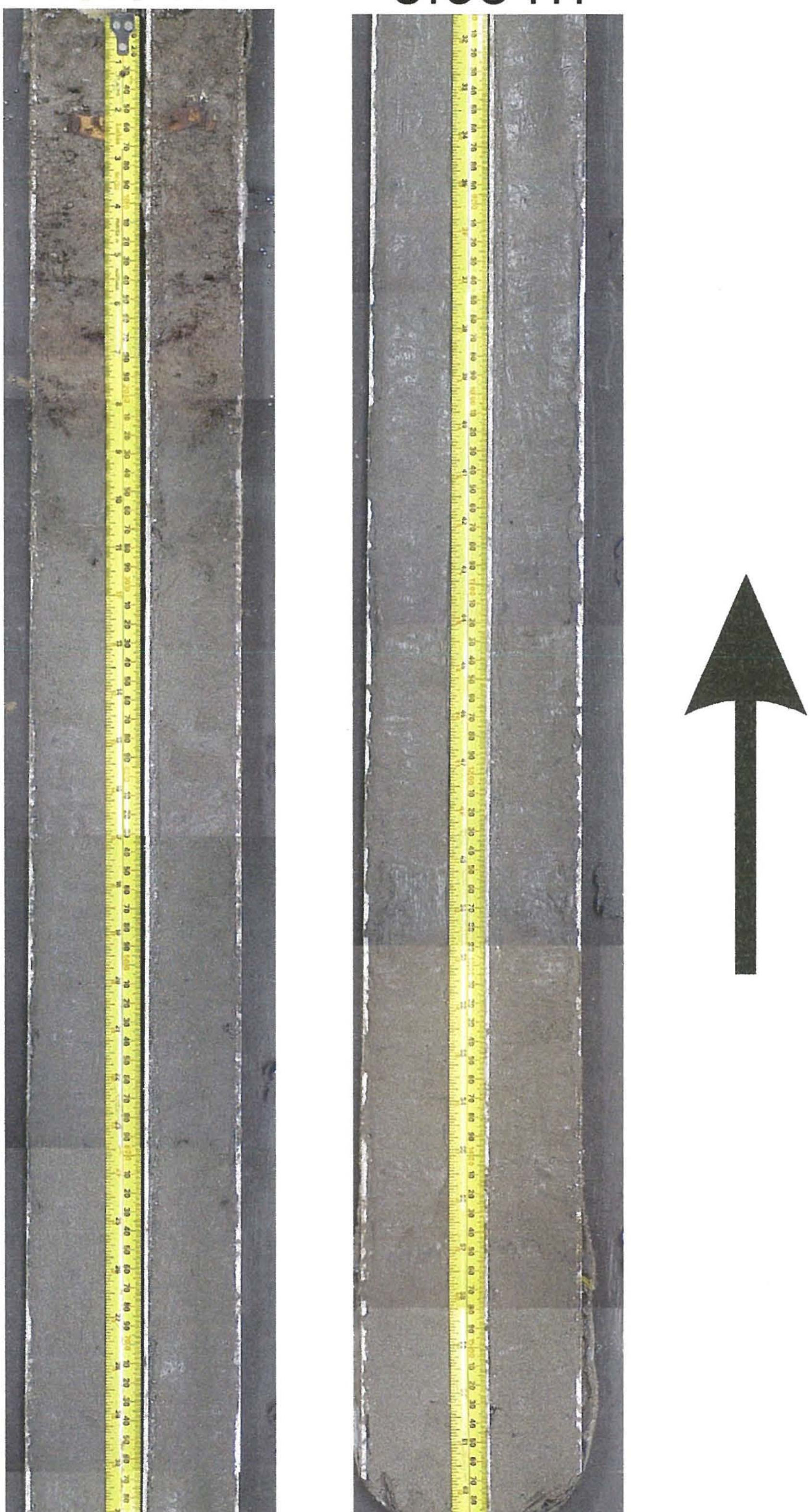
Notes

	Organic matter / mangrove roots
●	Undifferentiated shell material
5YR2	Munsell Rock Colour
G.S	Grainsize Analysis
XRD	X-Ray diffraction analysis

Logged Jared Lester
Date 8/8/2000
Checked

BIVC4

0.0 m 0.80 m



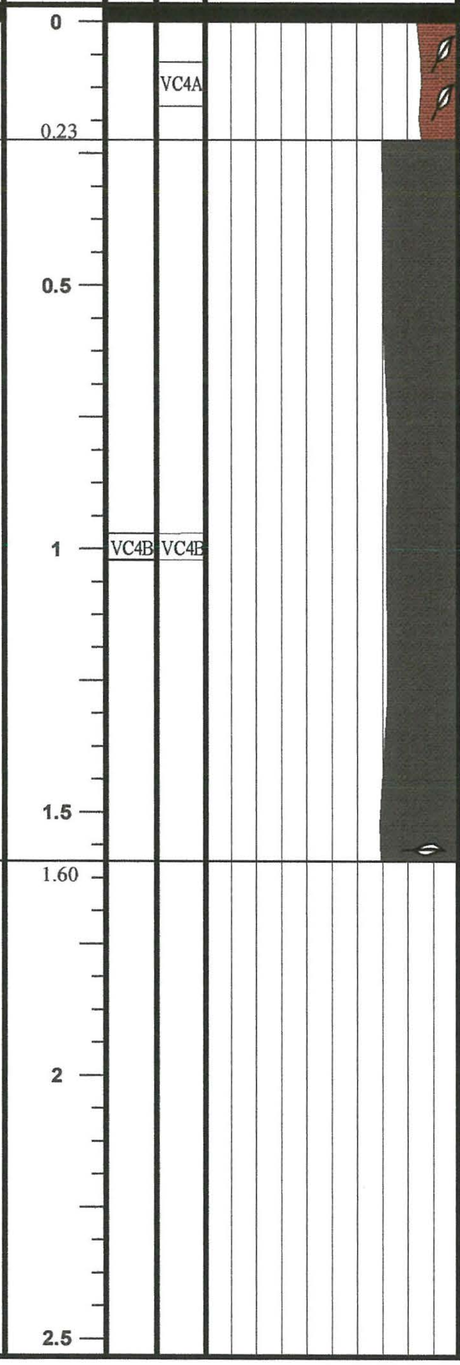
0.80 m 1.60 m

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Core Compaction: 45%	Project	North Bribie Island Spit Stability Study					
	Hole No.	BIVC4	Co-ordinates	511941 E		Angle	-
	R.L			7029136 N		Bearing	-
	Date	4/7/2000	Started	10:45 AM	Finished 11:30 AM	Method	Vibrocore

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize c p g vc c mf f vf si cy	Remarks - Description
	0 – 0.23		VC4A		Estuarine Mud. Dusky brown-grey (5YR2). Contains mangrove roots (up to 12 mm ϕ) as well as abundant fibrous roots and a single shell fragment (10 mm size). Isolated patches of very fine grained sandy silt.
	0.23 – 1.60	VC4B	VC4B		Sharp Contact. Contact defined by lack of root fibres, colour change and increase in grain size. Estuarine sediments : Very fine to fine grained dark grey (N3) quartz sand with approximately 20% silt/clay matrix. No bedding features. Minor specks of charcoal up to 4 mm throughout. Isolated strand of sea grass or plant matter at 1.58 m.
	1.60				End of Hole.



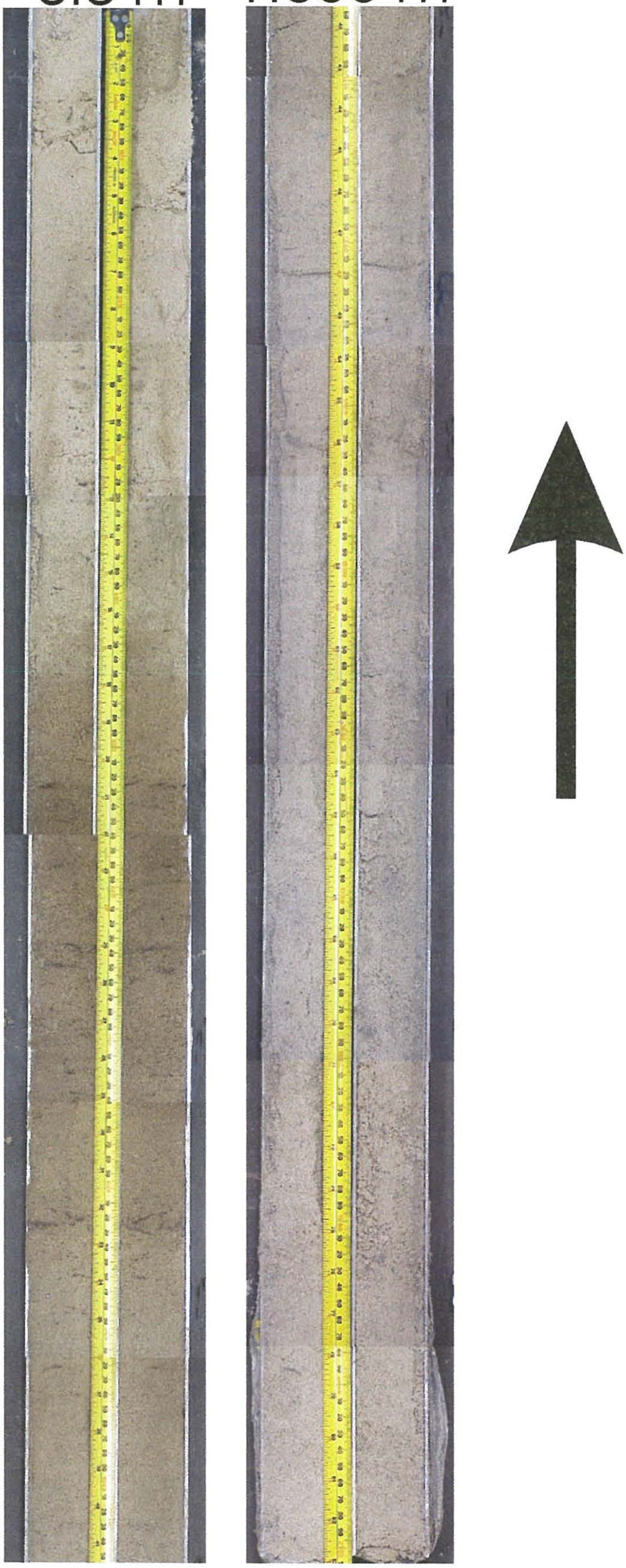
Notes

ø	Organic matter / mangrove roots
5YR2	Munsell Colour Rock
G.S	Grainsize analysis
XRD	X-Ray diffraction analysis

Logged	Jared Lester
Date	8/8/2000
Checked	

BIVC5

0.0 m 1.055 m



1.055 m 2.11 m

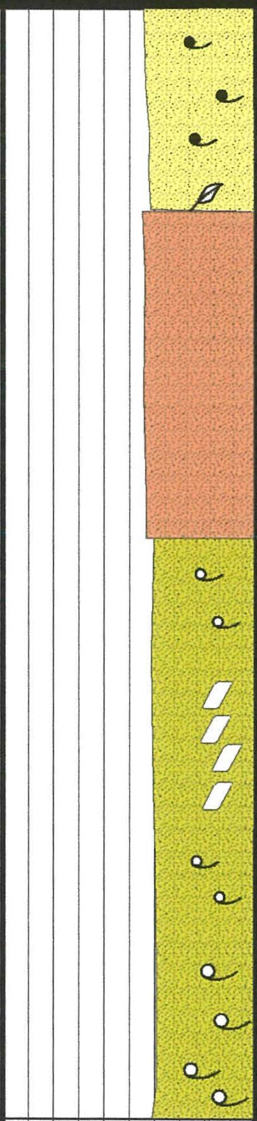
QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Core Compaction: 8%

