ASPECTS OF LATE QUATERNARY STRATIGRAPHY AND EVOLUTION OF SOME COASTAL EMBAYMENTS ON THE EAST COROMANDEL PENINSULA, NEW ZEALAND

A thesis
submitted in partial fulfilment
of the requirements for the
Degree of
Master of Science in Earth Sciences
at the
University of Waikato
by

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University of Waikato
1987

ABSTRACT

The stratigraphy, morphology and sedimentology of the late Quaternary deposits of eastern Coromandel coastal embayments are described, and depicted on a series of ~1:12 500 scale geological and morphological maps. Five stratigraphic units are recognised on the basis of morphology, chronology and depositional environment. The sequence consists of sediments deposited as barrier shorelines, and in the lee of barriers in estuarine and fluvial settings. Prograded, stationary and, rarely, receded barriers are identified, giving rise to three major coastal embayment categories, namely prograded barrier spit embayments, bay barrier embayments, and strand plain embayments. The various barrier types formed in response to different environmental controls, mainly sediment supply rates, coastal configuration and shelf dimensions.

The barrier sediments are mainly mature quartzofeldspathic-rich medium sands derived from reworking within the nearshore system. The fluvial sediments are typically immature, poorly sorted gravels, sand and muds transported from the hinterland by rivers. Estuarine sediments are commonly organic- or shell-rich medium to fine sand containing *in situ* plant remains and *in situ* estuarine shells. Ultimately, the sediments have been derived from stream and coastal cliff erosion of surrounding Whitianga and Coromandel Group Volcanics.

Distinctive tephras (Rotoehu Ash, c. 50 ky BP; Tuhua Tephra Formation, c. 6.2 ky BP; Taupo Pumice Formation, c. 1.8 ky BP; and Loisels Pumice, c. 650 y BP) constitute marker horizons in the deposits and, along with radiocarbon dates, have enabled the age structure of the barriers to be determined. Other relative age methods, including vegetation succession, soil development and weathering products, support the coastal chronosequence established from the interbedded tephras.

A model is synthesised to explain the accumulation of sand within the coastal embayments during the late Quaternary. Sea level changes are inferred to be the major control on sedimentation. Two main depositional phases are recorded by the barrier deposits (Pleistocene and Holocene barriers), and are associated with the last interglacial (c. 125 ky BP) and Holocene (6.5 ky BP to present) sea level stillstands. Since sea level reached its present position 6.5 ky BP, the Holocene barriers have experienced several phases of accretion and erosion due to variations in wave regime and sand supply into the embayments. Depositional environments are inferred for Pleistocene barrier samples from multivariate discriminant function analyses of sample textural data, and enable the estimation of the last interglacial sea level position and subsequent tectonic movements along the east Coromandel coast from the relative displacement of this level.

ACKNOWLEDGEMENTS

I wish to extend my gratitude to my co-supervisors Cam Nelson and Terry Healy for their assistance in the field, academic guidance and valuable criticism. Other members of the Earth Sciences staff are thanked for their interest, particularly Professors McCraw and Selby for drawing my attention to several field sites.

I would like to thank all farmers for field access, particularly Skipper Chapman, Roy Glen and Peter Simpson. The help of Earth Sciences technical staff is much appreciated, especially Mike Dravitski and his muscles for augering, and Steve Bergin for his cheerful laboratory assistance. I am grateful to Alan Hogg and the University of Waikato radiocarbon dating facility for providing several radiocarbon dates.

Special mention must be made of fellow students: Sue Boyle, Scott Nodder, Brent Green, Darryl Smith, John Utley and others, whose chatter, moods and friendships made thesis life more enjoyable (although longer!!).

Lastly, I would like to express my love and appreciation to Stephen Stokes and my family for their faith, encouragement and support. Thanks Buddy.

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CHAPTER ONE

INTRODUCTION

Linear sand barriers are common coastal landforms in New Zealand, and provide considerable scope for research into their late Quaternary history and development. To date these sand bodies have received relatively little attention in New Zealand earth sciences studies. Contributions to Quaternary research in other countries, particularly in Australia and the United States of America, have focused upon such shoreline systems, documenting their development and recreational uses, their potential as future petroleum traps and their importance in understanding Quaternary coastal landform evolution generally.

Sand-filled embayments are common along the east coast of Coromandel Peninsula, in northeast North Island, New Zealand. They exhibit a range of Quaternary landforms, dominated by sand barriers of varying dimensions. Holocene barriers have evolved and prograded in response to a moderate wave energy climate and abundant sediment supply during and since the post-glacial marine transgression, while remnant Pleistocene sand barriers provide evidence of earlier sea level oscillations. A similar sequence of sand accumulations is found on many parts of the Australian coast (Bird 1978, Thom et al., 1981). Since both Australia and New Zealand occur at comparable latitudes and in a generally similar swell environment (Davies 1980), and both the southeast Australian coast and the Coromandel coast are embayed rocky shorelines, it is reasonable to expect that certain aspects of New Zealand Quaternary coastal evolution could be analogous to that in Australia. However, the east Coromandel coast is unique on several counts:

1. It is situated at an active tectonic setting of a plate margin;
2. Nearby volcanic activity in the Pleistocene and Holocene has produced widespread tephras which mantle some coastal deposits, thus they are dateable from tephra stratigraphy. Additionally, the Pleistocene volcanic activity of mainly ignimbritic and rhyolitic eruptions provided an extra source of shelf sediment;

3. Structurally, the east Coromandel coast is characterised by small catchments and high terrain, and climatically experiences a moderately wet climate. These combine to produce a coastline which is dissected by many streams and rivers which supply sediment to the nearshore zone. Conversely, the tectonic structure (large catchments and low topographic relief) and the generally dry climate of the Australia coasts produce few rivers and in fact in certain regions promotes carbonate sedimentation on the continental shelf (Bird 1978).

It is the occurrence of barrier landforms along the east Coromandel coast and their implications for understanding Quaternary coastal evolution and sealevels, that this thesis addresses.

Definitions

Barrier: The term barrier is commonly applied to "bodies of detrital sediment, which rise above present sea level and block off or impound drainage from the hinterland" (Thom 1984). Coastal barriers are typically elongate sand bodies, parallel to the shore occurring as mainland-attached plains (either single or multiple beach ridges) or as barrier spits and islands (Figure 1.1). A barrier spit is a sand mass attached at one end, partially separated from the mainland by an intervening lagoon or estuary, swamp or marsh, sand or mud flat. Barrier islands are wholly separated from the mainland. Bay barriers refer to mainland-attached barriers.

1.1 Objectives of Study

The aim of this study is to contribute to the late Quaternary geomorphological and geological knowledge of the eastern Coromandel Peninsula embayments, and particularly the nature and origin of the sandy barrier formations. The major objectives include:

1. Production of a series of geological maps of several coastal embayments to illustrate the typical late Quaternary coastal deposits in juxtaposition to one another.

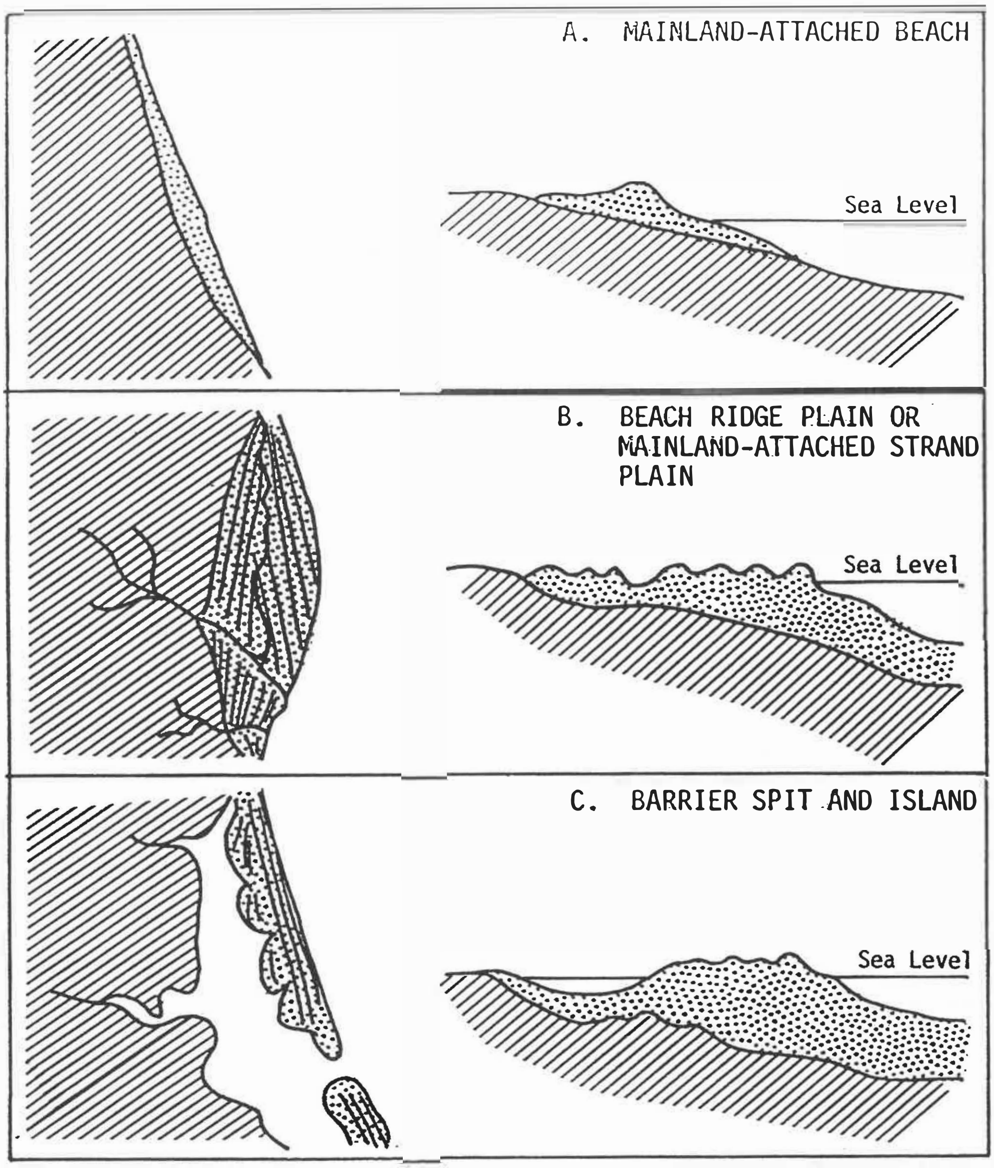


Figure 1.1 Generalised diagram illustrating the morphological relationship between barrier beaches, spits and strand plains (modified from Reinson 1984).

2. Determine vertical and lateral stratigraphic associations and erect stratigraphic columns through the lithological types from field exposures.
3. Documentation of geomorphological surface units.
4. Description of sedimentological characteristics of individual units in order to make inferences about depositional paleoenvironments.
5. Statistical analysis of textural characteristics using multivariate techniques, to attempt the identification of a "textural break" between eolian and foreshore paleoenvironments.
6. Evaluation of the age structure of the late Quaternary barrier systems from dated units or horizons.
7. Proposal of a classification scheme describing coastal embayment types and their various stages of development.
8. Comparison of the stratigraphic sequences determined for the eastern Coromandel coast with late Quaternary stratigraphy reported in Australia.
9. Presentation of a conceptual model of sedimentation to explain the factors leading to accumulation of sand within the embayments during the late Quaternary.

Aspects of the Coromandel regional setting are discussed in Chapter One. The next two chapters examine the stratigraphy, morphology, age structure, soils and distribution of the coastal deposits. The sedimentology and composition of the coastal sequences are reviewed in the laboratory-based Chapter Four. Chapter Five is concerned with multivariate discriminant analysis of textural data to attempt differentiation of barrier depositional environments. Features of the east Coromandel coastal system are reviewed more closely in Chapter Six. Lastly in Chapter Seven, aspects of late Quaternary sedimentation along the eastern Coromandel coast dealt with in this thesis, are synthesised into a general model of coastal sedimentation.

1.2 Regional Setting

1.2.1 Location

The Coromandel Peninsula (Figure 1.2) extends 300km northward from the Kaimai Ranges, forming part of the northeast coast of the North Island. It fronts the Pacific Ocean on its east side and forms the eastern margin of the Hauraki Gulf and Lowland to the west, thereby sheltering the Auckland coast from large wind and wave fetches.

The study area encompasses 120km of the eastern coastline from Bowentown Head tombolo, 26km northwest of Tauranga, to Waikawau Beach in the north, 10km south of Port Charles.

1.2.2 Physical Setting

The eastern Coromandel coast is characterised by a series of sandy barrier beaches and bays, interspersed with hardrock headlands. The barriers of Holocene age are surmounted by dunes rising up to 15m above present sea level (MHWM) and mantled with grasses, scrub and forest. The coastal barrier complexes impound remnant lagoons. These systems were once more extensive, but have been reduced by sedimentation and swamp encroachment, resulting in extensive marginal reedswamps. Other physiographic features on the coastal plain include remnants of poorly consolidated barriers of Pleistocene age, terraces, colluvial fans, alluvial plains and back barrier flats. The inner margins of these low-lying coastal plains abut steep, irregular slopes of an eroded volcanic and basement landscape.

Weather patterns in New Zealand are largely dominated by the eastward progression of anticyclones and troughs across the Tasman Sea (Quayle 1984). However, the east Coromandel coast is also exposed to humid airstreams originating from the tropical Pacific Ocean producing widespread heavy rainfall. The Coromandel region has three commonly occurring weathering patterns: (a) fine weather spells associated

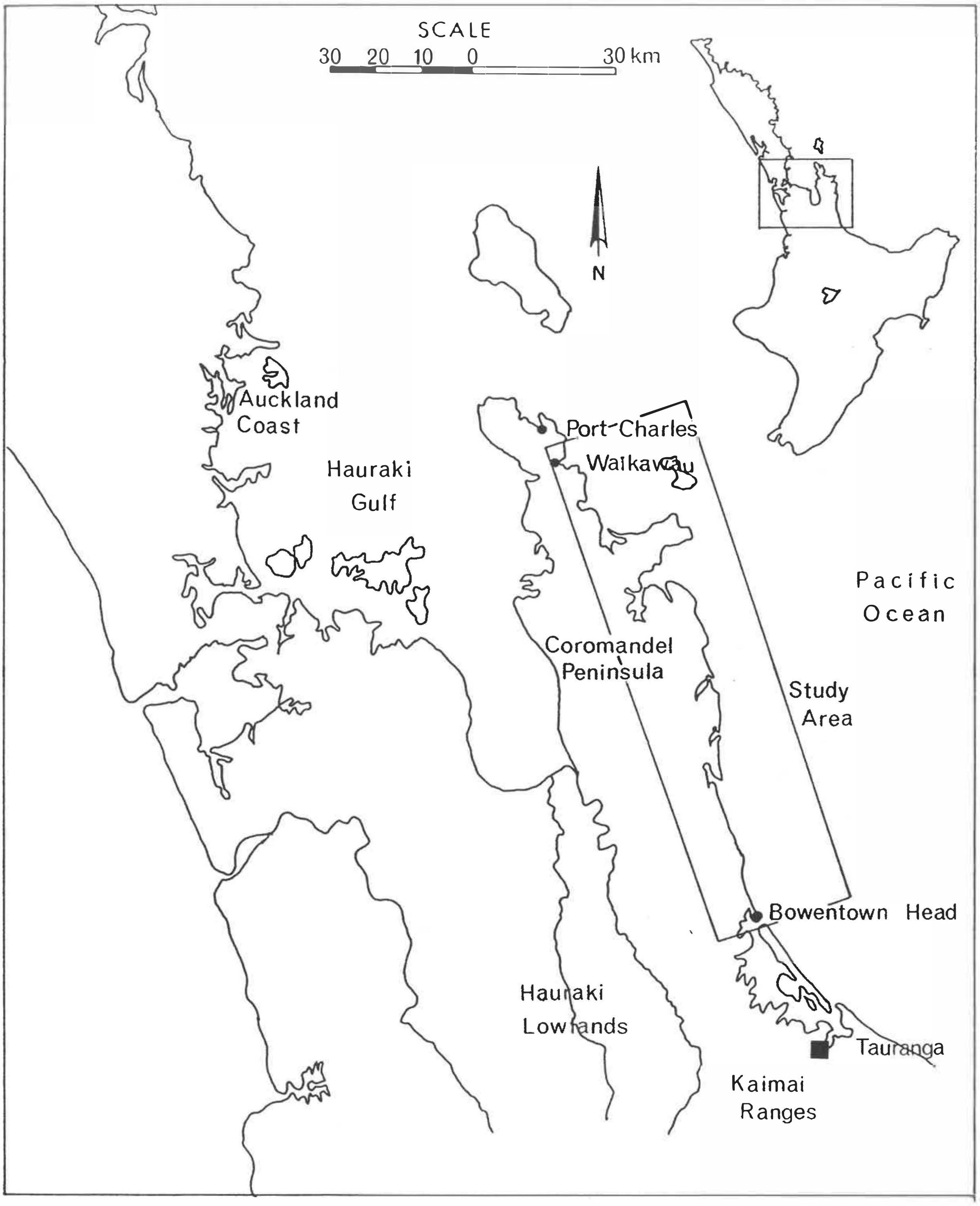


Figure 1.2 Location map of study area.

with eastward-moving anticyclones; (b) showery periods arising from strong westerly airstreams, and intensified by the orography of the Coromandel region (Maunder 1974), and (c) periods of moderate to heavy rain produced when the moist airstreams from the Pacific are forced to ascend the rising Coromandel ranges (Quayle 1984). Episodic orographically induced rainfall often causes flooding (de Lisle and Kerr 1963), and may cause severe erosion in the ranges and on the coast.

Relevant climatological data for the region are summarized in Figure 1.3. The climate is generally warm and humid, with rainfall ranging from 1500mm to 1800mm per annum (Maunder 1974). Dry spells are comparatively frequent during summer. The predominant winds are offshore, from a westerly quarter.

1.2.3 General Geology

The Coromandel Peninsula is a horst block whose basement geology consists of Jurassic lithic volcanic greywackes interbedded with argillite and siltstone, collectively of the Torlesse Supergroup (Hochstein and Nixon 1979), and locally represented by the Manaia Hill Group (Figure 1.4). The Manaia Hill Group is subdivided into two conformable formations; Moehau, the older and most widespread, and Tokatea Hill (Skinner 1972). Isolated occurrences of the Te Kuiti and Waitemata Groups are reported. Siltstones and limestones of the Te Kuiti Group crop out around the western side of the Peninsula. Fluviatile and lacustrine carbonaceous sediments of the Waitemata Group rest unconformably upon Moehau Formation near Otama (Skinner 1976). Tertiary volcanic rocks overlie the above formations, forming the surface 'hardrock' geology of much of the peninsula. A co-genetic quartz sinter, known as the Waitaia sinter, is grouped with the volcanic formations. It forms terraces and plugs and interdigitates with the Waitemata Group in the Kuaotunu region (Skinner 1976).

The extensive Miocene volcanics, which dominate the present topography, include andesitic lava flows, dacitic intrusives, flow-

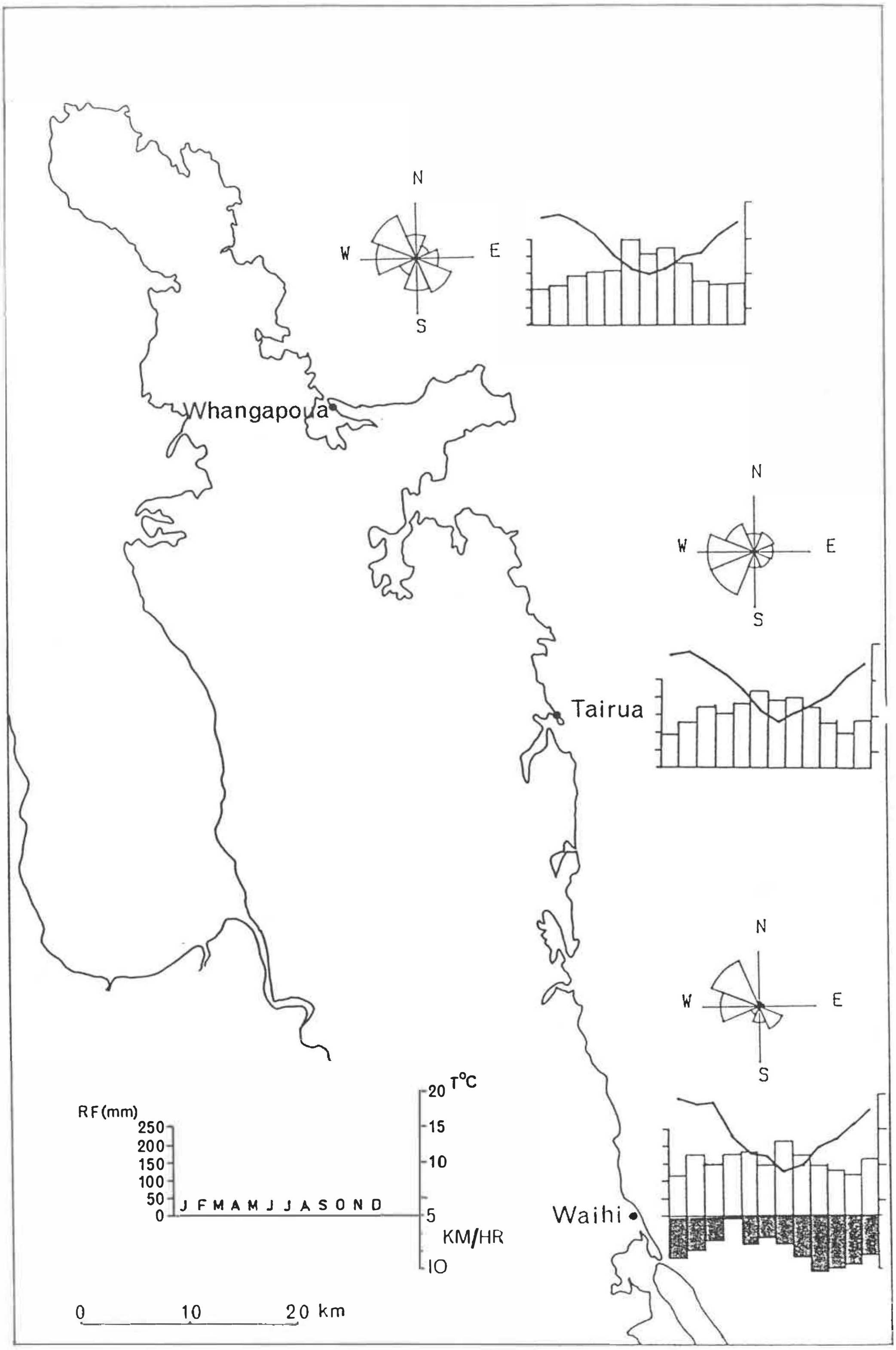


Figure 1.3 Climatologic data of labelled areas along the east Coromandel coast. Histograms represent average monthly rainfall, temperature and wind speed (1975-1980). Source NZ Meteorological Service.

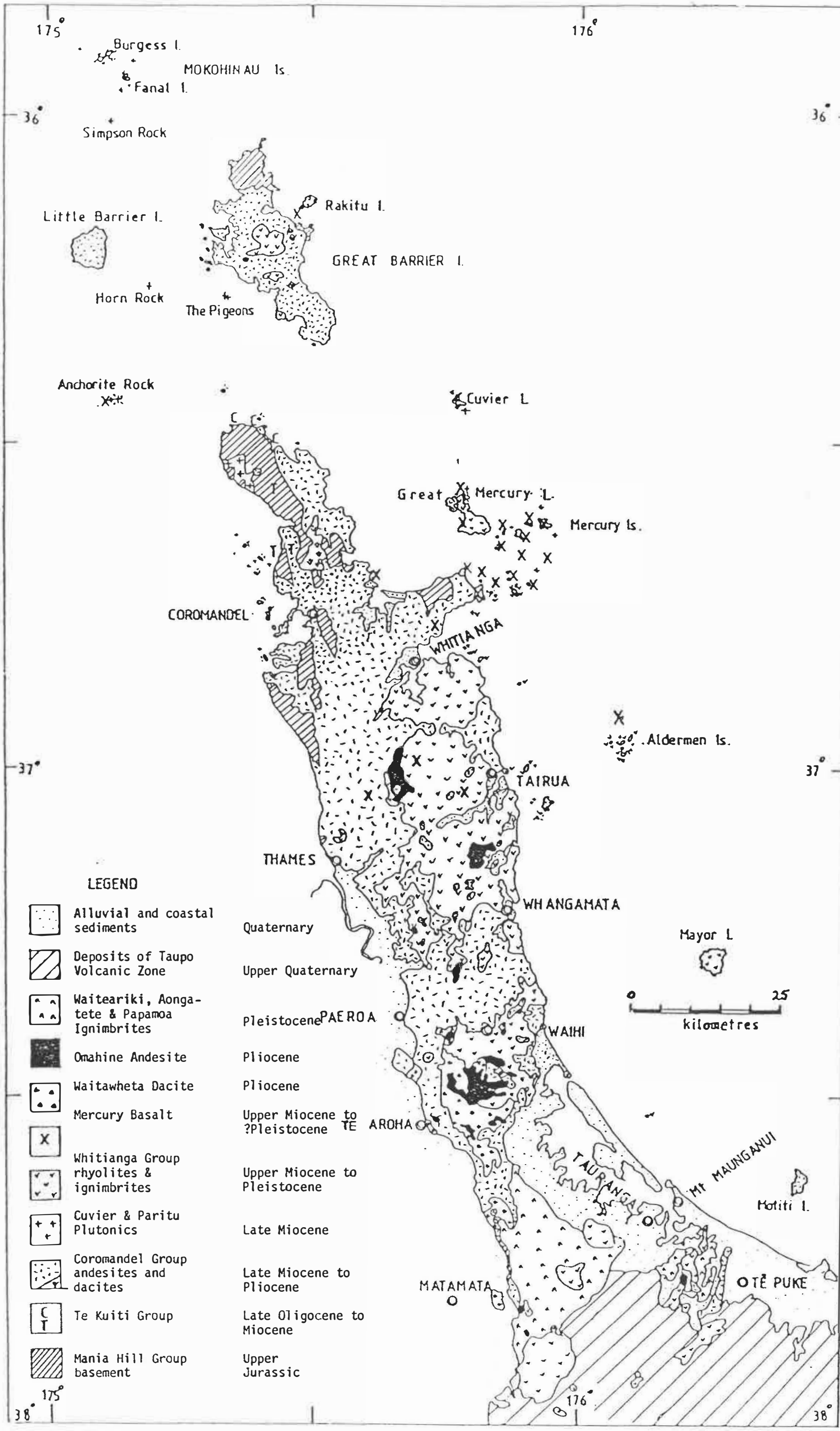


Figure 1.4 General geology of the Coromandel Peninsula (after Skinner 1986).

banded rhyolites and ignimbrite flow sheets (Skinner 1986). Henderson and Bartrum (1913) divided the volcanic rocks into three groups, namely the Rhyolite, Dacite and Andesite Series. Subsequent subdivisions into the Coromandel Group, Whitianga Group and Kerikeri Volcanics were made by Schofield (1967) and Skinner (1967). The oldest Coromandel Group volcanics, predominantly andesitic rocks (including the Beesons Island andesite (Skinner 1967)), erupted periodically between the early and late Miocene, younging in a southwards direction. The overlying rhyolitic rocks of the Whitianga Group, further subdivided into the Minden Rhyolite and Coroglen Ignimbrite (Skinner 1986), erupted from the late Miocene to early Pleistocene. Accompanying the Whitianga Group volcanism were hydrothermal alteration and base-metal mineralization. The latter has been the basis of the Coromandel Peninsula's past mineral wealth and future economic prospects.