Project	North Bribie Island Spit Stability Study				
Hole No.	BIVC5	**Co-ordinates**	512861 **E**	**Angle**	-
R.L			7032539 **N**	**Bearing**	-
Date	4/7/2000	**Started** 13:00	**Finished** 14:45	**Method**	Vibrocore

Unit	Depth (m)	Sample G.S	XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	VC5A			Dune sand: Quartz sand. Yellowish grey (5Y 7/2). Medium grained, clean well sorted, sub-angular to sub-rounded grains. Specks of dark minerals throughout, as well as minor shell fragments of 2-3 mm size. No bedding structures are evident. At 0.37m, exists a leaf of 30 mm size.
	0.5	VC5B			Iron stained quartz sand(Dune sand). Moderate brown (5YR 4/4). Medium grained, well sorted, sub-angular to sub-rounded grains. Bands of dark laminations are present possibly resulting from more intense iron staining, tannin, or organic substances. No bedding structures are evident.
	1 1.5 2 2.11	VC5C VC5D			Subtidal channel sand: Quartz sand. Yellowish grey (5Y 7/2) to light olive grey(5Y 5/2). Medium grained, clean, well sorted sub-angular to sub-rounded grains. Specks of dark minerals throughout as well as minor shell fragments, 1-2 mm. Rip-up clasts of grey, very low plasticity clay/silt up to 5 mm ϕ at 1.05m, 1.1m, 1.38m, and 1.55m. Slight increase in grainsize and an increase in the size and amount of shell fragments (up to 4-5 mm size) towards the base of the hole. End of Hole.
	2.5				

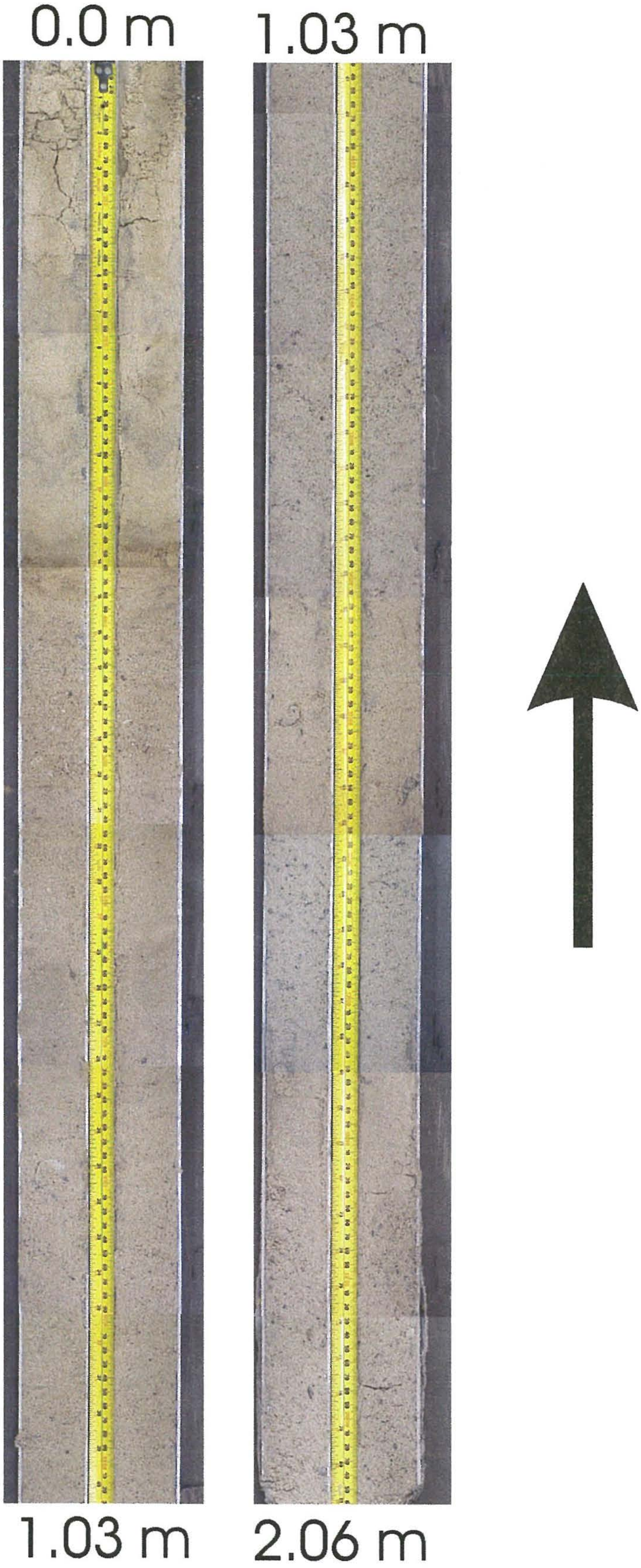


Notes

- Undifferentiated shell material
- Shale rip-up clast
- Organic matter
- 5YR2 — Munsell Colour
- G.S — Grainsize analysis
- XRD — X-Ray diffraction analysis

Logged	Jared Lester
Date	8/8/2000
Checked	

BIVC6

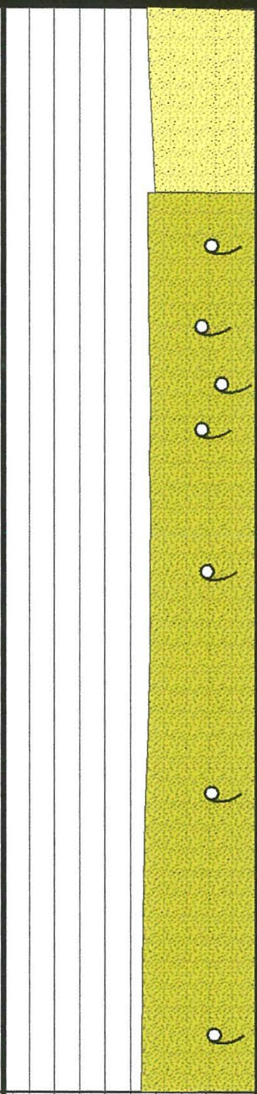


QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Core Compaction: 16%	Project	North Bribie Island Spit Stability Study			
	Hole No.	BIVC6	Co-ordinates	512943 E	Angle -
	R.L			7033363 N	Bearing -
	Date	5/7/2000	Started 10:30 AM	Finished 12:30 PM	Method Vibrocore

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 0.35	VC6A			Dune sand : Quartz sand. Yellowish grey (5Y 7/2). Medium grained, clean, well sorted, sub-angular to sub-rounded grains. Specks of dark minerals throughout forming thin bands (up to 2 mm thick) when concentrated.
	0.35 – 2.06	VC6B, VC6C			Subtidal channel sand : Quartz sand. Yellowish grey (5Y 7/2) to light olive grey (5Y 5/2). Medium grained, clean, well sorted, sub-angular to sub-rounded grains. Slightly coarsening with depth. -Abundant shell fragments (up to 25 mm diameter) throughout. -No bedding structures evident. -At 0.78 m exists an oyster shell, 25 mm diameter. -At 1.5 m exists a mussel shell, 20 mm diameter Grainsize appears to be slightly coarsening with depth. End of Hole.



Depth scale: 0, 0.5, 1, 1.5, 2, 2.06, 2.5

Notes

(shell symbol)	Undifferentiated shell material
5YR2	Munsell Colour
G.S	Grainsize analysis
XRD	X-Ray diffraction analysis

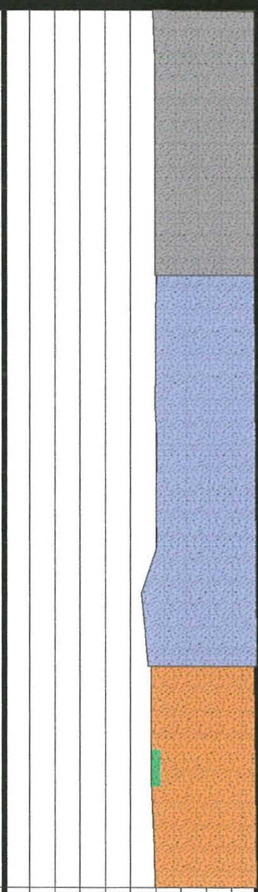
Logged	Jared Lester
Date	8/8/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH1
Co-ordinates	512871 E, 7032534 N
Angle	-
R.L	
Bearing	-
Date	19/6/2000
Started	10:30 AM
Finished	10:45 AM
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 0.5	AH1A			Dune sand : Light grey - chocolate brown (N3 - 5YR 4/1) medium-fine grained quartz sand containing plant roots and organic matter.
	0.5 – 1.25	AH1B, AH1D, AH1E			Pale purple-grey (N8 - 5P 6/2) medium-finegrained well sorted quartz sand.
	1.25 – 1.65	AH1G			Orange-brown (5YR 4/4), iron stained, medium-fine grained quartz sand containing traces of pyrite.
	1.65				Saturated sand. Hole collapse.



Notes

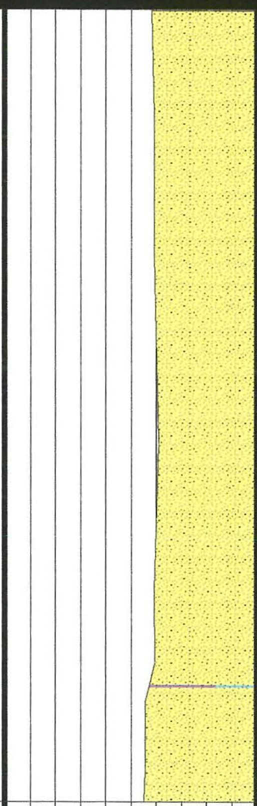
Logged	Jared Lester
Date	19/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study				
Hole No.	AH2	**Co-ordinates**	512899 **E**	**Angle**	-
R.L			7032519 **N**	**Bearing**	-
Date	19/6/2000	**Started** 12:00 PM	**Finished** 12:20 PM	**Method**	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	AH2A			Dune sand : Medium-fine grained quartz sand containing organic matter and root material (N3 - 5YR 4/1).
					Clean, white/grey (N8) medium-fine grained, well sorted quartz sand.
	0.5	AH2B			
		AH2C			
	1	AH2E			
		AH2F			Slight coarsening
	1.5	AH2G			Saturated sand. Oxidised sand below water table. Hole collapse.
	2				
	2.5				



Notes

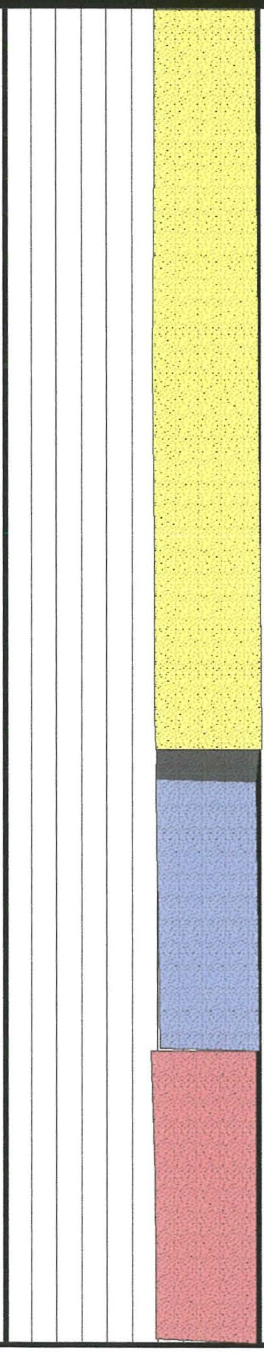
Logged	Jared Lester
Date	19/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH3
Co-ordinates	512947 E, 7032518 N
Angle	-
Bearing	-
R.L	
Date	19/6/2000
Started	13:30
Finished	15:30
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	AH3A			Dune sand : Clean, medium-fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).
	0.5	AH3B			
	1	AH3C			
					Dark grey/black medium-fine grained quarts sand containing root material. (Buried soil profile) (N3 - 5YR 4/1).
	1.5	AH3D			Light grey/purple medium -fine grained well sorted sand (N8 - 5P 6/2).
	2	AH3E			Light orange medium-fine grained well sorted quartz sand (5YR 4/4).
	2.5				