The present outline of the peninsula evolved during the Kaikoura Orogeny, along NNW- and NE-trending faults inherited from and controlled by pre-existing faults formed during the early Cretaceous Rangitata Orogeny (Skinner 1976). These faults produced the upthrown horst structure (Skinner 1967), while NE-trending faults tilted it towards the south (Skinner 1986) due to down throw directions progressively lowering Jurassic basement in that direction. Three physiographic sub-regions exist; the Moehau, Coromandel Ranges and the Kuaotunu Peninsula. The Kuaotunu Peninsula has been predominantly controlled by NE- and NNW-trending faults, and by the greywacke 'in lier' of Waitaia Ridge (Skinner 1967). Skinner (1986) suggests active faulting has continued through the late Pliocene and Quaternary following previous ENE and NW trends.

Since the cessation of volcanism, extensive erosion has modified the Coromandel Peninsula land surface producing the characteristic rugged landscape of today. Deep valleys produced by stream incision during periods of lower sea levels, contain many small eastward flowing streams. During the Quaternary the eroded volcanic debris has filled these valleys and low-lying areas with alluvium and provided a source of sediment, in addition to the erosion of basement rocks, for coastal barrier development.

Quaternary tephras, predominantly from central North Island eruptions, thinly mantle large areas of the Peninsula, forming an important parent material of the soils. Major constituents of the ash sequence include the Hamilton Ash beds, Rotoehu Ash, Tuhua Tephra Formation (Hogg, 1979), Taupo Ash and Kaharoa Ash (Hogg and McCraw 1983).

The offshore islands are geologically variable, from eroded remnants of rhyolite domes at the Alderman Islands (Hayward and Moore 1973), to surface exposures of extensive rhyolite submarine plateaus forming the Mokohinau Islands, to Great Barrier Island consisting of Mesozoic basement rocks intruded by plutonic rocks and capped by the andesitic Coromandel Group (Skinner 1986).

1.3 Research Techniques

The field programme included field mapping at a scale of 1:12500, completed using maps prepared from 1:25000 base topographic maps obtained from the Department of Lands and Survey. Detailed stratigraphic descriptions and sampling of coastal deposits were carried out. Sections were selected where deposits cropped out and were best preserved in stratigraphic sequence. Samples were collected mainly by hand, but an extensional hand auger was used to retrieve samples at depth, approximately every 30cm. Maximum auger extension achieved was 4.5m, although the nature of the sediment and the level of the groundwater table did not often permit this. A number of dune transects were surveyed using a Wild NK2 theodolite.

The laboratory techniques are outlined in Figure 1.5 and described more fully in Appendix 1. Textural analysis of sand-sized material was determined using the University of Waikato's Rapid Sediment Analyser. Mud percentages were analysed by pipette (Folk 1968). Sediment compositional studies were made using a binocular microscope,

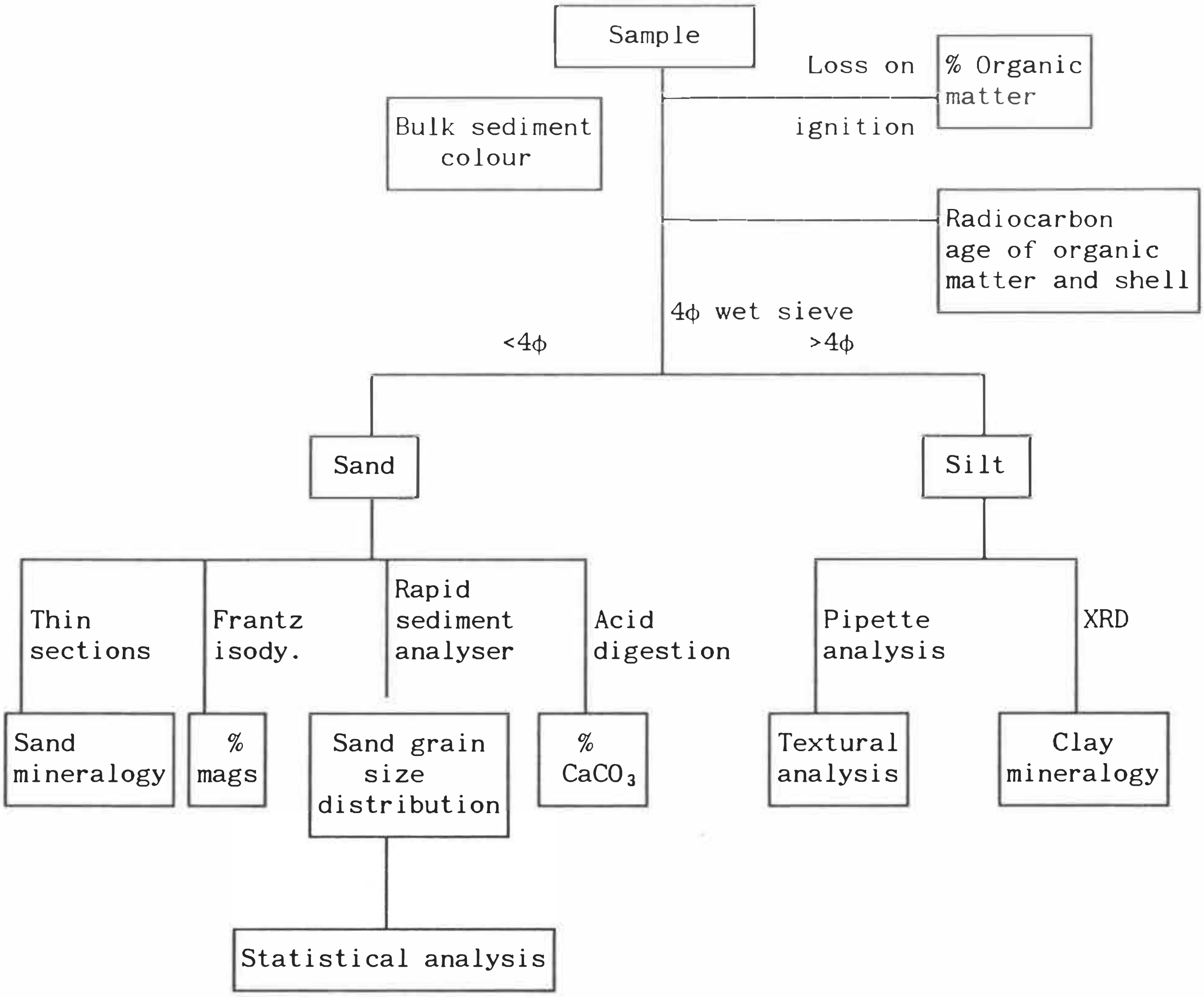


Figure 1.5 Laboratory procedures.

thin sections, detrital mounts and by point counting. Ferromagnesian mineral separation was carried out using a Frantz Isodynamic Separator, the percentages of heavy minerals determined and separate detrital mounts prepared. Aspects of chemical composition were studied, including percentages of calcium carbonate and organic matter, determined respectively by acid digestion and loss on ignition. Clay minerals were investigated by X-ray diffraction. Tephra fingerprinting was completed through titanomagnetite major element chemical analyses. Finally, radiocarbon dating of organic materials produced dates of several deposits.

Statistical procedures involved multivariate techniques, including discriminant function analysis and principal component analysis.

1.4 Research Background

1.4.1 Previous Work

The bulk of Coromandel research has been carried out on barrier systems recognised as Holocene features having formed during the past 6000 years or so, when the post-glacial sealevel reached its approximate present level (Healy and Kirk 1982). Marks and Nelson (1979) investigated the barrier complex of Matarangi Beach and Omaro Spit which encloses Whangapoua Harbour, an embayment formed by post-glacial drowning of a dislocated fault block (Skinner 1967). Stages of barrier evolution are traced in the parallel dune ridges which mark the alignment of former shorelines. The Whiritoa bay-head barrier sediments were documented by Willoughby (1981). Dune profiles and beach erosion have been investigated in several studies (e.g. Harray and Healy 1978, Healy et al. 1981) along the Coromandel coastline.

Relict coastal barriers on the east Coromandel coast are noted by Pain (1981) and Healy and Kirk (1982). Healy and Pain were involved in early collaborative fieldwork on the relict Pleistocene barriers (T Healy pers comm.).

The mantling Quaternary tephras of the Coromandel Peninsula are described by Hogg and McCraw (1983), and consist of mixed peralkaline and calcalkaline ashes. In his coastal reconnaissance study of Holocene deposits, Wellman (1962) described many sites and defined stratigraphic divisions on the basis of human occupation soils, ashes such as Kaharoa and Taupo, and whether the pumices were primary or water-borne. Wellman also defined the Ohui Ash, allotting ages to this and the other tephras, pumices and occupation layers. The validity of Ohui Ash as a separate air-fall unit was later checked by Pullar et al. (1977), who found each occurrence could be attributed to either Kaharoa Ash or sea-borne Taupo Pumice. Inconsistencies in the stratigraphic relationship between primary Loisels Pumice and Kaharoa Ash were later resolved with radiocarbon dating (Loisels Pumice *c.* 650 years old) (McFadgen 1982). However, the validity of Loisels Pumice as a separate single eruptive event is questionable (A Hogg pers comm.)

The region has been a major focus of archaeological studies (Smart and Green 1962, Green 1963, Leahy 1971) stemming largely from abundant middens, many located across the Holocene dunes. Radiocarbon dates of cultural material range from 200 y BP to 880 y BP (Prickett 1982), with McFadgen (1985) suggesting 900 y BP as the earliest Maori occupation date.

1.4.2 Previous Mapping of Coromandel Coastal Embayments

Early N.Z. Geological Survey Bulletins of the Hauraki Division (Fraser and Adam 1907, Bell and Fraser 1912, Henderson and Bartrum 1913) grouped the late Quaternary embayment sand fills as "unconsolidated or poorly consolidated debris". This included river terraces, drifting sand, swamp deposits, harbour-muds and sea beaches of pre-Pleistocene, Pleistocene and Recent age. Older dunes were marked occasionally but most commonly there was no differentiation between Quaternary deposits.

Table 1.1 Formations and Stratigraphy at Waihi Beach - Bowentown.

Formation (Kear and Schofield 1961)	Overlying Ash Beds (Selby et al. 1971)	Informal Stratigraphy (This study)
Waihi Beach Formation: alluvial & estuarine deposits, swamps, sand dunes	Lapilli of Taupo Pumice contained in sand dunes	Holocene dunes swamps salt marshes alluvial flats
Ocean View Formation: old reddish clayey sand dunes, gravels in clay matrix, white clays	Late Quaternary ash beds with Rotoehu Ash at base	Remnants of inner barrier of Pleistocene age
Athenree Formation: reddish weathered clays overlying white sandy clays with volcanic and carb. fragments	Late Pleistocene ash beds, overlying Hamilton and Kauroa Ash beds	
Tauranga Formation: Locally derived clayey sands, with angular and rounded pebbles, pumiceous sediments	Late Pleistocene ash beds, overlying Hamilton and Kauroa Ash beds	

Kear and Waterhouse (1961) mapped coastal surfaces between Waihi Beach and Bowentown, correlating these with European surfaces of similar altitude. Four formations were identified (Table 1.1), of which the Ocean View Formation includes remnant Pleistocene dunes and the lower Waihi Beach Formation contains the Holocene dune systems and extensive swamp areas. Re-examination of overlying sediments by Selby et al. (1971) revealed ash beds of known age and subsequently showed that correlation with the European sequence of sea levels was unreliable.

Skinner (1976) mapped the northern part of the Coromandel Peninsula at a scale of 1 : 63 360, the first in a series to reassess the geology and mineral resources of the Coromandel Peninsula. Within the embayments, including Waikawau, Otama, Kuaotunu and Opito, he differentiated the Quaternary stratigraphy into two sets of terraces, high (above 6m) and low (below 6m); older fixed dune sand; moving dune sand; and alluvium-swamps.

CHAPTER TWO

COASTAL STRATIGRAPHY OF THE EASTERN COROMANDEL EMBAYMENTS

A fundamental objective of this thesis is the organisation of the Quaternary depositional record into stratigraphic units, enabling correlation of Quaternary sequences between nearby embayed localities. Simple subdivision of the east Coromandel coastal Quaternary infill is difficult. Subdivision into lithological units was hampered by lithologic similarity of sequences which have accumulated in different depositional environments, localised lateral and vertical lithology variation; and, at several localities, preservation of similar depositional sequences that are of different age, for instance Pleistocene and Holocene sand barriers, a result of the cyclical nature of the Quaternary climatic change.