Notes

Logged	Jared Lester
Date	19/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH3
Co-ordinates	512947 **E** / 7032518 **N**
Angle	-
Bearing	-
R.L	
Date	19/6/2000
Started	13:30
Finished	15:30
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	2.5				Light orange medium-fine grained well sorted quartz sand. As above.
	3.0	AH3G			Dune sand : Yellowish, medium-fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).
					Minor root material
	3.5				Minor root material
	4.0				
		AH3I			
	4.5				Saturated sand. Hole collapse.
	5.0				

Notes

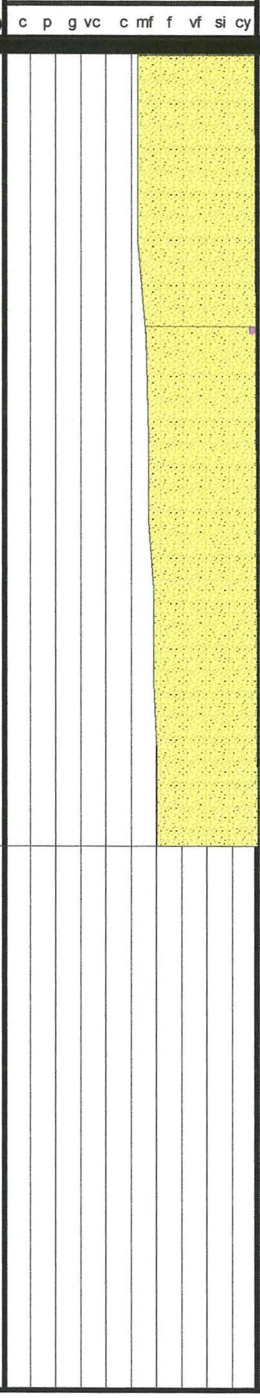
Logged	Jared Lester
Date	19/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH4
R.L	
Date	21/6/2000
Started	12:30 PM
Finished	12:45 PM
Co-ordinates	512951 **E**; 7033370 **N**
Angle	-
Bearing	-
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	AH4A			Dune sand : Clean, medium grained quartz sand fining with depth containing scattered inclusions of dark minerals (5Y 8/4 - 5Y 7/2).
	0.5				
	1	AH4C			
	1.5	AH4D			Saturated sand. Hole collapse.
	2				
	2.5				



Notes

Logged	Jared Lester
Date	21/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH5
Co-ordinates	513022 E; 7033367 N
Angle	-
R.L	
Bearing	-
Date	21/6/2000
Started	13:15
Finished	13:30
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c m f vf si cy)	Remarks - Description
	0 – ~0.3	AH5A		mf – vf	Dune sand : Clean, medium-fine grained quartz sand containing minor flecks of dark minerals and shell fragments (5Y 8/4 - 5Y 7/2).
	~0.3 – ~0.65	AH5C		mf – vf	
	~0.8				Saturated sand. Hole collapse.

Depth scale: 0, 0.5, 1, 1.5, 2, 2.5

Notes

Logged: Jared Lester

Date: 21/6/2000

Checked:

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study				
Hole No.	AH6	Co-ordinates	513084 E	Angle	-
R.L			7033346 N	Bearing	-
Date	21/6/2000	Started	13:45	Finished	15:30
Method	Hand auger				

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	AH6A		f–mf	Dune sand : Clean, medium-fine grained quartz sand containing minor shell fragments and flecks of dark minerals (5Y 8/4 - 5Y 7/2).
	0.5				
					Heavy mineral sand band 5cm thick
	1				
	1.5				
	2				
	2.5				

Notes

Logged Jared Lester

Date 21/6/2000

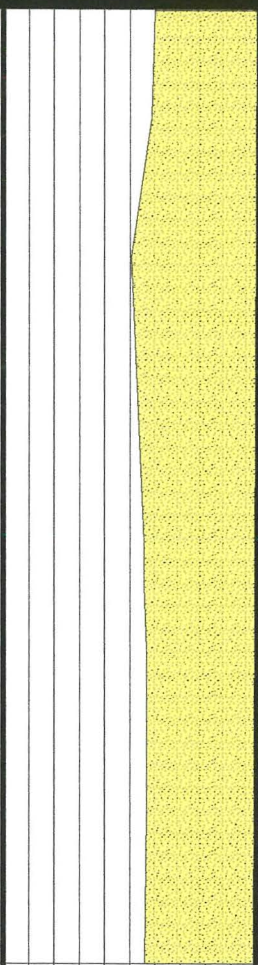
Checked

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH6
Co-ordinates	513084 E
	7033346 N
Angle	-
Bearing	-
R.L	
Date	21/6/2000
Started	13:45
Finished	15:30
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	2.5				Dune sand : Clean, medium-fine grained quartz sand containing minor shell fragments and flecks of dark minerals (5Y 8/4 - 5Y 7/2).
	3.0	AH6E			Beach sand (near inlet?) : Clean, medium-coarse quartz sand containing shell fragments and minor specks of weathered feldspar. Clean, medium grained quartz sand containing minor shell fragments and flecks of dark minerals.
	3.5				
	4.0	AH6G			
		AH6H			Saturated sand. Hole collapse.



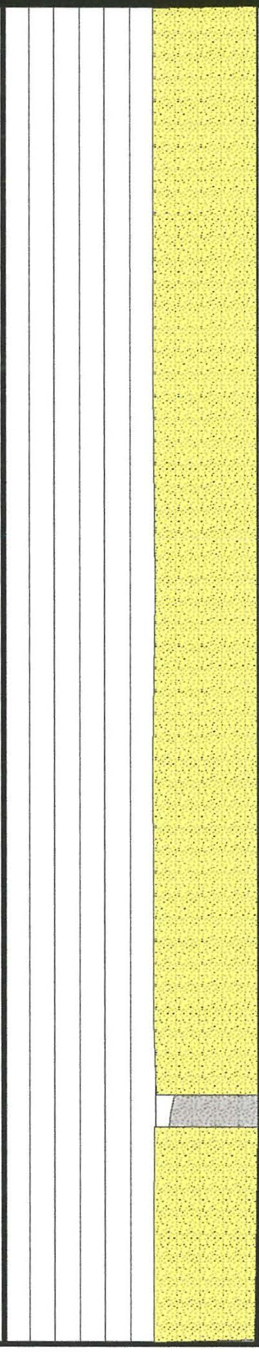
Notes

Logged	Jared Lester
Date	21/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY
LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH7
Co-ordinates	512760 E, 7029344 N
Angle	-
Bearing	-
R.L	
Date	22/6/2000
Started	10:15 AM
Finished	11:45 AM
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c m f vf si cy)	Remarks - Description
	0 – 0.5	AH7A			Dune sand : Buff coloured, clean, medium-fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).
	1 – 1.5	AH7C			Minor root material and iron staining.
	2	AH7D			Pale grey, fine grained sand band 10 cm thick (N8).
	2 – 2.5	AH7E			Buff coloured, clean, medium-fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).



Notes

Logged Jared Lester
Date 22/6/2000
Checked

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH7
Co-ordinates	512760 **E**, 7029344 **N**
R.L	
Angle	-
Bearing	-
Date	22/6/2000
Started	10:15 AM
Finished	11:45 AM
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	2.5	AH7F		mf–si	Dune sand : Buff coloured, clean, medium-fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).
	3.0	AH7G			
	3.5				Saturated sand. Hole collapse
	4.0				

Notes

Logged Jared Lester

Date 22/6/2000

Checked

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study				
Hole No.	AH8	Co-ordinates	512728 E	Angle	-
R.L			7029330 N	Bearing	-
Date	22/6/2000	Started 13:00	Finished 13:45	Method	Hand auger

Unit	Depth (m)	Sample G.S	XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 2	AH8A, AH8B, AH8E		mf – cy	Dune sand : Buff coloured, medium grained, clean, well sorted quartz sand grading to medium-fine grained sand with depth (5Y 8/4 - 5Y 7/2). Between 0.2 to 0.7 m. Minor silty bands containing root material and organic matter.
	2				Saturated sand. Hole collapse.
	2.5				

Depth scale: 0, 0.5, 1, 1.5, 2, 2.5

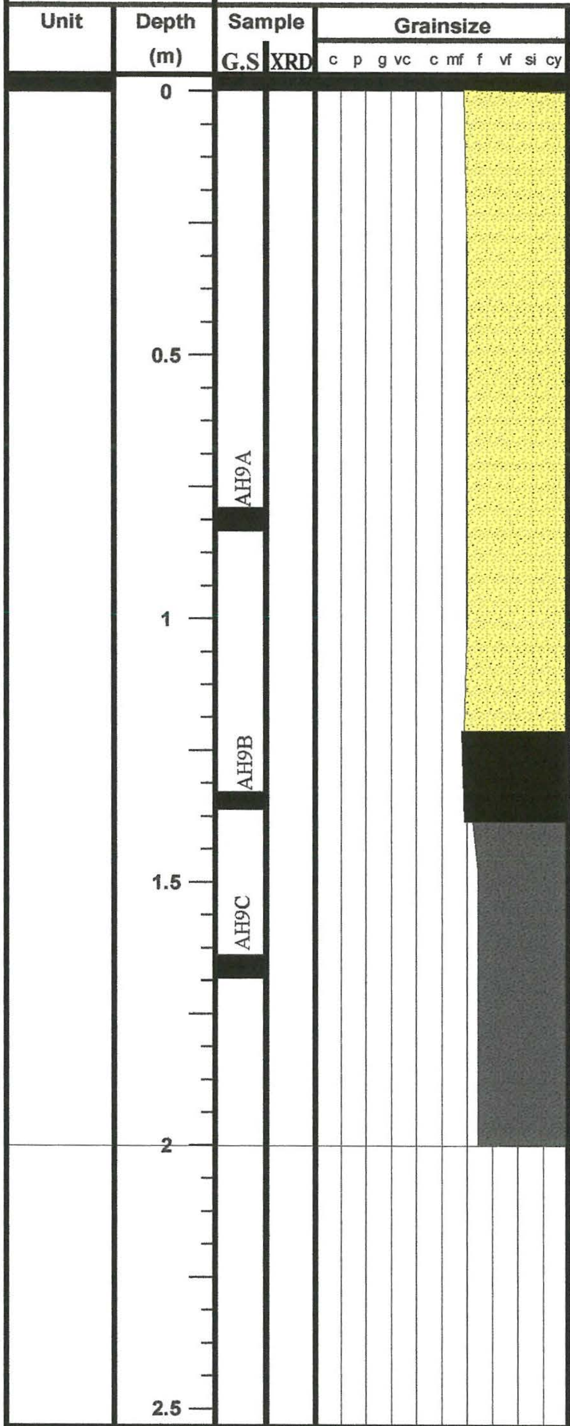
Notes

Logged	Jared Lester
Date	22/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study				
Hole No.	AH9	**Co-ordinates**	512667 **E**	**Angle**	-
R.L			7030722 **N**	**Bearing**	-
Date	30/6/2000	**Started** 13:45	**Finished** 14:15	**Method**	Hand auger



Remarks - Description

Beach sand :
Buff coloured, clean, medium-fine grained quartz sand (5Y 8/4 - 5Y 7/2).

Sharp contact.

Estuarine/tidal channel (undifferentiated). Dark grey-black, organic medium-fine grained sandy mud (N3 - N2).

Estuarine sand. Black/grey fine grained sand containing minor clay (N3).

Saturated sand. Hole collapse.

Notes

Logged	Jared Lester
Date	30/6/2000
Checked	

QUEENSLAND UNIVERSITY OF TECHNOLOGY

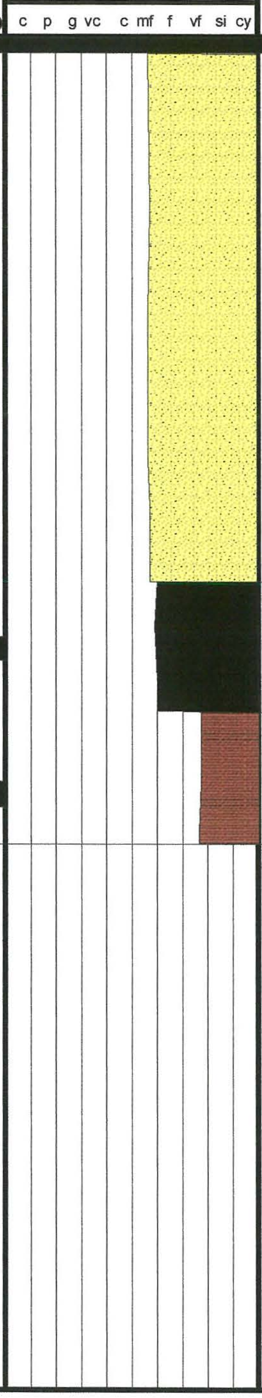
LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH10
Co-ordinates	512832 **E** / 7028140 **N**
R.L	
Angle	-
Bearing	-
Date	10/7/2000
Started	10:30 AM
Finished	10:45 AM
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Remarks - Description
	0 – 1	AH10A		Beach sand : Clean, medium grained well sorted quartz sand containing minor shell fragments (5Y 8/4 - 5Y 7/2). Sharp contact
	1 – 1.25	AH10C	AH10C	Estuarine/tidal channel (undifferentiated) : Dark grey - black (N3 - N2), organic, medium-fine grained slightly silty sand.
	1.25 – 1.5	AH10D	AH10D	Estuarine sediments. Dark brown/grey (5YR2) sandy clay. Strand of plant matter, possibly seagrass at base. Hole Collapse

Depth scale (m): 0, 0.5, 1, 1.5, 2, 2.5

Grainsize



Notes

Logged Jared Lester

Date 8/8/2000

Checked

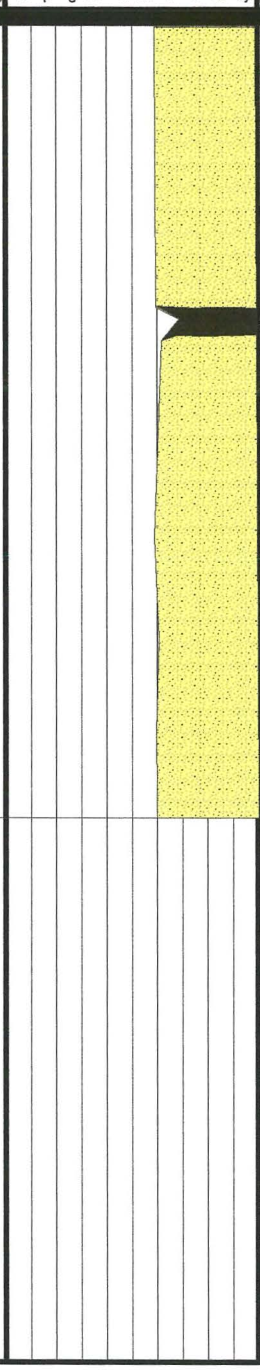
QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project North Bribie Island Spit Stability Study

Hole No. AH11	**Co-ordinates**	512768 **E**		**Angle**	-
R.L		7029339 **N**		**Bearing**	-
Date 10/7/2000	**Started** 11:50 AM	**Finished** 12:05 PM		**Method**	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0	AH11A			Beach sand : Clean, medium-fine grained well sorted quartz sand containing minor shell fragments (5Y 8/4 - 5Y 7/2).
	0.5				Band of heavy mineral sand 10 cm thick.
	1				
	1.5				Satured sand. Hole Collapse.
	2				
	2.5				



Notes

Logged Jared Lester
Date 10/7/2000
Checked

QUEENSLAND UNIVERSITY OF TECHNOLOGY

LOG SHEET

Project	North Bribie Island Spit Stability Study
Hole No.	AH12
Co-ordinates	512966 E / 7033955 N
Angle	-
Bearing	-
R.L	
Date	7/9/2000
Started	10:30 AM
Finished	10:45 AM
Method	Hand auger

Unit	Depth (m)	Sample G.S	Sample XRD	Grainsize (c p g vc c mf f vf si cy)	Remarks - Description
	0 – 1			f	Dune sand : Clean, fine grained well sorted quartz sand (5Y 8/4 - 5Y 7/2).
	1				Water Table
	1 – 1.3			f	Dune sand : Light grey (N7), fine grained, well sorted quartz sand. Saturated and gives off a faint organic smell.
	1.3				Saturated sand. Hole collapse.

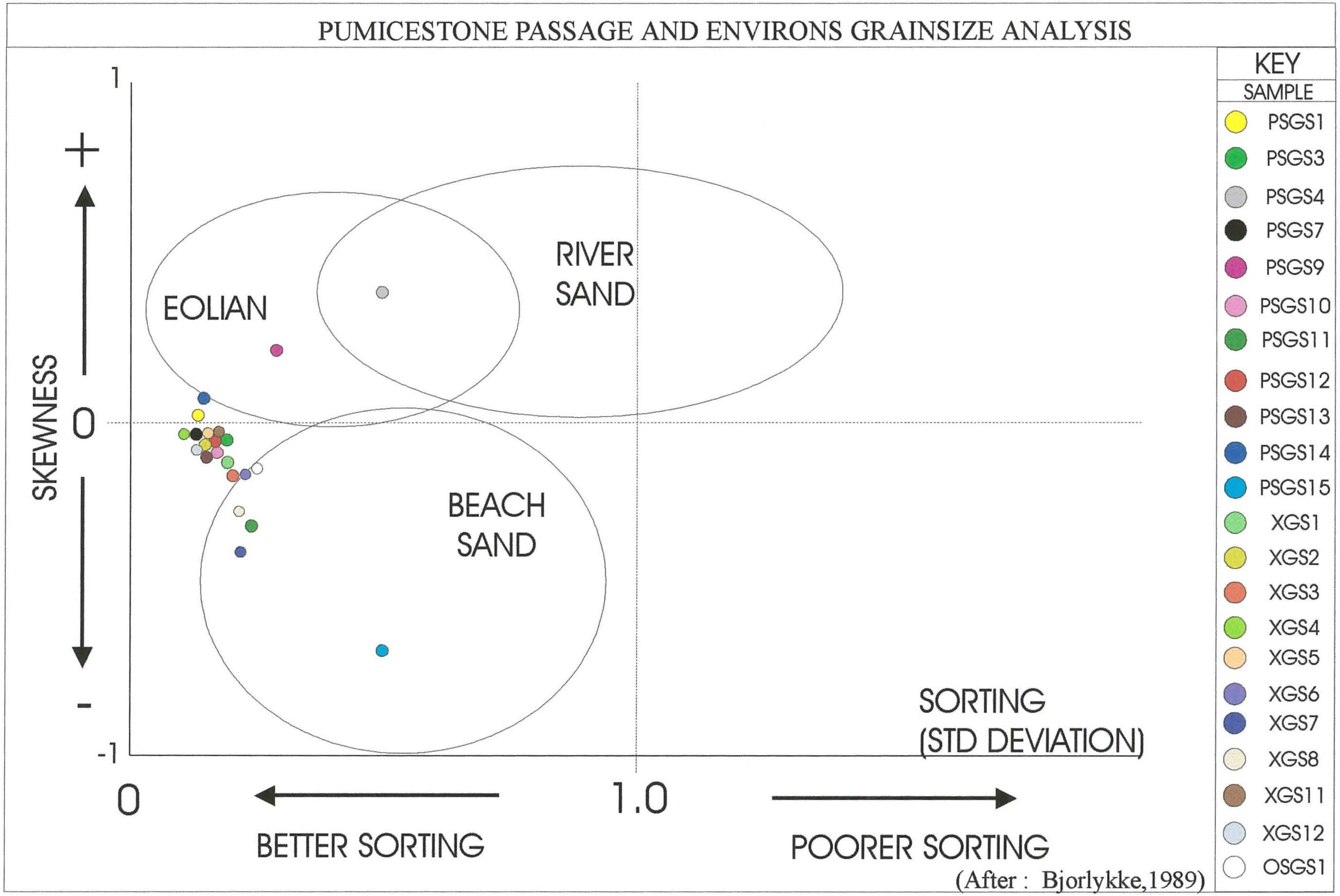
Depth scale (m): 0, 0.5, 1, 1.5, 2, 2.5

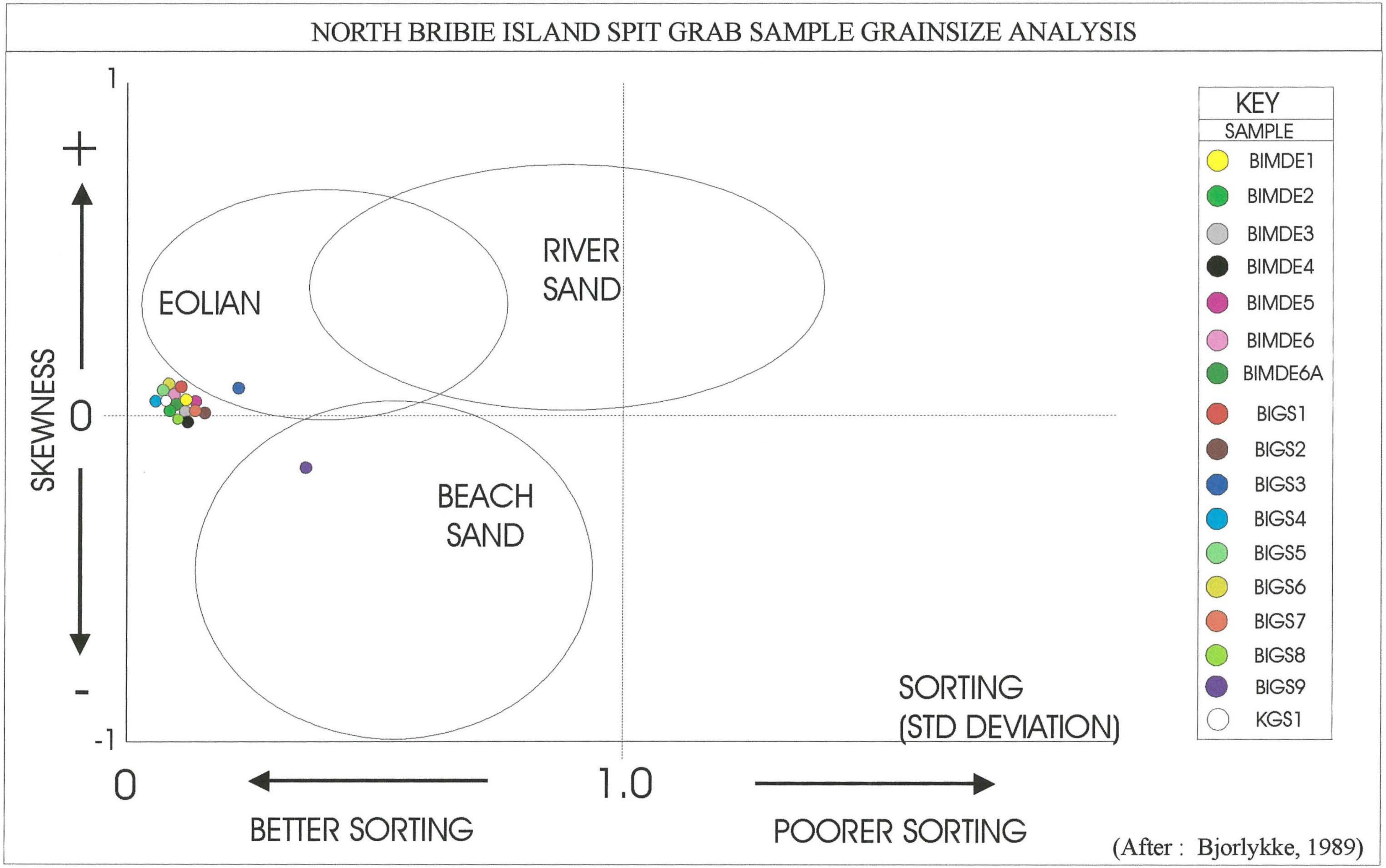
Notes

Logged	Jared Lester
Date	7/9/2000
Checked	

APPENDIX C

Grainsize data and plots of grab samples.