Chronostratigraphy which concerns itself with the age of the strata (Miall 1984) is not wholly applicable to the east Coromandel depositional sequence, mainly due to the short time-span of the Quaternary and subsequent division of the stratigraphic record into small intervals of geological time, and the unavailability of dating techniques capable of accurately determining the age of the sediments. Whilst, the application of morpho-stratigraphy, a classification of landforms according to their relative order of age (Miall 1984) can be difficult in vertical section, lateral relationships of shoreline sequences are particularly suited. Geomorphology as a stratigraphic tool, enabled recognition of several sediment bodies and was one criterion on which to base a chronology of depositional events. Therefore, the criteria for stratigraphic subdivision of the late Quaternary embayment infill included morphology, chronology and depositional environment (see Section 2.1).

In the following section the basis of age assessment across the Quaternary sequence is reviewed, and the stratigraphic units and relationships are described. Unit descriptions are expressed in terms of depositional environment, stratigraphic extent, lithology, morphology and chronology.

Age Assessment

The nature of the Quaternary infill of the eastern Coromandel embayments generally demanded that age equivalence be demonstrated by stratigraphic marker beds (e.g. tephrochronology) rather than absolute dating methods. Age relationships in the field were also established by relative age methods, which ascertained the order of stratigraphic units in relation to each other (e.g. soil development). The techniques are discussed below.

Superposition: With vertical sequences superposition was generally employed. "The principle of superposition states that, in the absence of evidence for disturbance or reworking, the overlying sediments in a succession are younger than those lying beneath them" (Lowe and Walker 1984).

Tephrochronology: Distinctive tephras, particularly the Rotoehu Ash (*c*. 50 ky BP; McGlone et al., 1984), Tuhua Tephra Formation (*c*. 6200 y BP; Lowe et al. 1980, Hogg and McCraw 1983) and Taupo Pumice (*c*. 1800 y BP; Healy et al., 1964), and possibly Loisels Pumice (*c*. 650 y BP; McFadgen 1982), constitute marker horizons in the eastern Coromandel Quaternary stratigraphic record (Table 2.1). These isochronous horizons, dated initially by radiometric methods, serve as a basis for time-stratigraphic correlation between the depositional sequences of the Coromandel embayments.

The Rotoehu Ash was defined by Nairn (1972) as multiple airfall tephra units that underlie, are interbedded with, and mantle the pyroclastic flow deposits of the Rotoiti Breccia Formation. Rotoehu Ash is widely distributed in the central North Island, with a long

Table 2.1 Idealised section of chronohorizons.

Terminology (McFadgen 1985, Hogg and McCraw, 1983)	Chronohorizon	Years (B.P.)	Terminology (this study)	Other workers
Hoaton Chronozone	poor soil	present	topsoil	
	lowest European artifacts			
		150		
Ohuan Chronozone	buried soil			
		450		
Tamatean Chronozone	buried soil			
	Loisels Pumice	650	Loisels Pumice	McFadgen (1982)
	Kaharoa Ash	890	Kaharoa Ash	Pullar et al. (1977)
	lowest cultural charcoal	900		
	Taupo Pumice	1800	Taupo Pumice Formation	Healy et al. (1964)
Field class 1	Tuhua Tephra	6200	Tuhua Tephra	
Field class 2 (RPS#)	Waiohou	11300		
	Rotorua	13500		
	Okareka	17000	Brown Quaternary Ashes	-
Field class 3	Haupara + paleosol	37000		
	Rotoehu Ash + paleosol			
Field class 4	Rotoehu Ash	>42000	Rotoehu Ash	Pullar et al. (1973)
Unamed	Sub-Rotoehu Ash paleosol		Sub-Rotoehu Ash paleosol	

- Rotorua Paleosol Sub-group

fall-out lobe to the north-west covering the Coromandel Peninsula (Birrell et al., 1977). Mineral constituents of the ash include rhyolitic volcanic glass, biotite and cummingtonite (Lewis and Kohn 1973). It is recognised in the field as a light yellow orange (10YR 8/3) fine sandy loam, slightly firm and as having a distinct lower boundary. An associated paleosol is typically a yellowish brown (10YR 5/6) silt loam.

There is doubt as to the absolute age of Rotoehu Ash, with several dates ranging from 29.4 ky BP to 44.2 ky BP. Recently McGlone et al. (1984) discounted several younger ages as belonging more likely to a younger event, Mangaone Tephra Formation. Accurate dating is also hindered because the Rotoehu formation falls near the conventionally accepted range of carbon-14 dating. The age currently accepted for the Rotoehu Ash is 50 ky BP (D Lowe pers. comm, McGlone et al. 1984), with radiocarbon dates ranging from 40 to 50 ky BP (Pullar and Heine 1971), and suggestions of up to 75 ky BP (Kennedy 1984).

The field classes or tephra groups of Hogg and McCraw (1983) have been adopted in a modified from by this study (Table 2.1). Classes 2 and 3 were grouped together and are here referred to as the "Brown Quaternary Ashes". This mixture of composite tephras forms a yellowish brown (10 YR 6/8) fine ash paleosol in the field, immediately overlying Rotoehu Ash. At the base of the brown Quaternary Ashes, lumps of Rotoehu Ash (termed cream puffs') are sometimes present within the ashes and associated paleosols.

Tuhua Tephra Formation defines a rhyolitic peralkaline tephra erupted from Mayor Island (Tuhua), renaming confused Whangamata Ash terminology. The tephra is represented by reddish brown pumiceous lapilli 60-70cm deep within the type area, a 5km radius of Whangamata, fining to a coarse or fine ash grade surrounding this lobe (Hogg and McCraw 1983). The lapilli fragments up to 35mm show intense weathering discolouration (reddy brown surface) fading to pale yellow towards the centre, are easily crushed and have a distinct lithic and crystal component. Lithic components include grey and white rock fragments, while the crystals are dominated by anorthoclase and aegerine and minor cossyrite, riebeckite and tuhualite. Aegerine is a diagnostic marker mineral for Tuhua Tephra (Lowe 1981, Hogg and McCraw 1983).

The Taupo Pumice was erupted from near the Horomatangi Reefs, Lake Taupo (Wilson et al., 1986) and is part of the Taupo Pumice Formation. It occurs on most North Island coasts as lapilli-like granules in sand dunes, and in beach deposits as large pieces up to 0.5m (McFadgen 1985). In the field, it appears a light yellowish brown colour with coarse irregular gas cavities and is normally crushable in the hand (McFadgen 1985). Sea-rafted Taupo Pumice is normally a lighter grey colour and consists of larger pumice pieces (0.1-0.5m) (Pullar et al., 1977).

Little is known of Loisels Pumice which is supposedly recognised by its grey colour (dacitic), darker grey banding (andesitic) (Pullar et al., 1977) and fine gas cavities. McFadgen (1985) describes it as strong, cannot be crushed in the hand, and is distributed along the eastern North Island coast and in the very north.

Initially field evidence suggested two pumices occurred across the coastal dunes; a grey pumice (possibly Loisels); and a yellow-white pumice (Taupo) exhibiting variable weathered samples. It was hoped that geochemical data would enable separation or grouping of these individual pumices. Pumice descriptions and microprobe analyses (EDXA) of titanomagnetite grains extracted from eastern Coromandel pumices are given in Table 2.2 and Appendix 2. An Analysis of Variance test was carried out upon the chemical data (Table 2.3), (after Davis 1978, Lapin 1980). Results of the analysis suggests that the three grey pumices (1,2 and 5) are accepted as the same pumice at a 99% confidence level for both Fe and Ti data, and the hypothesis that the yellow-white pumices (3 and 4) are the same is rejected. Therefore analysis of variance of eastern Coromandel pumice probe data suggests:

1. Three significantly different tephras occur across the eastern Coromandel Holocene coastal deposits; and,

Table 2.2 Pumice descriptions and microprobe analyses.

Pumice No.	Description[#]	Field interpretation	Probe chemical data[@]
1.	Dark grey, light grey bands, hard, rare FM minerals, small pieces up to 3.5 cm dia.	Loisels Pumice	Ti = 4.47 (1.23) Fe = 60.80 (1.45)
2.	Dark grey, light grey bands, highly vesicular rare FM minerals, small pieces up to 2 cm dia.	Loisels Pumice	Ti = 4.84 (0.78) Fe = 59.69 (1.73)
3.	Light grey, large pieces commonly up to 6 cm dia., crushes between fingers, large tabular FM minerals	Taupo Pumice Formation	Ti = 6.09 (0.31) Fe = 57.83 (1.36)
4.	Yellow brown weathered surface over light grey pumice, easily crushed, rare FM minerals, inclusions of blue-grey rock fragments, small pieces up to 3 cm dia.	Taupo Pumice Formation	Ti = 3.70 (1.07) Fe = 62.89 (1.98)
5.	Dark grey and light grey bands, rare FM minerals, hard, abundant vesicles	Loisels Pumice	Ti = 4.90 (0.83) Fe = 59.20 (1.13)

[#] - FM ferromagnesian
[@] - values given mean (standard deviation)

Table 2.3 Results of analysis of variance test on titanomagnetite microprobe data (A titanium, B total iron). Numerical value corresponds to the F statistic. Also given are the acceptance (A) or rejection (R) decisions at the 0.05 (upper) and 0.01 (lower) levels of significance.

A.

Ti	T1	T2	T3	T4	T5
T1		0.36 A A	9.64 R R	2.07 A A	0.34 A A
T2			12.98 R R	6.13 R A	0.00 A A
T3				36.24 R R	14.44 R R
T4					6.23 R A
T5					

B.

Fe	T1	T2	T3	T4	T5
T1		2.96 A A	20.07 R R	4.86 R A	7.45 R A
T2			4.25 A A	12.05 R R	0.17 A A
T3				35.49 R R	4.83 R A
T4					20.90 R R
T5					

2. That there is a geochemical basis for separation of a grey (suggested as Loisels) pumice and Taupo Pumice, supporting Pullar et al. (1977).

Further mineralogical investigations of the heavy mineral assemblage of Pumice 4 identified the mineral aegerine, a marker mineral unique to Tuhua Tephra Formation. It should be possible through the occurrence and identification of Tuhua Tephra Formation, Taupo Pumice Formation and a grey (possibly Loisels) pumice to delimit subaerial coastal sediments of different ages.

Soil Development: The relative ages of some Holocene landforms have been determined from the degree of pedogenic development. The application of this technique is based upon the assumption that the degree of soil development is a direct function of time and that other soil forming factors, such as topography, temperature, rainfall and parent material are more or less constant over time. While differences in the stages of soil development can be related to the progressive ageing of dune systems, they do not provide a reliable basis for calculating absolute ages because of climatically induced variation in weathering rates (Thompson 1983). However in this study it is reasonable over the small latitudunal zone studied, and the similarity of the sediments making up the dunes that differences in soil development provide additional evidence to geomorphic and stratigraphic data in establishing relative age sequences. Closely related to soil chronosequences is the progressive floral succession from sand-colonising plants to forest vegetation with increasingly older sand deposits. This vegetation sequence provides relative age-relationships within the dune terrain at a regional scale.

Radiocarbon Dating: Radiocarbon dates are an additional means of validating other stratigraphic and correlative interpretations at a local scale. Dates used in this study are obtained from previous workers, and several were determined during the course of this project (Table 2.4). The dated material includes shells, wood and charcoal.

Table 2.4 Radiocarbon dates.

Date Number[1]	Date[2] (years B.P. 1950)	Locality (Coromandel Peninsula)	Author	Sample layer and samples
WK874 A	780±165	Otama	This study	Charcoal below Loisels Pumice in paleosol (unit HB-3)
WK875 A	>mod	Otama	This study	Wood from layer 1 (unit F)
WK876 A D	810±50 500±50	Tairua	This study	Shells in sand flats (unit HSF)
NZ595 A	143±40	Tairua	Smart and Green (1962)	Charcoal from oven in lower occupa- layer (layer 2) in buried soil (N44/2)
NZ1296 A D*	453±40 410±100	Hot Water Beach	Leahy (1974)	Shells above Loisels Pumice (site N44/69)
NZ1297 A D*	524±40 485±100	Hot Water Beach	Leahy (1974)	Shells above Loisels Pumice (site N44/69)
NZ1875 A D*	570±60 525±120	Tairua	Smart and Green (1962)	Shells from lower occupation layer (layer 2) in paleo- sol (site N44/2)
NZ1876 A D*	250±70 200±140	Tairua	Smart and Green (1962)	Shells from upper occupation layer (layer 6) in paleo- sol (site N44/2)
NZ354	660±50	Mahinapua Bay (Opito)	Golson (in Green 1963)	Charcoal below Loisels Pumice

1. A - uncorrected, D - corrected marine shell dates (* as in McFadgen 1982).
2. >mod - sample has been living since 1950.

2.1 Stratigraphic Units

The stratigraphy was correlated from one embayment to another on the basis of several criteria:

1. Elevation and topographic expression of deposits;
2. Degree of soil development;
3. Vegetation association with (2);
4. Radiometric dates of primary and secondary materials;
5. Depositional environment.

The five mapable units common to nearly all embayments are:

1. A Pleistocene Barrier Unit consisting of sands deposited as the beach and dune components of barrier shorelines during a Pleistocene high stand sea level.
2. A Holocene Sand Flat Unit consisting of sediments deposited in the lee of barrier deposits.
3. A Holocene Barrier Unit consisting of sands deposited as the beach and dune components of barrier shorelines during and since the Holocene transgression and at the present day.
4. A Fluvial Unit consisting of gravel-dominated and organic-rich sediments, either transported in an alluvial system or occurring in low-lying flood basin regions.
5. An Estuarine Unit consisting of sediments deposited under sheltered marine conditions.