PUMICESTONE PASSAGE AND ENVIRONS GRAINSIZE ANALYSIS
1
+
0
-
-1
SKEWNESS
EOLIAN
RIVER SAND
BEACH SAND
SORTING (STD DEVIATION)
0
1.0
BETTER SORTING
POORER SORTING
(After : Bjorlykke,1989)
KEY
SAMPLE
PSGS1
PSGS3
PSGS4
PSGS7
PSGS9
PSGS10
PSGS11
PSGS12
PSGS13
PSGS14
PSGS15
XGS1
XGS2
XGS3
XGS4
XGS5
XGS6
XGS7
XGS8
XGS11
XGS12
OSGS1



NORTH BRIBIE ISLAND SPIT GRAB SAMPLE GRAINSIZE ANALYSIS
1
+
SKEWNESS
0
-
-1
EOLIAN
RIVER
SAND
BEACH
SAND
SORTING
(STD DEVIATION)
0
1.0
BETTER SORTING
POORER SORTING
KEY
SAMPLE
BIMDE1
BIMDE2
BIMDE3
BIMDE4
BIMDE5
BIMDE6
BIMDE6A
BIGS1
BIGS2
BIGS3
BIGS4
BIGS5
BIGS6
BIGS7
BIGS8
BIGS9
KGS1
(After : Bjorlykke, 1989)

APPENDIX D

Microscope analysis.

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC1A		
Composition	Percent	Texture/Description
Quartz Carbonate Lithics Dark Minerals	97% 1-2% 1% 0.5%	Clear and sub-angular, opaque and sub-rounded, yellow and sub rounded. Shell fragments Red and grey chert, volcanics
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC1C		
Composition	Percent	Texture/Description
Quartz Carbonate Lithics	96% 1% 2-3%	Majority is sub-rounded. Clear and sub-angular, opaque and sub-rounded, pink and sub rounded. Shell fragments Red and grey chert, volcanics
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC2A		
Composition	Percent	Texture/Description
Quartz Carbonate Lithics Dark Minerals	94% 1% 2% 3%	Clear and sub-angular, opaque and sub-rounded, yellow and sub-rounded, smoky and sub-rounded, pink and sub rounded. Shell fragments Red and grey chert, hornblende, minor mica (1 grain)
Modal Grain Size: Medium grained Sorting: Moderately sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC2B		
Composition	Percent	Texture/Description
Quartz	94%	Clear and sub-angular, opaque and sub rounded, pink and sub-rounded.
Carbonate	1%	Shell fragments
Lithics	2%	Red chert, hornblende, minor mica
Dark Minerals	3%	
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC3B		
Composition	Percent	Texture/Description
Quartz	82%	Clear – opaque and sub-angular – sub-rounded
Carbonate	10%	Bi-valves, shell fragments
Lithics	1-2%	Volcanics
Feldspar	0.5%	Angular K-feldspar
Mud	5%	
Modal Grain Size: Fine grained Sorting: Moderately well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 6.1% mud

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC5A		
Composition	Percent	Texture/Description
Quartz	93%	Clear and sub-angular, opaque and sub-rounded, minor yellow quartz that is sub-rounded.
Lithics	3-5%	Red and grey chert, rock fragments
Dark minerals	2%	
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC5B		
Composition	Percent	Texture/Description
Quartz Lithics Dark minerals	92% 5% 3%	Iron stained, clear and sub-angular, opaque and sub-rounded. Rock fragments
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC5C		
Composition	Percent	Texture/Description
Quartz	92%	Clear and sub-angular, opaque and sub-rounded.
Lithics	3-5%	Red and grey chert
Dark minerals	3%	
Carbonate	0.5%	Shell fragments
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC5D		
Composition	Percent	Texture/Description
Quartz	91%	Clear and opaque sub-angular - sub-rounded, pink and sub-rounded.
Carbonate	4%	Shell fragments
Lithics	3%	Red and grey chert
Dark minerals	2%	
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC6A		
Composition	Percent	Texture/Description
Quartz Dark minerals Lithics	87% 10% 3%	Opaque and sub-rounded, clear, yellow and sub-angular – sub-rounded. Sub-rounded Red chert, minor mica
Modal Grain Size: Medium – fine grained Sorting: Very well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC6B		
Composition	Percent	Texture/Description
Quartz Carbonate Lithics Dark minerals	89% 5% 5% 1%	Clear and opaque sub-angular – sub-rounded. Smokey and pink sub-rounded. Shell fragments Grey chert
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: VC6C		
Composition	Percent	Texture/Description
Quartz Carbonate Lithics Dark minerals	85% 8% 5% 2%	Clear and sub-angular, opaque and pink sub-rounded Shell fragments Red and grey chert, rock fragments
Modal Grain Size: Medium grained Sorting: Moderately well sorted		Grain Shape: subangular - subrounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: PSGS11		
Composition	Percent	Texture/Description
Quartz	95%	Clear and sub-angular, opaque and sub-rounded
Lithics	2%	Chert, rock fragments
Carbonate	2%	Shell fragments
Dark minerals	1%	
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: PSGS12		
Composition	Percent	Texture/Description
Quartz	95%	Clear and sub-angular, opaque and yellow sub-rounded Chert, rock fragments
Lithics	3%	Shell fragments
Carbonate	1%	
Dark minerals	1%	
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: AH6A		
Composition	Percent	Texture/Description
Quartz	94%	Clear, smoky, yellow and sub-angular – sub-rounded, opaque and sub-rounded – rounded.
Lithics	2%	Rock fragments
Carbonate	2%	Shell fragments – well worn
Dark minerals	1%	
Organics	1%	Root material
Modal Grain Size: Medium – fine grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: XGS14		
Composition	Percent	Texture/Description
Quartz	97%	Clear and angular - sub-angular, opaque and sub-rounded, smoky and yellow sub-angular – sub-rounded.
Lithics	1%	Chert, rock fragments (volcanic)
Carbonate	1%	Shell fragments
Dark minerals	1%	
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: PSGS15		
Composition	Percent	Texture/Description
Quartz	94%	Clear, smoky, yellow and sub-angular – sub-rounded. Opaque, pink and sub-rounded – rounded.
Carbonate	3%	Large shell fragments
Lithics	2%	Rock fragments
Dark minerals	1%	
Modal Grain Size: Medium – coarse grained Sorting: Poor – moderate sorting		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

NORTH BRIBIE ISLAND SAND SPIT MICROSCOPE ANALYSIS Sample No.: OSGS1		
Composition	Percent	Texture/Description
Quartz	96%	Clear and sub-angular, opaque and sub-angular - sub-rounded, yellow and sub-rounded.
Lithics	1-2%	Chert, rock fragments
Carbonate	0.5-1%	Shell fragments
Dark minerals	0.5%	
Modal Grain Size: Medium grained Sorting: Well sorted		Grain Shape: sub-angular – sub-rounded Sand Mud Ratio: 100% sand

APPENDIX E

X-ray diffraction data plots.

X-RAY DIFFRACTION ANALYSIS

General

XRD is a widely used technique for mineral identification, particularly for fine-grained materials where the grain size is too small to be usefully studied with the optical microscope. In addition, the XRD analysis can provide information on the degree of structural disorder, particle size, and the nature of isomorphous substitutions.
The method is based on the fact that X-rays are scattered by the electrons around atoms which form the atomic layers in crystals (lattice spacings). A particular crystalline material has a particular structure or lattice. The scattered x-rays reinforce each other in directions that depend on the lattice repeat distances and the wavelength of the x-rays. The angles of diffraction gives an indirect indication of the spacings (*d* spacings) between atomic layers and therefore can be used for mineral identification.

The advantages of the method include the fact that:
1) it is non-destructive,
2) the samples are reasonably easy to prepare,
3) the material can be processed even in very small quantities,
4) modern computer-linked instruments are quite straightforward to operate and maintain.

The limitations of the XRD analysis include:
1) the method is capable of identifying only crystalline materials,
2) components of the same mineral series (i.e. micas, feldspars, amphiboles) which have very similar crystallographic structures are difficult to separate due to their very similar XRD patterns.

Micronizing

The micronizing vessel consists of a plastic cylinder filled with 48 stacked small agate or corundum cylinders. The particle size of the sample material to be crushed in this type of mill is to be no larger than 100 microns (i.e. what is obtainable from a swing mill). Approximately 3 g of sample and 10-12 ml of alcohol are placed into the micronization vessel and then into the arm of the mill. The timer on the mill is typically set to 0.2 (hr) (i.e. 12 minutes). Other settings of the timer can be made. The slurry obtained is homogenous and the particle size is ideally in the range of 1 to 5 microns. The mixture of sample/alcohol is placed in a pre-labeled beaker and left to dry overnight in an oven at 50-60^0 C. The sample will require remixing prior its use to counteract any segregation of phases during the drying step. The micronized powder is used to identify all the mineral phases of the sample providing that the phases are present in sufficient abundance.

Randomly-orientated powder samples

About 1.5-2 g of powder is lightly packed (to avoid as much as practical pressure orientation), into the back side of a circular cavity of an aluminum plate. The front face of the sample holder rests on a polished metal block. The pressing is done using a small plastic cylinder and a metal ring for guidance. After the powder is packed, the plastic cylinder and metal ring are removed and the second half of the holder is carefully clicked on. The entire holder is then lifted, inverted and placed face upward into the autosample changer carousel. When the entire batch is ready, the carousel is placed into the autosample changer and the data acquisition task begun.

Orientated specimens

Preparation of orientated samples is suitable and sometimes absolutely necessary for identification of clay minerals. Clay silicates have a particular structure developed along the (001) crystallographic plane which makes them difficult to identify in a non-orientated (random) sample preparation, especially when the clay phases are in small quantities. The mechanism of orientating clay crystals exploits their sheet structure and to make the sheets lay one atop of the other in the same plane. This produces a pseudo-macrocrystal and creates a more intense diffraction pattern of the (001) basal spacing series.

The first step is to disperse the sample in about ten times its volume of distilled water. Light grinding and shaking of the mixture (or ultrasonic dispersion) leads to a dissociation of the clay particles and separation of clay size material from the coarser (mineral) fractions. The material left in suspension is generally finer than 2 microns and can be taken with a pipette, spread over a glass slide and the slide then placed on top of a warm surface to dry. In about an hour at 50^0 C, the water evaporates leaving behind a gravimetrically deposited clay fraction. The glass slide is placed on a plastic holder which fits on the back of the Co-machine holders.

REFERENCES

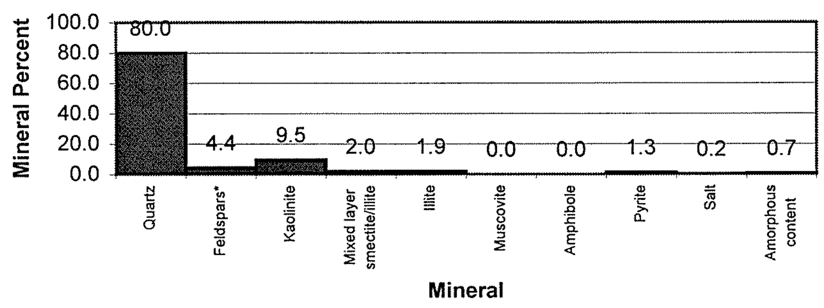
JENKINS R. & SNYDER R. L. 1996. Introduction to X-ray Powder Diffractometry, Chapter 9 (Specimen preparation), Chemical Analysis, Vol. 138, pp. 231-259, Wiley.