In the following discussion, 'Holocene' refers to a time range inclusive of the present day, and includes those deposits formed during and since the post-glacial marine transgression (5000-7000 yrs BP), and those actively-accreting today. The nomenclature used for describing primary sedimentary structures and stratigraphic contacts follows Reineck and Singh (1973), Allen (1984) and Miall (1984). Pedologic descriptive terminology is used after Taylor and Pohlen (1970). Colours are coded according to the Standard Soil Colour Chart (1970). Floral and faunal identifications are from Moore and Adam (1968) and Child (1974) respectively. Grid references are expressed in terms of the NZMS 260 map series.

Pleistocene Barrier Unit (PB)

The Pleistocene Barrier unit was deposited as bay barriers and barrier spit shorelines which have been preserved as subdued remnants of an elongated ridge trending parallel to the coast. The upper portion of the unit consists of eolian dune deposits. The lower part consists mainly of beach deposited sediments. The unit may unconformably overly Tertiary volcanic rocks. At Otama, the exposed lower contact is defined by an iron pan, immediately above a gleyed paleosol which lies upon weathered Mahinapua Andesite. The upper contact is clearly defined by Rotoehu Ash. Laterally, the flanks of the ridges abut Tertiary volcanic rocks or are overlain by onlapping sediments of the Holocene Sand Flat and Holocene Barrier Units.

Lithologically, the unit is composed of leached semi-consolidated quartzfeldspathic sands and can be separated into five sub units (Figure 2.1). Locally at Otama, unit PB-1 occurs. Unit PB-1 consists of pale yellow (2.5 Y 8/3) to grey (5 Y 5/1) sandy mud lenses interdigitating with clean sand and small organic fragments, probably deposited in an estuarine environment. This sub unit may possibly be the estuarine equivalent of the Pleistocene Barrier Unit at the same high stand of sea level. The beach sediments (unit PB-2) consist of bright yellowish orange (10 YR 7/6) sands exhibiting thinly bedded landward-dipping planar laminations with gentle to low anglē ($<5^o$) discordances (Figure 2.2).

The upper and more commonly exposed dull yellow orange sands of the eolian unit (PB-3) comprise large scale ($\lambda > 8$m) tabular cross-beds (Figure 2.3) and second order wedge planar cross-beds (Figure 2.4) dipping from 10^o to 30^o. The dip of bounding surfaces become shallower, higher in the section. At the stratotype (T10/572957) at the eastern end of Otama Beach (Figure 2.1) a distinct heavy mineral-rich lamina, 3cm thick, marks the bounding surface between unit PB-2 and PB-3 and can be traced laterally for 50m. Such thick heavy mineral-rich deposits are often characteristic of the backshore or berm environment (Clifton 1969, Schofield 1970, Reading 1978).

Figure 2.1 Unit PB exposed at Otama type section (T10/572957). A well developed soil, Brown Quaternary ashes and Rotoehu Ash exhibiting cream puffs' overlie the Pleistocene Barrier Unit. At the boundary there is a gradational zone of illuviated sands (grey) and iron-rich sands. Note the heavy mineral-rich layer adjacent to hand.

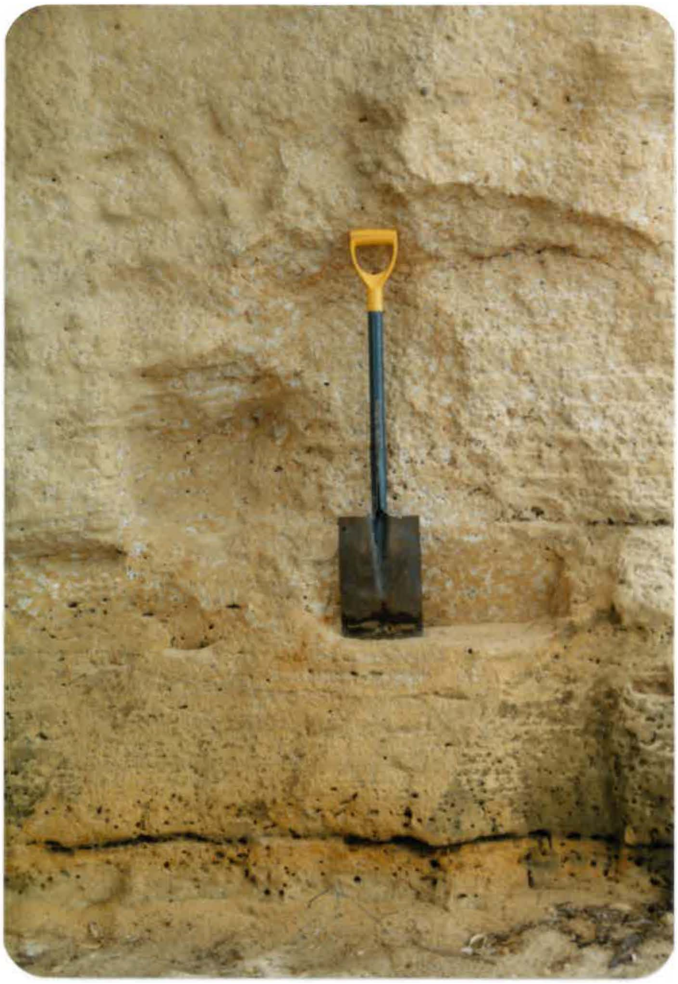


Figure 2.2 Planar laminations of unit PB-2 pass upwards into poorly defined trough cross-beds just below the spade, at Otama (T10/570953). At approximately the level of the spade handle larger cross-beds are evident representing unit PB-3. Iron mottling characteristic of the Pleistocene Unit is seen in the photo (see Figure 2.6).

Figure 2.3 Large scale cross-bedding of unit PB-3 at Otama embayment (T10/571956) fronted by the modern lagoon. Water-table influenced iron staining is extensive at this site. Grey sandy muds (unit PB-1) are buried below the distinctive orange staining at the base of the cliff.

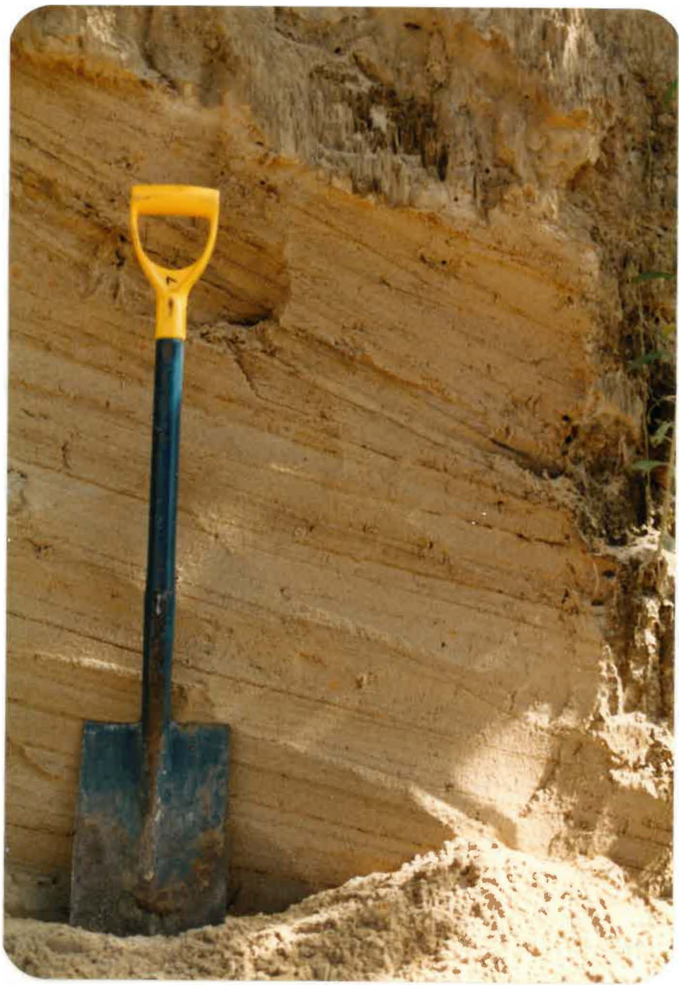


Figure 2.4 Steeply dipping (10°-30°) eolian wedge-planar cross-beds of unit PB-2, at Opoutere T12/663516.

The sand fraction is made up principally of quartz and feldspar, with minor quantities of heavy minerals, primarily opaque minerals, hornblende and hypersthene, and traces of lithic fragments. Heavy mineral contents are commonly 2-4% increasing up to 8% in the beach unit. Clay mineral types include allophane and halloysite in abundances upto 12% total clay. The proportion and distribution of these minerals were confirmed by thin-section petrography, x-ray diffraction and pipette analysis (see Chapter 4).

Iron eluviation is a prime post-depositional feature of this Pleistocene Barrier Unit in the form of leisegang structures and common mottles peppering the sands. Leisegang rings up to 10cm thick form irregular coalescing and diverging structures (Figure 2.5) which act as impermeable iron pans to leaching waters. Individual mottles are random irregular nuclei consisting of an outer light grey (7.5 YR 8/1) rind enclosing a yellow orange (7.5 YR 7/8) ferruginous-cemented centre (Figure 2.6). The degree of mottling ranges from 20% to 40% in PB-3, decreasing to 10% in the lower PB-2 unit. The formation of these mottles could be attributed to water droplets within the sand, leaching the immediately surrounding sand as they dry up, depositing the illuviated iron in the centre..

Contemporary insect burrows, particularly mason bee burrows, occur at several locations within the unconsolidated sands of units PB-2 and PB-3 (Figure 2.7). At the Otama section, the occurrence of a discontinuous pebble layer in the eolian unit, may indicate a deflation surface, often observed within dune forms (Selby 1986).

Podzolised eolian sands of variable development and thickness occur in the upper section of most exposures. At Otama (Figure 2.1), up to 8m of moderately weathered sand is overlain by a diffuse zone of iron accumulation (unit PB-4) leached from grey (5 Y 6/1) clean quartz sands (unit PB-5) above. Overlying late Quaternary ashes, consisting of the Rotoehu Ash as the basal member and the brown Quaternary ashes, are veneered by a dark brown (7.5 YR 3/4), 20 to 40cm thick moderately developed soil exhibiting crumb structure. In many cases along the

Figure 2.5 Leisegang ring structures dissect unit PB-3 at Tairua (T11/641630). Podzolised sands (A_2 horizon) are capped by small cream puffs (white lumps) of weathered Rotoehu ash and a soil.

Figure 2.6 Mottling characteristic of the leached barrier sands of eastern Coromandel. Ferrugenous-stained centres are encircled by an irregular rind of leached sand in unit PB-3, at Otama. Scale 55cm diameter.

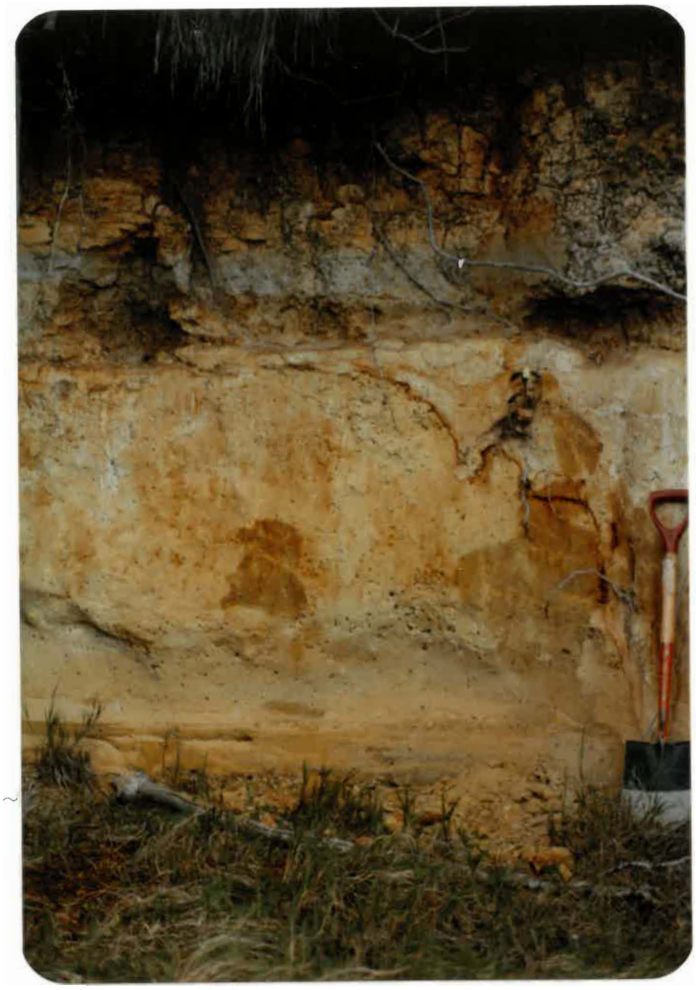


Figure 2.7 Shower bedded Rotoehu Ash (7.5 YR 8/1, light grey) overlies illuviated fine sand (PB-5), eluviated iron-stained sand (PB-4) and insect burrowed dune sand (PB-3) at Tairua (T12/628599).

coast pohutakawa (*Metrosideros excelsa*) trees delineate the unit. In farmed regions, pasture grasses cover much of the deposit.

The Barrier Unit is clearly of Pleistocene age because of the occurrence of the Rotoehu Ash immediately above the podzolised sands of the eolian unit. Refinement of this Pleistocene age estimate is not possible until more accurate dating of the Rotoehu Ash becomes available. In this writers opinion, a reasonable period of time needs to have elapsed after the sand accumulated and before the deposition of the Rotoehu Ash (c. 50 ky BP). This view is based on the appearance of a possible paleosol below the Rotoehu Ash at Bowentown and Athenree sections, and what seems an eroded podzol profile as interpreted at the Tairua and Otama sections. In this case prior to Rotoehu Ash deposition, the Pleistocene barrier would need to be colonized by forest vegetation, normally required for podzol development (Thompson and Bowman 1984) and undergo a period of erosion.

Holocene Sand Flat Unit (HSF)

The Holocene Sand Flat Unit was deposited under a variety of conditions including: (a) quiet water deposition in marginal marine environments where lagoons formed in the lee of barriers; (b) by eolian and washover processes accumulating sand in back barrier environments, low-lying flat regions onlapping the landward flanks of barrier dunes and extending into the lagoon; (c) the progressive infilling of an estuary by fluvial and marine sediments leading to the development of swampy stabilised flats (Figure 2.8).

The unit is Holocene in age, as indicated from spatial relationships within the embayments. Specific localities are labelled with more definitive dates on the basis of radiocarbon dates and the occurrence of pumice layers. It occurs as low-lying flats, usually 1-2m above present sea level (Figure 2.9) and extends for distances of a kilometre or more landward of the barrier ridge. It stratigraphically onlaps the Pleistocene Barrier Unit, Holocene Barrier Unit and is in

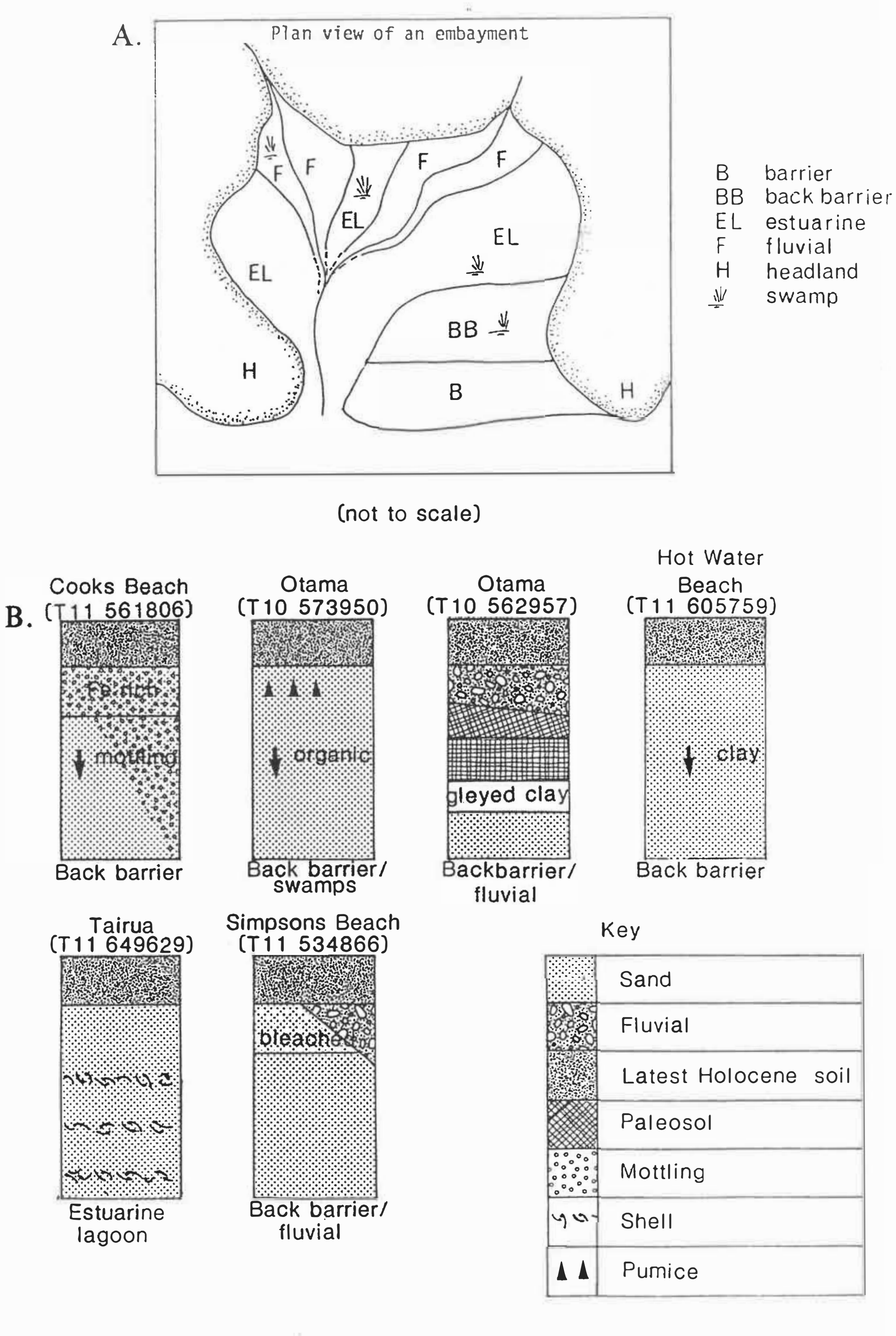


Figure 2.8 Generalised diagram illustrating the diverse depositional environments of the Holocene Sand Flat unit. A. Environment distribution within an embayment. B. Stratigraphic variance associated with environments (refer Figure 2.11).

Figure 2.9 Back barrier flats of Cooks Beach extend between bedrock hills and Holocene dune ridges. At this location (T11/564812), the sands form humus podzols.

part overlain by the Fluvial and Estuarine units. At Tairua, the lower contact or stratigraphic termination is observed, onlapping the Pleistocene Barrier Unit (Figure 2.10). The stepped boundary is sharp, separating unweathered light grey (10 YR 8/1) Holocene Sand Flat sediments from ferruginous-stained bright yellowish orange (10 YR 6/6) sands of the Pleistocene Barrier Unit.

Lithologically, considerable variance exists across the sands, being either organic, shelly or iron-rich, or containing buried soils (Figure 2.11). At the Cooks Beach type section (T11/561806) (Figure 2.9, 2.11c) a brownish grey (5 YR 5/1) topsoil up to 30cm thick grades downwards into a bright brown (7.5 YR 5/8) iron accumulation zone. Below this zone, the lithified sands are relatively iron-free but become increasingly stained with depth. Dark reddish brown (5 YR 3/4) mottling increases with depth, up to 25% at 80cm. Long, slender, vertical traces in the profile are thought to be root traces or *Dikaka* (Glennie and Evamy 1968). The surface of the section is disrupted by contemporary burrows and surface wash.

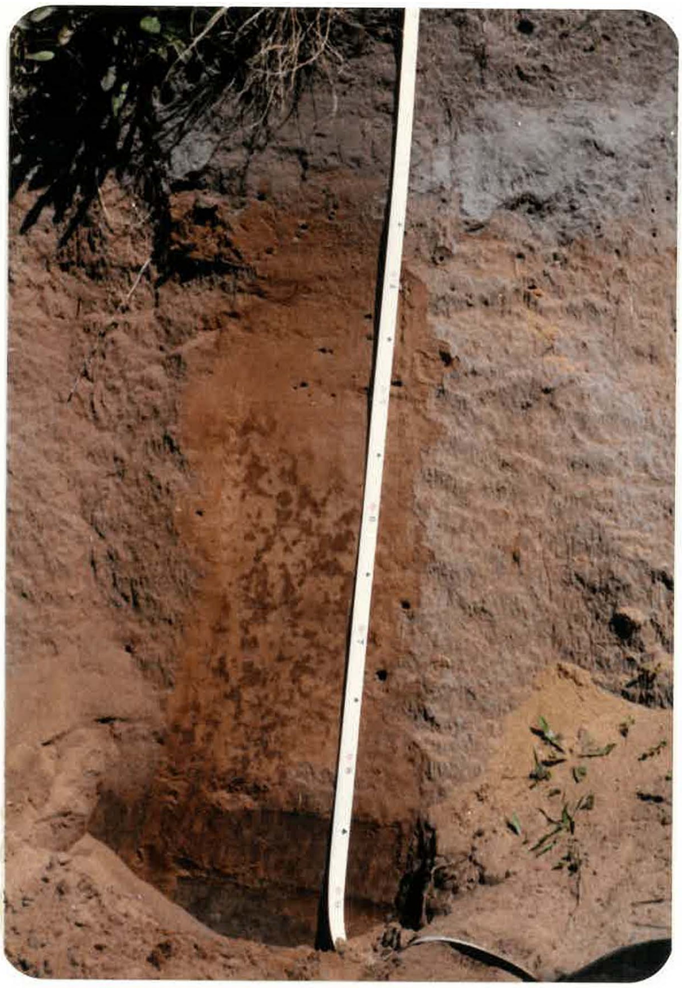
Low-angle (2°) planar cross-bedding of fragmented and whole disarticulated shells, gravel and heavy minerals are observed within this unit at Tairua (T11/649629) (refer to Figure 2.11b). Shells identified include cockles (*Chione stutchburyi*), pipi (*Amphidesma australe*), small turrets (*Zeacolpus fulminatus*) and white biscuits (*Dosinia lambata*). Shell proportions range from 10% to 50% through the section. Shell material carbon dated (*c*. 500 yrs BP, Table 2.4) and the occurrence of Loisels? Pumice 1 in the surficial 10cm of sand (T11 647635) indicates an approximate time plane.

At Otama (T10/562951), complex stratigraphic relationships, suggest the Holocene Sand Flat Unit is the product of more than one episode of deposition. Two significant unconformities are identified by paleosols indicating two separate periods of exposure and non-deposition. At the surface a matrix-supported alluvial deposit unconformably overlies the Holocene Sand Flat Unit, and is grouped and discussed under the Fluvial Unit. The uppermost buried soil has a

Figure 2.10 Unconsolidated sands (white) of unit HSF overlie weathered, iron-stained sands of unit PB. The stepped contact is clearly visible.

Figure 2.11 Lithologic variance of the Holocene sand flat unit; A, Organic-rich; B, Shell-rich; C, Iron-rich; D, Clay-rich and associated podzols. Locations are Otama (T10/573950), Tairua (T11/649629), Cooks Beach (T11/561806), Otama (T10/562951), respectively.






well developed nutty structure and is brownish black (7.5 YR 3/2) grading down into a thin moderately developed prismatic horizon. The second buried soil has a weakly developed structure but overlies a dull yellow orange (10 YR 7/3) clay with well developed prismatic structure. Below well sorted quartz sands, grade from light grey (7.5 YR 8/2) leached sand into dull reddish brown (5 YR 4/3) ferruginous-cemented sands and downwards into light yellow orange (10 YR 8/3) massive sand.

Another Otama section (T10/573950) is dominated by dark reddish brown (2.5 YR 3/4) organic-rich massive sand containing incorporated buried tree branches and logs. The boundary between sand and 6cm of topsoil is marked by a fairly continuous layer of dark grey Loisels? Pumice 2 (Figure 2.11a).

Texturally, the Holocene Sand Flat sediments are primarily muddy sands with ocassional sands. The muddy sands were deposited in lower energy estuarine environments, while the sands probably reflect washover and eolian deposits on back barrier flats. The sediments of this unit have a similar composition to the sands of the Pleistocene Barrier Unit, predominantly quartzofeldspathic-rich with small quantities of heavy minerals (<2%). Shell carbonate content varies locally, commonly between 2-8%. The skeletal material is mainly derived from organisms, primarily bivalves and gastropods living in low energy estuarine environments. The proportion of clay fraction ranges from 10-20%. X-ray Diffraction Analysis did not identify any crystalline minerals in this fine fraction, suggesting only amorphous material is present.

Several locations of the Holocene Sand Flat Unit, for example Cooks Beach and Mataora exhibit degrees of indurated organic-cemented hardpans, which are commonly termed coffee rock. Similar organic-cemented quartz sands in coastal regions have been described by numerous authors (e.g. Coaldrake 1962, Ward et al. 1979). These deposits are distinctive podzol B horizons, characterised by accumulated humus, low-iron content, lateral uniformity in appearance and composition and frequent hard cementation, and often develop at the top of the water table in quartz sands on coastal plains (Farmer et al. 1983). Farmer et al. (1983) states the organic precipitates of humus podzols fill the space between clean quartz sand grains whereas, in freely-draining podzols the sand grains are coated with organic matter and sesquioxides, consistent with observations of this study. For mode of formation refer to Farmer et al. (1983).

Holocene Barrier Unit (HB)

The Holocene Barrier Unit comprises the dune and beach deposits of Holocene progradation and currently active beaches and foredunes found in the eastern Coromandel embayments. Morphologically, they occur as large accumulations of sand fronting the coastal embayments, and more commonly than not exhibit a succession of dune ridges which can be divided into several groupings according to soil formation and overlying vegetation types and cover (Figure 2.12).

The unit is overlain by onlapping sediments of the inter-dune Holocene Sand Flat, Fluvial and Estuarine Units. Underlying stratigraphy of this barrier unit is not known but is suggested as Jurassic greywackes, Tertiary volcanics and Pleistocene deposits.

Sediments of the beach deposits are commonly heavy mineral-rich, exhibiting thin low angle (2°-5°) wedge planar laminations with low angle discordances, interrupted by abundant trace fossils (Figure 2.13). Each laminae is inversely graded, with heavy mineral concentrations grading up into a coarser quartzose layer. Trace fossils include simple elongated vertical and horizontal spherical tunnels, 0.5-2cm long, and up to 5mm diameter, as well as irregular branched shafts (Figure 2.14). Several vertical structures thin upwards to a narrow tube, while others widen. These traces are assigned to Scoyenia and Skolithos ichnofacies (Collinson and Thompson 1982; Ekdale et al. 1984). Shell-rich lenses are a consistent occurrence within these deposits.