BISH D. L. & POST J. E. 1989. Sample Preparation for X-ray Diffraction, Chapter 4 (Modern powder X-ray diffraction), Rev. Mineral, Vol 20, pp. 72-99. Mineral Soc. Am., Washington DC.

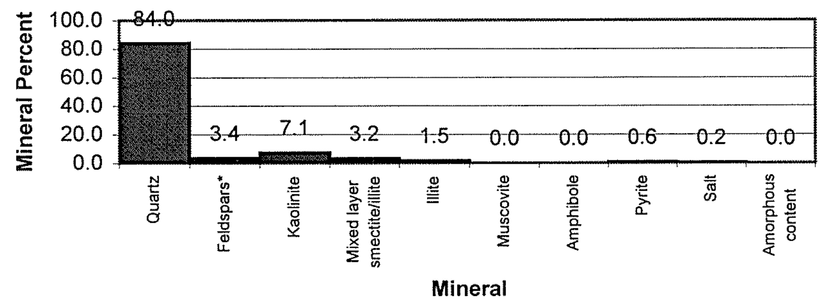
NOTE

The identification and quantification of sediment mineral phases presented in this thesis was assisted by several computer programs: 1) TRACES (plot of XRD traces, locate peaks and export data), 2) JADE (search-match program) and 3) SIROQUANT (quantification program which expresses the composition of the sample in percentages of dry weight). The error of the quantification was calculated as Chi Squared (goodness of fit between the experimental XRD trace and the calculated one) and ranged between **3.2-3.8**.

VC1B - X-Ray Diffraction Analysis

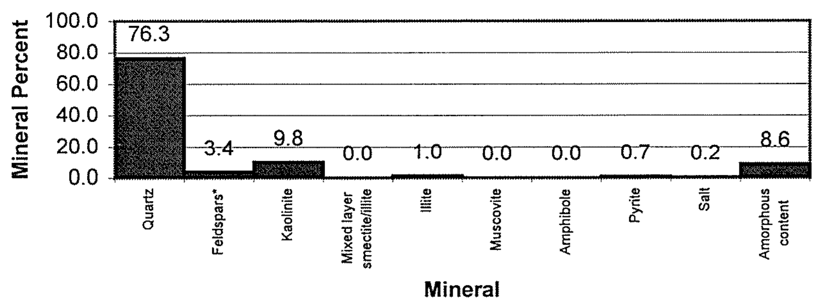


VC4B - X-Ray Diffraction Analysis

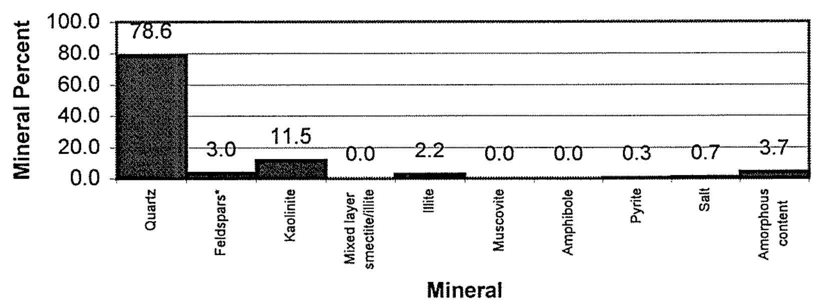


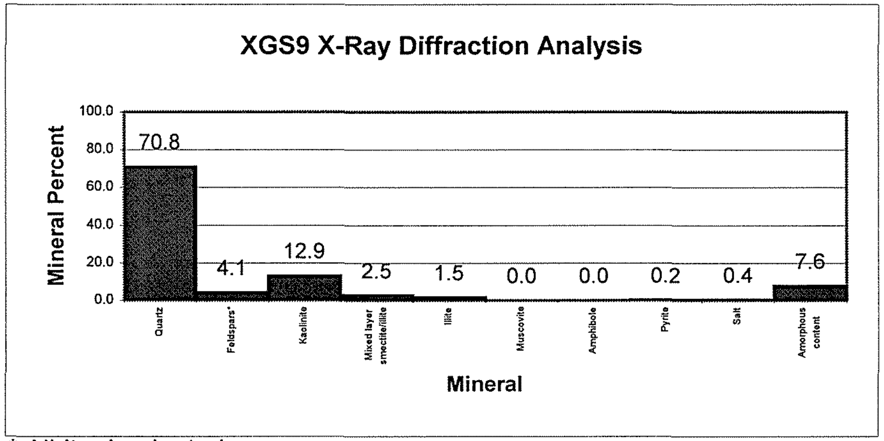
* Albite dominated

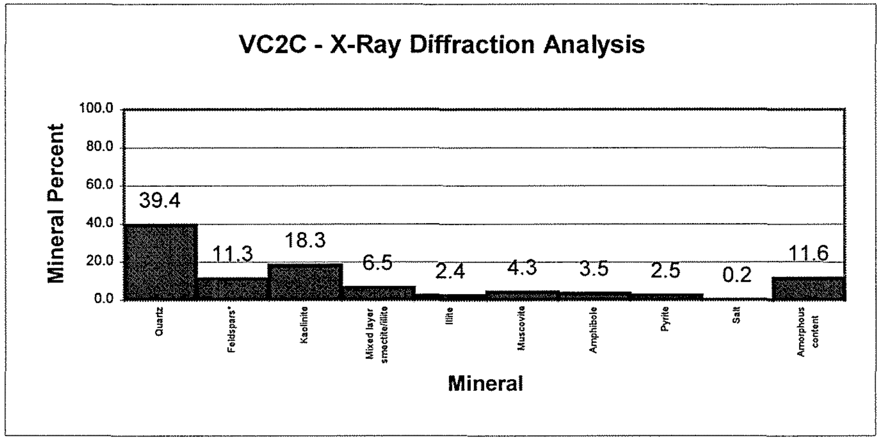
VC4A - X-Ray Diffraction Analysis



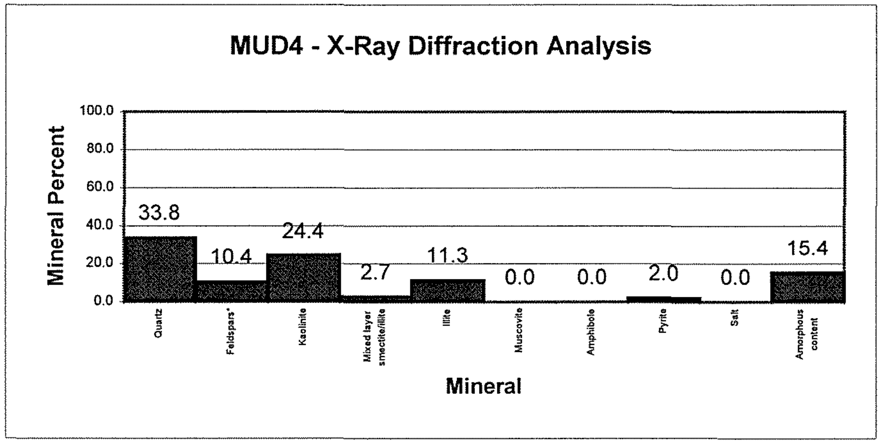
PSGS4 - X-Ray Diffraction Analysis

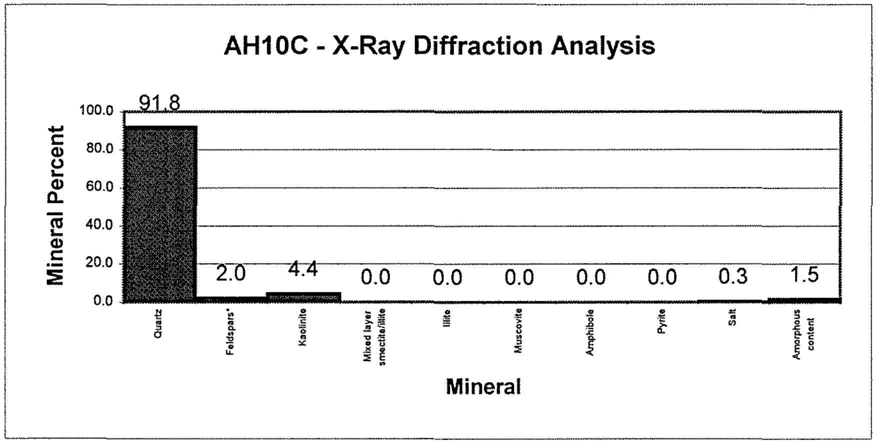


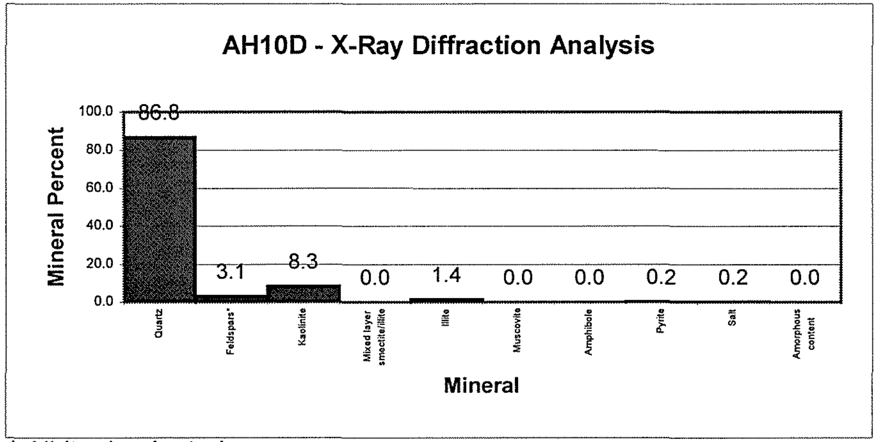


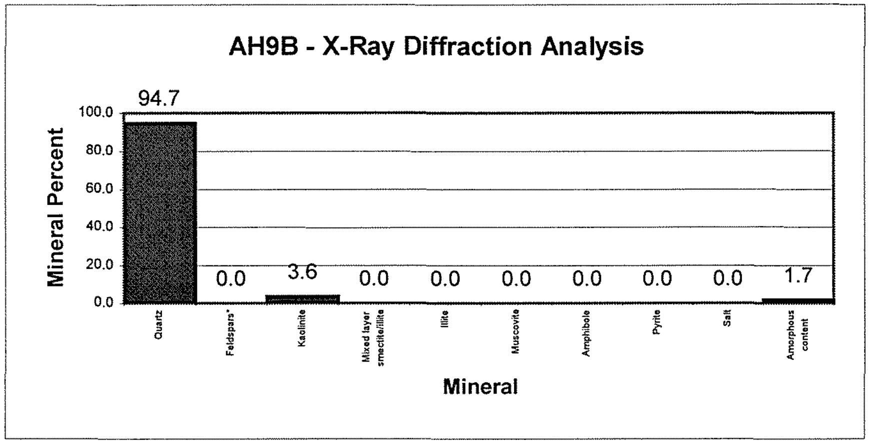


* Albite dominated









* Albite dominated

APPENDIX F

Cyclone and storm data (1861-2000).

This table is a brief summary of the records of cyclones and the major storm events that have impacted on the Sunshine Coast of Southeast Queensland. Full records are held by the Australian Bureau of Meteorology.