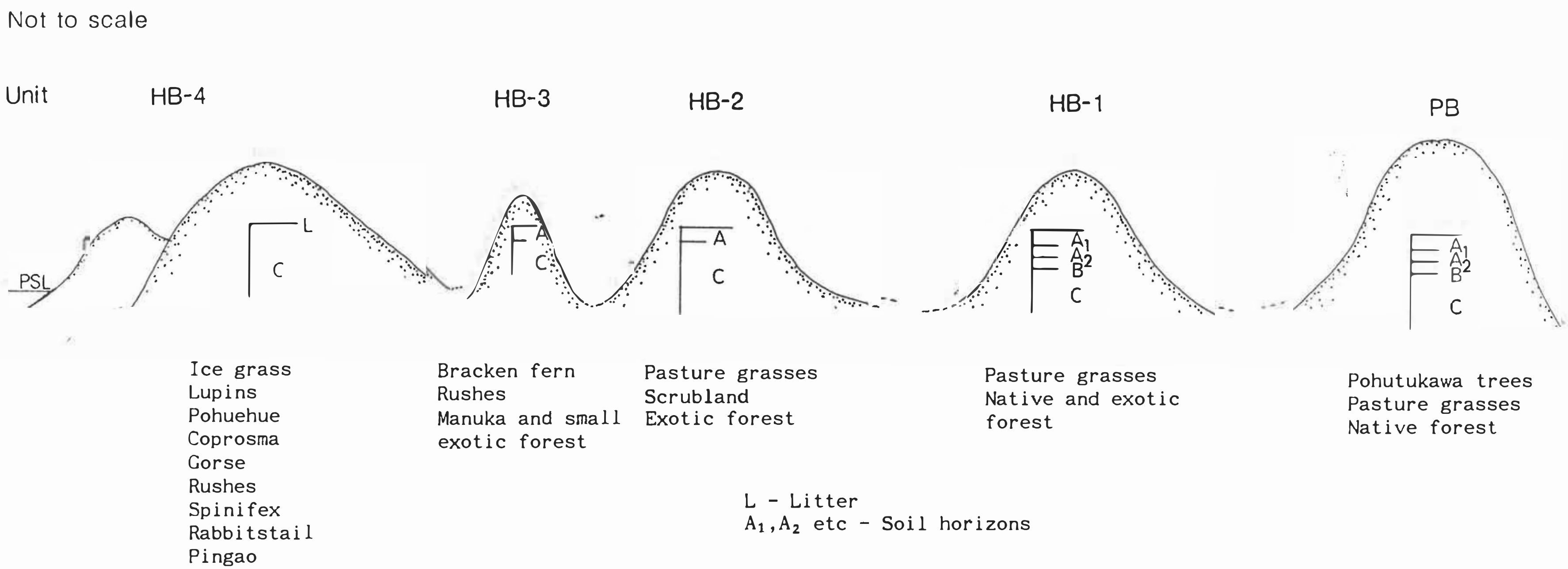


Figure 2.12 A succession of dune ridges comprise the Holocene barrier unit. Each has a particular vegetation association and soil development (HB-1 - HB-4, Holocene barrier set 1 - Holocene barrier set 4). Moving inland, the vegetation succession matures and soil development increases. Soil horizon thicknesses are not shown.

Figure 2.13 At Wharekaho embayment (T11/539863), wedge-planar beds of titanomagnetite-rich sands underlie massive quartz feldspathic-rich sands of unit HB-2. Taupo Pumice occurs in a discontinuous lense adjacent to the spade head.

Figure 2.14 Close-up of Figure 2.13, showing heavy mineral depleted and enriched wedge-planar beds disrupted by abundant trace fossils. The traces including Ophiomorpha denicolites (Walker 1984) and Skolithos (Collinson and Thompson 1984), are assigned to Skolithos and Scoyenia ichnofacies and indicate a sandy shoreface depositional environment.

The dune unit, consists predominantly of well sorted sands ranging from unconsolidated through to semi-coherent sands. Common tabular and trough cross-beds with dips 2°-6°, cut indurated exposures (Figure 2.15). At Cooks beach (T11/565813), rare heavy mineral-enhanced planar laminations dipping 3°-5° are traceable for 1m.

The degree of induration is largely dependent on ferruginous-staining development. Ferruginous mottling can be well developed, up to 25% in the more coherent deposits. Semi-coherent sands are extensively burrowed by mason bees and ants at most exposures.

The Holocene Barrier Unit of some embayments can be separated into four subunits according to soil development, pumice appearance and vegetation cover. These groupings tentatively suggest a succession of dune-building or barrier-accreting phases. Initially it was hoped these subunits could be correlated on a regional scale and an age range for each subunit resolved.

Unit HB-1, at its stratotype (T12/663512, east Opoutere) podzolised sands grade from dull orange (7.5 YR 7/4) or bright brown (7.5 YR 5/6) moderately weathered sands vertically upwards into typical podzol horizons. These are a dark reddish brown (10 R 3/2) iron-rich lithified horizon and a light grey (5 YR 8/1) leached zone above (Figure 2.16). Up to 30cm of soil development overlies this unit. The black (7.5 YR 2/1) moderately developed crumb soil is occasionally disrupted by Maori middens (Figure 2.17). Vegetation cover is mostly pasture grasses and large pinus radiata forest. At Opoutere a 20cm thick layer of yellow-brown Tuhua Tephra Formation (Pumice 4) occurs about 1.6m below the upper surface of unit HB-1. The presence of Tuhua Tephra (*c*. 6200 y BP) enables a rough approximation of the age of this possible barrier accreting phase, from 6500 to 6000 y BP.

Unit HB-2 is characterised by dull orange (7.5 YR 7/4) leached well sorted sand covered by 20cm of topsoil. Iron staining and mottling is present at some sites. Soil development consists of an A-

Figure 2.15 At Opoutere (T12/663511), overlapping wedge-shaped low angle cross-laminae typify the internal structure of unit HB-1.

Figure 2.16 Podzolised mottled sands of unit HB-1 crop out at Opoutere (T12/663512). One metre below the spade Tuhua Tephra forms a 30cm thick lense.

Figure 2.17 Maori middens or shell pits are common archaeological sites across the Holocene dune sets (HB-1, HB-2). This midden is exposed at Cooks Beach (T11/562808).

horizon 20cm thick, brownish black (10 YR 2/3) moderately developed crumb structure covered by pasture and pine trees. At the stratotype (T11/503825, Whitianga), Taupo Pumice (Pumice 3) as lapilli and blocks up to 0.5m, occurs in a lense up to 20cm thick. The Wharekaho and Cooks Beach sections, have small pieces of yellow brown possible Taupo Pumice forming discontinuous layers, at a constant level. A suggested age and interval for the formation of unit HB-2 is 2000-1500 y BP arising from the pumice occurrence.

Massive, incoherent well sorted sands, covered by 10cm of topsoil comprise unit HB-3. The sands are dull reddish brown (2.5 YR 4/4) to dull orange (7.5 YR 7/3). The type section (T10/569952, Otama) consists of 10cm of topsoil underlain by 15cm of light brownish grey (7.5 YR 7/2) sand and a discontinuous layer of grey Loisels? pumice (Figure 2.18). Below is a paleosol, containing charcoal (*c.* 780 yrs BP, Table 2.4) and water-rounded pebbles up to 5cm long. Unusual chips on the pebbles ends were not consistent with Maori workings (L Furey pers comm.) Soil development consists of an A-horizon 10cm thick, brownish black (10 YR 2/3) weakly developed crumb structure covered by grasses, bracken fern (*Pteridium aquilinum* var. *esculentum*), rushes and pine trees (*Pinus radiata*).

Age estimation of this subunit is more difficult due largely to the questionable validity of Loisels Pumice and the relatively high error in the carbon date. Clearly, sections at Otama, Opito, Wāikawau and Wharekaho had random or extensive distributions of a dark grey pumice. The Wharekaho (T11/540864) section contained a band of pumice (Pumice 5) 20cm thick, with pieces from 0.5cm to 5cm long, 45cm from the surface (Figure 2.19). Other radiocarbon dates from dune sites along eastern Coromandel (Table 2.4) support a very approximate age range for this dune accretion phase at 900 to 500 y BP.

Unit HB-4 is characterised by light grey (5 YR 8/1), loose, non-cohesive sands covered by 1-2cm of litter (Figure 2.20). It occurs in all embayments, normally as large sand accumulations up to 15m above sea level. Stabilising vegetation is primarily low-growing scrubs

Figure 2.18 Chipped, rounded pebbles were located in a buried soil of unit HB-3 at Otama. ?Loisels Pumice appears in a discontinuous layer 4-5cm above the paleosol. The sands are organically stained and disrupted by Dikaka ichnofossils assigned to the Scoyenia ichnofacies (Seilacher 1967).

Figure 2.19 A lense of sea-rafted ?Loisels Pumice is contained within heavy mineral-rich sand of HB-3 at Wharekaho (T11/540864).

Figure 2.20 Unconsolidated quartzofeldspathic-rich sands of unit HB-4, at Otama (T10/565955). Locally, sand binding and low-lying scrubs form thick woven vegetation cover.

including pohuehue (*Muehlenbeckia complexa*), comprosma (*Comprosma propinqua*), coastal tree-daisy (*Olearia solandri*), gorse (*Ulex europaeus*), manuka and rushes and minor sand-binding plants including ice grass (*Disphyma australe*) and lupins (*Lupinus arboreus*).

Presently-accreting coastal dunes also comprise unit HB-4, however the covering vegetation sequence has changed from scrubland to sand binding plants. Spinifex (*Spinifex hirsutus*), rabbitstail (*Lagurus ovatus*) and pingao (*Scirpus frondosus*) form intertwining mats of grasses trapping further sediment. Shore convolvus (*Calystegia soldanella*) is also found in several regions. Limited soil formation and radiocarbon dates (Table 2.4) suggest that this phase of dune activity probably was initiated <500 y BP, and continues at present.

The well to very well sorted sediments of the Holocene Barrier Unit are predominantly quartz and feldspar, with minor quantities of heavy minerals including hypersthene, hornblende and augite and traces of aegerine, cummingtonite, riebeckite, biotite and volcanic glass. Shells include fresh angular fragments and whole shells as well as brown, ironstained, abraded and burrowed specimens and vary from less than 10% in the eolian deposits to 30% in contemporary beach deposits. The sediments of the Holocene Barrier Unit exhibit a progressive compositional variation from recent sediments through successively older dune ridges, including an increase in clay percent (0-5%), an increase in organic matter percent (0-5%), and a decrease in shell carbonate content (9-0%).

Fluvial Unit (FU)

The Fluvial Unit is described as alluvial deposits formed in fluvial environments, and freshwater swamp deposits present as surficial deposits across the coastal plain. The alluvial deposits occur at or near stream margins within each embayment, and form by lateral accretion of point bars or deposition in flood basins and levees by addition of sediment during flood stage where streams overtop their banks (Walker and Cant 1984). Freshwater swamps occur locally in water-logged hollows of the coastal plain and form from the progressive infilling and decay of organic material. The Fluvial Unit can conformably overlie, the Holocene Sand Flat Unit where swamp deposits have infilled ponded hollows. The unit also laps under, onlaps and unconformably overlies the Holocene Sand Flat Unit.

Sediments of the Fluvial Unit are primarily organic muds, sandy gravels and gravelly sands and rare silty sands. At the stratotype (T11/643639, west Tairua) for alluvial deposits, poorly sorted gravelly sand forms lenses of sediment interpersed with wedges of finer sediment. Pebbles of diverse composition (including sinter fragments, rhyolitic and andesitic rock fragments) and up to 6cm long are subrounded and irregular. In other locations, this unit is dominated by orange (5 YR 6/8) to light grey (10 YR 8/1) fine sand and silt. Generally, in each separate lense of sediment, an upward-fining sequence is observed.

Swamp deposits are unconsolidated organic-rich sediments covered by clumps of rushes and pasture grasses. The deposit consists of a black (10 YR 2/1) moist silt loam with well developed granular structure disrupted by organic material, overlain by a mass of roots and undecayed plant material. In general, these deposits are actively accreting at the present day.

Buried soils and incorporated plant material are a common stratigraphic association of the Fluvial Unit. At Otama (T10/562951) a matrix-supported gravel overlies buried logs (*c.* >mod, Table 2.4), soils and sands of the Holocene Sand Flat Unit (Figure 2.21). At Wharekaho, a section (T11/538864) reveals a buried soil, bounded either side by a flood of poorly sorted fine sediment (Figure 2.22). Strict time correlation of this unit across the embayments is not possible. Age estimations arise from the age of the underlying stratigraphic contact, as the fluvial deposits are normally contemporaneous with this boundary. At Otama, the wood samples dated at living since 1950, indicate an extremely modern alluvial event.

Figure 2.21 Lenses of poorly sorted gravels and sands with incorporated logs and boulders (lower right) are typical of the Fluvial Unit. At this Otama site (T10/562951) the gravels overlie the Holocene Sand Flat unit.