DATE	EVENT	DATE	EVENT
2/1863	Cyclone	5-7-6/1961	Low
17-19/3/1864	Cyclone	9-11/7/1962	Low
6-7/1864	Low	1/1/1963	Cyclone Annie
21/4/1867	Cyclone	24/4/1963	Cyclone
26-28/4/1867	Cyclone	7-8/5/1963	Low
14-17/6/1869	Low	13-14/1/1964	Cyclone Audrey
5/3/1870	Cyclone	30/1/1965	Cyclone Judy
28/12/1873	Cyclone	25-28/6/1965	Low
25/2/1874	Cyclone	9-13/6/1966	Low
24/2/1875	Cyclone	28-30/1/1967	Cyclone Dinah
16/3/1875	Cyclone	22/2/1967	Cyclone Barbara
14-20/7/1876	Low	18/3/1967	Cyclone Elaine
3/6/1878	Low	2-4/4/1967	Cyclone Glenda
15/5/1879	Low	21-22/6/1967	Low
24-27/6/1879	Low	26-28/6/1967	Low
21/1/1887	Cyclone	17/2/1971	Cyclone Dora
8/2/1887	Cyclone	20-22/2/1971	Cyclone Fiona
22/2/1887	Cyclone	11/2/1972	Cyclone Daisy
17/2/1888	Cyclone	2/4/1972	Cyclone Emily
8-11/10/1888	Low	5-8/7/1973	Low
17-19/7/1889	Low	24/1/1974	Cyclone Wanda
28/1-1/2/1890	Cyclone	6/2/1974	Cyclone Pam
11/3/1890	Cyclone	13/3/1974	Cyclone Zoe
24/3/1890	Cyclone	19/1/1976	Cyclone David
8/6/1891	Low	1/2/1976	Cyclone Alan
2/4/1892	Cyclone	22/2/1976	Cyclone Beth
21/1/1893	Cyclone	4/3/1976	Cyclone Colin
1/2/1893	Cyclone	6-10/3/1977	Cyclone Otto
11/2/1893	Cyclone	29-30/7/1979	Low
17/2/1893	Cyclone	7-8/1/1980	Cyclone Paul
10-12/6/1893	Low	12-14/2/1980	Cyclone Ruth
10/2/1894	Cyclone	24/2/1980	Cyclone Simon
26/7/1897	Low	6-9/5/1980	Low
6-7/3/1898	Cyclone	15/2/1981	Cyclone Cliff
11/1/1911	Cyclone	21-22/5/1981	Low
15-16/8/1912	Low	3-5/6/1983	Low
21-22/9/1914	Low	7-9/4/1984	Cyclone Lance
8-10/10/1914	Low	8-10/7/1985	Low
9-11/2/1915	Cyclone	2-3/9/1985	Low
23-28/9/1916	Low	4-7/4/1988	Low
3/3/1919	Cyclone	10-11/4/1988	Low
28/7/1919	Low	14-16/9/1988	Low
5/4/1921	Cyclone	4/4/1989	Cyclone Aivu
22-24/7/1921	Low	24-26/4/1989	Low
2-6-10/1921	Low	3/2/1990	Cyclone Nancy
18-23/6/1925	Low	13/1/1992	Cyclone Betsy

This table is a brief summary of the records of cyclones and the major storm events that have impacted on the Sunshine Coast of Southeast Queensland. Full records are held by the Australian Bureau of Meteorology.

DATE	EVENT	DATE	EVENT
2/1863	Cyclone	5-7-6/1961	Low
17-20/5/1926	Low	21-22/2/1992	Low
2/4/1927	Cyclone	16/3/1992	Cyclone Fran
29-30/11/1927	Cyclone	17/3/1993	Cyclone Roger
14/2/1928	Cyclone	20/1/1994	Cyclone Rewa
21/4/1928	Cyclone	14-16/2/1995	Low
28-29/2/1929	Cyclone	8/3/1995	Cyclone Violet
15-17/6/1929	Low	9/1/1996	Cyclone Barry
29-30/6/1929	Low	14-17/2/1996	Low
1-8/2/1931	Cyclone	1/5/1996	Low
7/7/1931	Low	9/3/1997	Cyclone Justin I
1/2/1934	Cyclone	26/3/1998	Cyclone Yali
1-2/9/1934	Low	4-5/2/1999	Low
22/3/1936	Cyclone	8-10/2/1999	Low
15/3/1937	Cyclone	20/5/1999	Low
19/1/1938	Cyclone	27-28/12/1999	Low
27/3/1938	Cyclone	28/4 – 3/5/2000	Low
27-29/1/1939	Cyclone		
6/3/1939	Cyclone		
30/5/1941	Low		
8/2/1942	Cyclone		
31/1/1943	Cyclone		
23-25/3/1946	Cyclone		
4/4/1946	Cyclone		
23/1/1947	Cyclone		
28/1/1948	Cyclone		
24/3/1948	Cyclone		
14-16/6/1948	Low		
2/3/1949	Cyclone		
16-19/1/1950	Cyclone		
27-28/2/1950	Cyclone		
15-26/6/1950	Low		
16/11/1950	Low		
25-30/1/1951	Cyclone		
19/3/1951	Cyclone		
8-9/6/1951	Low		
29/8/1953	Low		
20/2/1954	Cyclone		
11-13/7/1954	Low		
27/3/1955	Cyclone		
19/2/1957	Cyclone		
8-12/6/1958	Low		
21/1/1959	Cyclone Beatrice		
24-25/5/1960	Low		

APPENDIX G

Southern Oscillation data obtained from Australian Bureau of Meteorology website (http://www.bom.gov.au).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Av.
1876	11.3	11	0.2	9.4	6.8	17.2	-5.6	12.3	10.5	-8	-2.7	-3	4.95
1877	-9.7	-6.5	-4.7	-9.6	3.6	-16.8	-10.2	-8.2	-17.2	-16	-12.6	-12.6	-10.04
1878	-8.7	-21.1	-15.5	-8.8	2.1	-3.1	15.9	13	17.7	10.9	15.1	17.9	2.95
1879	12.7	14.3	13.2	12.7	2.1	16.4	21.8	22.6	18.9	15.2	9.8	-5.5	12.85
1880	10.8	7.7	14.3	5.3	12.3	9.1	1.6	14.3	8.1	4.8	7.2	-1.9	7.80
1881	-7.3	-5.5	1.8	0.3	-4.3	-4.7	-5.6	-11.4	-13.6	-23.9	7.2	9.8	-4.77
1882	-6.8	-1.3	5.1	1.2	6.8	-12	-21.3	-25.6	-14.8	-2.5	2.6	10.3	-4.86
1883	6	9.1	-25.3	14.4	13.9	3.4	-10.2	1.4	-8.2	4.8	5.2	-15.2	-0.06
1884	-12.5	-5	9.4	-15.4	1.3	9.1	-3	-5	-7	4.2	-1.4	-12.6	-3.16
1885	-16.3	1.6	5.1	-0.5	-4.3	-14.4	-5	-9.5	-4	-17.8	-15.9	5.2	-6.32
1886	-0.6	1.6	2.9	4.5	6	5	7.4	13.6	13.5	13.4	10.5	14.4	7.68
1887	12.2	11	10	9.4	-4.3	5	4.8	4.6	5.1	4.8	-5.3	5.2	5.21
1888	-3	-2.2	-11.7	-23.6	-9.8	-16	-16.7	-8.9	-9.4	-14.7	-12.6	-2.4	-10.92
1889	-25.9	-1.7	-27.5	-0.5	-1.9	22	1.6	2.1	11.1	4.2	23	22	2.38
1890	20.8	11	14.3	6.9	3.6	5.8	-2.3	-3.1	9.3	3.6	2.6	0.6	6.09
1891	15.6	-3.6	-9.5	4.5	-0.3	-1.5	-6.3	-8.9	-10.6	0.6	-4.7	-4.5	-2.43
1892	2.7	-10.2	11.1	6.9	10	19.6	7.4	5.9	6.3	8.5	-0.7	3.7	5.93
1893	11.3	7.7	-1.4	1.2	-3.5	10.7	14	7.8	5.7	7.9	2.6	1.6	5.47
1894	17.5	10	5.6	-3	-5.1	-1.5	-2.3	-5.7	-1.6	1.8	7.2	0.1	1.92
1895	5.6	3	-0.3	-7.1	-8.2	-4.7	-0.4	-6.3	-4	-5.6	-8.6	-3.5	-3.34
1896	1.3	4.9	-6.3	-8.8	-42.2	-30.6	-20.6	-22.4	-19	-19	-11.9	-14.2	-15.73
1897	-12.5	-7.4	-16.6	-17.8	-16.9	0.2	-2.3	0.8	0.2	1.8	-8	10.3	-5.68
1898	7	6.3	19.2	11.1	-1.9	-2.3	6.1	2.1	3.2	-0.7	-2.7	-0.4	3.92
1899	13.2	9.1	13.8	4.5	-7.4	-10.4	-5.6	-10.1	-1.6	6.1	15.8	-3	2.03
1900	-7.3	-6.5	-25.3	-18.7	-7.4	26.1	10	7.8	-16.6	-17.2	-6	-5.5	-5.55
1901	-0.1	3	9.4	4.5	-0.3	19.6	14.6	9.8	-16	-22.1	-8.6	-1.9	0.99
1902	17	-2.2	11.6	7.8	7.6	2.6	1.6	-8.9	-17.8	-7.4	-3.4	-3	0.46
1903	-9.2	-10.2	17.6	17.7	7.6	-0.6	6.1	0.1	8.7	4.2	1.3	15.9	4.93
1904	14.1	16.2	9.4	31.7	9.2	-7.1	-8.9	0.8	0.2	1.2	-17.2	2.6	4.35
1905	-9.2	-16.8	-30.2	-42.6	-37.4	-31.4	-21.3	-7.6	-7	-5.6	-17.9	-13.1	-20.01
1906	-3.5	-7.4	-5.2	-8.8	1.3	-3.9	6.8	15.5	18.3	9.1	21.7	4.7	4.05
1907	5.1	1.6	-0.3	4.5	10	8.3	-4.3	-8.2	0.2	0.6	-2	8.8	2.03
1908	-10.6	7.7	0.2	16.8	-1.1	-2.3	2.2	5.3	17.7	7.9	2.6	-5.5	3.41
1909	-2.5	-3.2	-0.3	-14.5	2.1	22.8	10.7	9.8	0.8	4.2	9.2	4.7	3.65
1910	5.6	15.2	12.7	5.3	0.5	22	20.5	9.8	15.3	10.3	19.7	15.9	12.73

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Av.
1911	3.2	1.6	3.5	2	-8.2	-12	-12.8	-12.1	-8.8	-11.7	-7.3	-1.4	-5.33
1912	-9.7	-17.3	-9	-21.1	-13	-6.3	-0.4	-7.6	-4	-8	2.6	-8	-8.48
1913	-3.5	-5	1.3	-6.3	-8.2	-3.9	-1.7	-7.6	-9.4	-9.2	-11.9	-7	-6.03
1914	-5.4	2	9.4	-14.5	-0.3	-16.8	-18	-17.2	-12.4	-8.6	-11.9	-1.4	-7.93
1915	-21.6	-2.2	-20.4	-17.8	-12.2	6.6	14	7.2	7.5	2.4	-14.6	9.8	-3.44
1916	5.6	-3.6	-6.3	-0.5	6.8	9.1	25.7	16.2	4.5	6.1	9.8	15.4	7.40
1917	5.1	10	18.1	21.8	21.8	21.2	28.3	34.8	29.7	15.2	21	22.5	20.79
1918	14.6	16.6	-2	16.8	10	-4.7	-14.1	-4.4	-8.2	-5	1.3	-8	1.08
1919	-14.9	-11.2	-12.8	-3	-7.4	-10.4	-8.9	-6.9	-5.8	-10.5	-11.3	-9.1	-9.35
1920	1.8	-1.7	-4.1	0.3	-2.7	6.6	9.4	5.3	5.1	-4.3	-0.1	9.8	2.12
1921	10.8	6.7	8.9	-7.1	2.1	22	2.9	-6.9	5.1	9.7	8.5	8.2	5.91
1922	8	9.1	5.6	-5.5	-5.1	5.8	2.2	-1.2	5.1	6.1	8.5	11.8	4.20
1923	5.6	4.4	8.9	8.6	2.1	1	-11.5	-18.5	-14.8	-6.2	-12.6	2.1	-2.58
1924	-5.4	1.1	2.4	-15.4	11.5	8.3	7.4	10.4	8.1	7.9	11.8	5.2	4.44
1925	5.6	13.8	14.9	14.4	-1.1	-4.7	-13.4	-10.8	-6.4	-12.9	-9.3	-7	-1.41
1926	-5.4	-14.5	-13.3	-7.1	-2.7	-7.1	-1	-7.6	1.4	4.2	1.3	6.2	-3.80
1927	5.1	1.1	18.1	6.9	6	8.3	6.1	-5	-0.4	-4.3	-8	7.7	3.47
1928	-10.1	10.5	13.8	11.9	-2.7	-7.9	-0.4	9.8	8.1	9.1	2.6	11.8	4.71
1929	16	18	5.1	4.5	-12.2	1	1.6	0.1	-0.4	7.9	11.1	5.7	4.87
1930	12.7	7.7	1.8	-3.8	2.1	-5.5	-4.3	-1.8	-7	3.6	1.9	-1.4	0.50
1931	7	-14.9	5.6	8.6	13.1	18.8	9.4	0.1	5.1	-12.9	-4.7	4.7	3.33
1932	1.8	-3.6	-2.5	-2.1	2.8	-4.7	-5	-6.9	-8.8	-4.3	-4.7	3.2	-2.90
1933	-11.1	4.9	-2	3.6	6	-3.9	3.5	-0.5	2	3.6	7.2	8.2	1.79
1934	6.5	0.1	0.2	6.1	-7.4	10.7	2.9	-22.4	-6.4	4.2	13.1	-2.4	0.43
1935	6.5	-4.6	12.2	2.8	-6.6	-2.3	-0.4	2.1	6.3	7.3	3.9	-4	1.93
1936	-2	0.6	1.8	22.6	4.4	-1.5	4.2	-8.9	2.6	-0.1	-13.9	0.6	0.87
1937	9.4	-5	6.2	2	-0.3	3.4	-5.6	3.3	0.8	-2.5	-2	6.7	1.37
1938	7.5	3.4	-3.6	3.6	13.1	18	18.5	13	7.5	12.8	1.9	13.8	9.13
1939	17	7.7	11.6	9.4	-1.1	-1.5	8.1	-0.5	-9.4	-14.7	-8	-8.6	0.83
1940	-0.1	-4.1	-10.6	-9.6	-14.5	-19.3	-15.4	-18.5	-19.6	-18.4	-6.7	-29.4	-13.85
1941	-9.7	-15.4	-10.6	-11.2	-6.6	-14.4	-20.6	-19.1	-8.2	-20.2	-9.3	-8.6	-12.83
1942	-13	-3.6	-5.8	-5.5	5.2	8.3	-1	4	8.7	8.5	-4	13.8	1.30
1943	9.4	10.5	4	13.5	2.8	-7.9	2.9	7.8	5.7	9.1	3.9	-8.6	4.43
1944	-8.2	3.9	5.6	-5.5	-1.1	-3.9	-8.9	3.3	2.6	-8.6	-6.7	4.2	-1.94
1945	5.1	6.3	13.2	-7.1	-0.3	8.3	3.5	11.7	8.7	2.4	-3.4	6.7	4.59

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Av.
1946	-2.5	4.4	-2	-9.6	-11.4	-9.6	-10.2	-4.4	-16	-12.3	-1.4	-5.5	-6.71
1947	-4.9	-4.1	11.6	-4.6	-13.7	2.6	9.4	7.2	11.7	-1.9	9.2	5.2	2.31
1948	-3	-2.7	-4.1	2.8	3.6	-4.7	0.9	-4.4	-7.6	6.1	4.6	-5.5	-1.17
1949	-7.3	2	5.6	1.2	-5.8	-12	-1.7	-4.4	2	5.4	-6	7.7	-1.11
1950	5.1	17.6	17.6	16.8	7.6	26.9	21.1	12.3	6.9	17.1	12.5	23	15.38
1951	16.5	9.6	-1.4	-1.3	-6.6	5	-8.2	-0.5	-7	-8	-3.4	-3	-0.69
1952	-9.2	-7.9	0.2	-8.8	6	7.4	3.5	-3.7	-3.4	1.8	-0.7	-12.6	-2.28
1953	2.2	-6	-5.8	-0.5	-31.9	-2.3	-1	-17.2	-13	-0.1	-2	-4	-6.80
1954	6	-3.6	-0.9	6.9	4.4	-1.5	4.2	10.4	4.5	1.8	3.9	12.8	4.08
1955	-5.4	15.2	2.9	-3	13.1	16.4	19.2	14.9	14.1	15.2	15.1	9.3	10.58
1956	11.3	12.4	9.4	11.1	17.9	12.3	12.6	11	0.2	18.3	1.9	10.3	10.73
1957	5.6	-2.2	-0.9	1.2	-12.2	-2.3	0.9	-9.5	-10.6	-1.3	-11.9	-3.5	-3.89
1958	-16.8	-6.9	-1.4	1.2	-8.2	0.2	2.2	7.8	-3.4	-1.9	-4.7	-6.5	-3.20
1959	-8.7	-14	8.4	3.6	2.8	-6.3	-5	-5	0.2	4.2	11.1	8.2	-0.04
1960	0.3	-2.2	5.6	7.8	5.2	-2.3	4.8	6.6	6.9	-0.7	7.2	6.7	3.83
1961	-2.5	6.3	-20.9	9.4	1.3	-3.1	2.2	0.1	0.8	-5	7.2	13.8	0.80
1962	17	5.3	-1.4	1.2	12.3	5	-0.4	4.6	5.1	10.3	5.2	0.6	5.40
1963	9.4	3	7.3	6.1	2.8	-9.6	-1	-2.4	-5.2	-12.9	-9.3	-11.6	-1.95
1964	-4	-0.3	8.4	13.5	2.8	7.4	6.8	14.3	14.1	12.8	2.6	-3	6.28
1965	-4	1.6	2.9	-12.9	-0.3	-12.8	-22.6	-11.4	-14.2	-11.1	-17.9	1.6	-8.43
1966	-12	-4.1	-13.9	-7.1	-9	1	-1	4	-2.2	-2.5	-0.1	-4	-4.24
1967	14.6	12.9	7.8	-3	-3.5	6.6	1.6	5.9	5.1	-0.1	-4	-5.5	3.20
1968	4.1	9.6	-3	-3	14.7	12.3	7.4	0.1	-2.8	-1.9	-3.4	2.1	3.02
1969	-13.5	-6.9	1.8	-8.8	-6.6	-0.6	-6.9	-4.4	-10.6	-11.7	-0.1	3.7	-5.38
1970	-10.1	-10.7	1.8	-4.6	2.1	9.9	-5.6	4	12.9	10.3	19.7	17.4	3.93
1971	2.7	15.7	19.2	22.6	9.2	2.6	1.6	14.9	15.9	17.7	7.2	2.1	10.95
1972	3.7	8.2	2.4	-5.5	-16.1	-12	-18.6	-8.9	-14.8	-11.1	-3.4	-12.1	-7.35
1973	-3	-13.5	0.8	-2.1	2.8	12.3	6.1	12.3	13.5	9.7	31.6	16.9	7.28
1974	20.8	16.2	20.3	11.1	10.7	2.6	12	6.6	12.3	8.5	-1.4	-0.9	9.90
1975	-4.9	5.3	11.6	14.4	6	15.5	21.1	20.7	22.5	17.7	13.8	19.5	13.60
1976	11.8	12.9	13.2	1.2	2.1	0.2	-12.8	-12.1	-13	3	9.8	-3	1.11
1977	-4	7.7	-9.5	-9.6	-11.4	-17.7	-14.7	-12.1	-9.4	-12.9	-14.6	-10.6	-9.90
1978	-3	-24.4	-5.8	-7.9	16.3	5.8	6.1	1.4	0.8	-6.2	-2	-0.9	-1.65
1979	-4	6.7	-3	-5.5	3.6	5.8	-8.2	-5	1.4	-2.5	-4.7	-7.5	-1.91
1980	3.2	1.1	-8.5	-12.9	-3.5	-4.7	-1.7	1.4	-5.2	-1.9	-3.4	-0.9	-3.08

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Av.
1981	2.7	-3.2	-16.6	-5.5	7.6	11.5	9.4	5.9	7.5	-5	2.6	4.7	1.80
1982	9.4	0.6	2.4	-3.8	-8.2	-20.1	-19.3	-23.6	-21.4	-20.2	-31.1	-21.3	-13.05
1983	-30.6	-33.3	-28	-17	6	-3.1	-7.6	0.1	9.9	4.2	-0.7	0.1	-8.33
1984	1.3	5.8	-5.8	2	-0.3	-8.7	2.2	2.7	2	-5	3.9	-1.4	-0.11
1985	-3.5	6.7	-2	14.4	2.8	-9.6	-2.3	8.5	0.2	-5.6	-1.4	2.1	0.86
1986	8	-10.7	0.8	1.2	-6.6	10.7	2.2	-7.6	-5.2	6.1	-13.9	-13.6	-2.38
1987	-6.3	-12.6	-16.6	-24.4	-21.6	-20.1	-18.6	-14	-11.2	-5.6	-1.4	-4.5	-13.08
1988	-1.1	-5	2.4	-1.3	10	-3.9	11.3	14.9	20.1	14.6	21	10.8	7.82
1989	13.2	9.1	6.7	21	14.7	7.4	9.4	-6.3	5.7	7.3	-2	-5	6.77
1990	-1.1	-17.3	-8.5	-0.5	13.1	1	5.5	-5	-7.6	1.8	-5.3	-2.4	-2.19
1991	5.1	0.6	-10.6	-12.9	-19.3	-5.5	-1.7	-7.6	-16.6	-12.9	-7.3	-16.7	-8.78
1992	-25.4	-9.3	-24.2	-18.7	0.5	-12.8	-6.9	1.4	0.8	-17.2	-7.3	-5.5	-10.38
1993	-8.2	-7.9	-8.5	-21.1	-8.2	-16	-10.8	-14	-7.6	-13.5	0.6	1.6	-9.47
1994	-1.6	0.6	-10.6	-22.8	-13	-10.4	-18	-17.2	-17.2	-14.1	-7.3	-11.6	-11.93
1995	-4	-2.7	3.5	-16.2	-9	-1.5	4.2	0.8	3.2	-1.3	1.3	-5.5	-2.27
1996	8.4	1.1	6.2	7.8	1.3	13.9	6.8	4.6	6.9	4.2	-0.1	7.2	5.69
1997	4.1	13.3	-8.5	-16.2	-22.4	-24.1	-9.5	-19.8	-14.8	-17.8	-15.2	-9.1	-11.67
1998	-23.5	-19.2	-28.5	-24.4	0.5	9.9	14.6	9.8	11.1	10.9	12.5	13.3	-1.08
1999	15.6	8.6	8.9	18.5	1.3	1	4.8	2.1	-0.4	9.1	13.1	12.8	7.95
2000	5.1	12.9	9.4	16.8	3.6	-5.5	-3.7	5.3	9.9	N/A	N/A	N/A	5.98

APPENDIX H

Aerial Photograph of Golden Beach prior to urbanisation (1940) showing relict beach ridges (after BPA, 1993).

BRIBIE ISLAND SPIT AND NORTH PUMICESTONE PASSAGE (1940)
- Source: Beach Protection Authority Queensland

Successive beach ridges formed when sea level was higher than present.

0 0.25 0.5
Kilometres