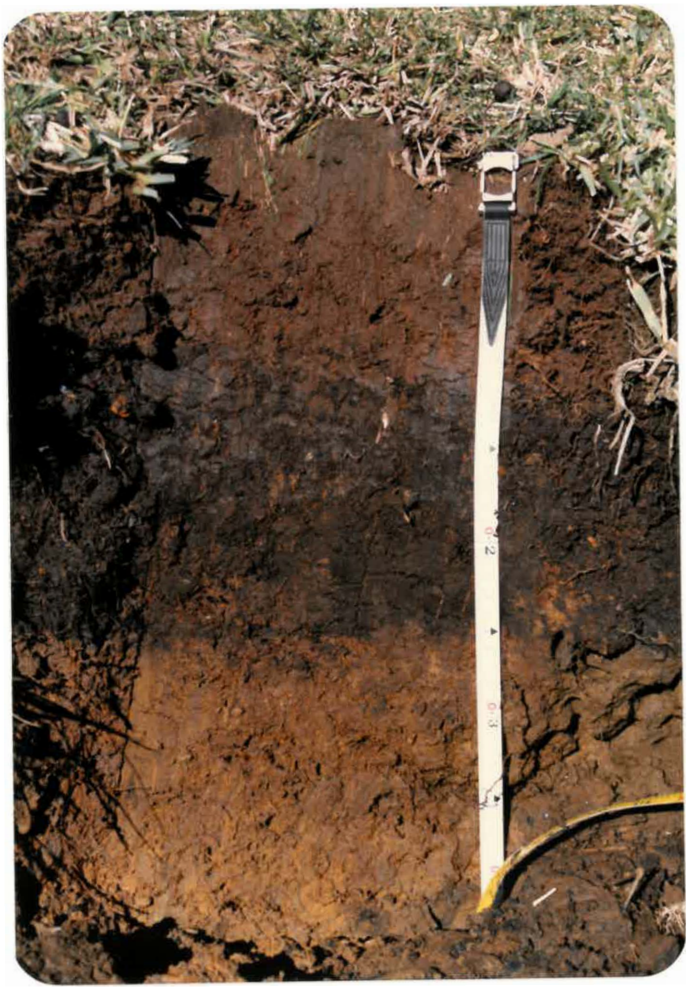


Figure 2.22 A paleosol is preserved and bounded between two fluvial events, at Wharekaho (T11/538864).

Estuarine Unit (EU)

The Estuarine Unit is present as surficial deposits in the coastal embayments, and are deposited under marginal marine conditions, part forming today and part relict of previous depositional processes, for example washover processes. It occurs as the unconsolidated surface sediment of coastal estuarine-lagoons and is time equivalent of the lateral younger Holocene Barrier Units (Figure 2.23). Complex lithostratigraphic relationships, mainly burrowed ripple-laminated subaqueous sand, flaser mud layers and shell facies interfinger vertically and laterally to combine as the Estuarine Unit.

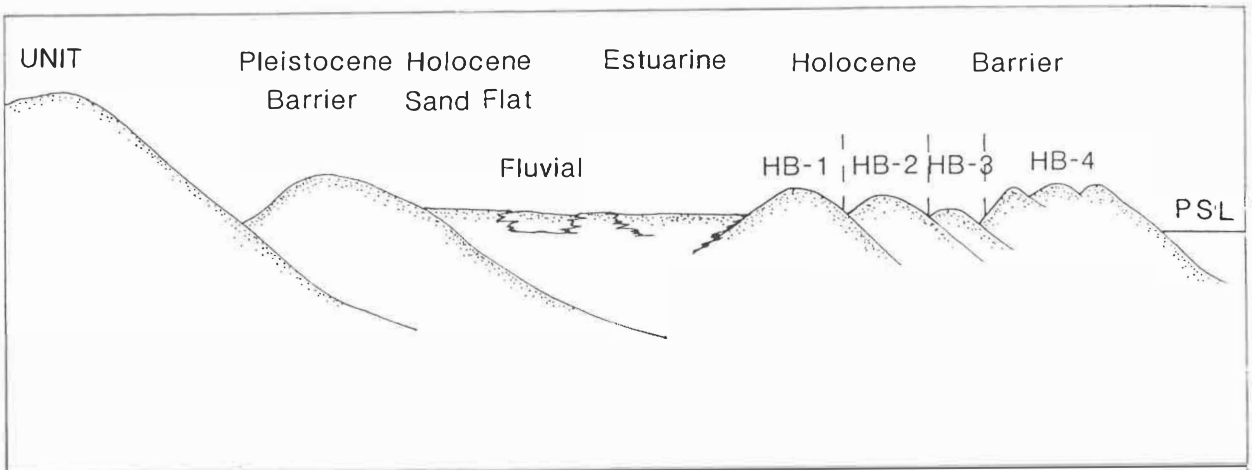
Texturally, the Estuarine unit is primarily burrowed muddy sands, where mud percentages range from 10-26%. Organic gases are often released when the sediments are disturbed. At the stratotype (T12/370297, Opoutere) brownish grey (7.5 YR 4/1) reduced muddy sediments disrupted by benthic burrowing are overlain by a top 4cm layer of dull brown (7.5 YR 5/4) oxidised muddy sand. Fauna living on and in this unit, includes grey scavenger whelks (*Cominella glandiformis*), mudflat horn shells (*Zeacumantus lutulentus*), mudflat snails (*Amphibola crenata*) and cockles (*Chione stutchburyi*). Thin root and reed fibres a product of the covering flora may occur in this unit. Eel grass (*Zostera novae-zealandii*), rushes (*Scirpus americanus* and *Juncus maritimus*), mangrove (*Avicennia resinifera*) trees and plantlets and manuka (*Leptospermum scoparium*) partially or wholly stabilise the Estuarine Unit (Figure 2.24).

2.2 Summary

Five stratigraphic units have been determined according to depositional environment, morphology and chronology; Pleistocene Barrier Unit, Holocene Barrier Unit, Holocene Sand Flat Unit, Estuarine Unit, and Fluvial Unit. The relationships and field characteristics of these units are integrated in Figure 2.25. Chronology across and between the units is based largely on

Figure 2.23 Rippled sands are exposed at low tide and comprise the Estuarine Unit at Wharekaho (T11/540864). Across the estuary, reeds partially stabilise the muddy sands of this unit.

Figure 2.24 At Otama, manuka and rushes have colonised the Estuarine Unit located behind dune ridges of the Holocene barrier. Note washover fan or break in dune ridge (HB-3) on the right. View looking east.



DEPOSITIONAL ENVIRONMENT	barrier; backbarrier estuary; floodplain swamp; estuary; barrier
AGE APPROXIMATIONS	Pleistocene 125 ky; Holocene; Holocene-Recent; Recent; Holocene 6.5 - 6.0 ky; 2.0 - 1.5 ky; 0.9 - 0.5 ky; Recent 0.5 ky
TEPHRA ASSOCIATION	Rotoehu Ash; Tuhua Tephra; Taupo Pumice; Loisels Pumice?
RADIOCARBON DATES	500 y; modern; 780 y
SOIL THICKNESS (cm)	40; 20; 10; 0; 30; 20; 10; 2
SEDIMENTARY STRUCTURES	tabular cross bedding; massive; massive, trough cross bedding; ripple laminations, flaser; tabular cross bedding, massive planar laminations; massive
WEATHERING FEATURES	leisegang structures mottling; iron staining; mottling; mottling

Figure 2.25 Generalised shore-perpendicular cross-section of an east Coromandel embayment illustrating the spatial relationships between the stratigraphic units, and summarising the field characteristics of each. (Note: sm - small, PSL - present mean sea level).

tephrochronology. Various tephras (Rotoehu Ash, Tuhua Tephra Formation, Taupo Pumice Formation and possibly Loisels Pumice) overlie the coastal deposits, and have value as marker beds of known age.

CHAPTER THREE

COASTAL GEOLOGICAL AND MORPHOLOGICAL MAPS OF THE EAST COROMANDEL EMBAYMENTS

The distribution of the stratigraphic units described in Chapter 2 are outlined in the following section. First, the areal distribution and extent of the stratigraphic units are presented on geological maps for four embayments, chosen because they are considered to be representative of the general coastal Quaternary stratigraphy. Second, each of the basic stratigraphic units are presented on associated morphological maps. Major geomorphological attributes of primary (mapped) and secondary (supplementary and additional) locations (Figure 3.1) are also discussed.

3.1 Geological and Morphological Maps

Owing to the subdivision of the stratigraphic units on the basis of chronology, morphology and depositional environment, the maps produced contain not only information on genesis, but also on morphology and, in some cases, ages of the Quaternary deposits.

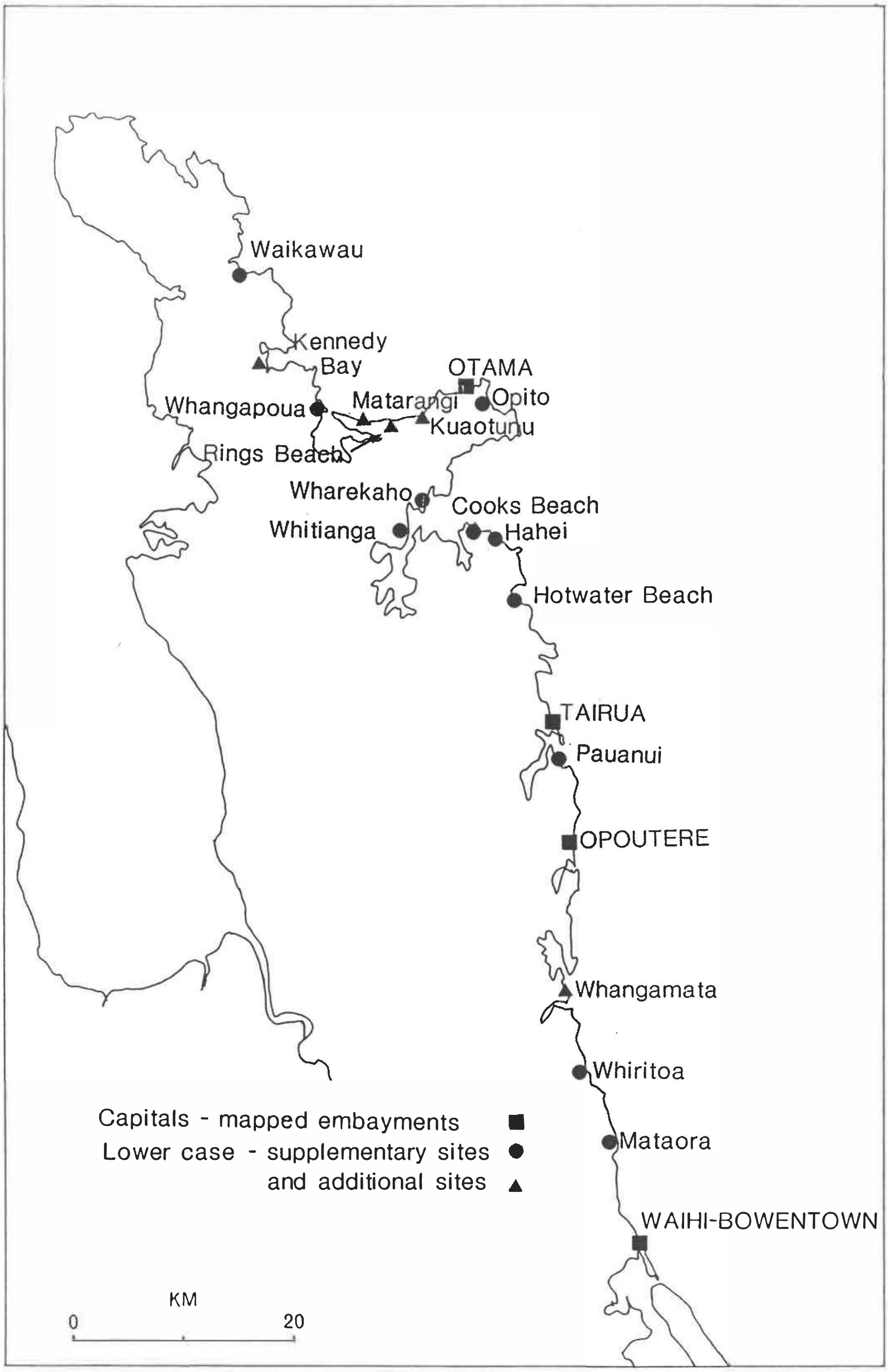


Figure 3.1 Mapped embayments and supplementary and additional site locations.

Otama (refer to maps 1 a,b)

The Otama embayment (Figure 3.2), fronted by a bay barrier beach stretching 4.8km between two rocky bluffs, extends 4km inland at its widest point. More commonly the surrounding highlands, dominated by ridges up to 100m in elevation, abut the sandy infill approximately 2km inland.

The highlands consist of Upper Jurassic Moehau Formation comprising lithic volcanic greywackes and interbedded conglomerates (Skinner 1972). These extend from the western side of the embayment around to the main valley, and include the two terraces fronting the eastern side of the embayment. The remaining geology is Mahinapua Andesite of the Coromandel Group (Skinner 1976). A 30m high spur of basement, unconformably overlain by Waitaia Sinter (Skinner 1976) juts into the low-lying flats, partially dividing the embayment.

The streams draining the Otama embayment feed a largely infilled estuary consisting of low-lying reed swamps. Bordering much of the beach is a barrier system of Holocene age bearing a sequence of transverse dune ridges of up to 14m high. The dune ridges can be separated into two sets based upon soil development, weathering features and vegetation, and suggest phases of barrier accretion. The seawardmost Holocene dunes display a hummocky topography caused by sand blowouts and transgressive sand movement. At the eastern end, the beach, typically exhibiting a well developed berm backs onto a Pleistocene paleobarrier system. The coastwise-aligned Pleistocene barrier forms an eroded cliff face behind the beach, consists of at least three megadune forms and is similar in form, alignment and scale to the current Holocene barrier.

Geological Key

- Fluvial Deposits
- Estuarine Deposits
- Holocene Barrier (no. dune set)
- Holocene Sand Flat
- Pleistocene Barrier
- Pleistocene Flat
- Basement (incl. Tertiary Volcanics, Jurassic greywacke, etc)

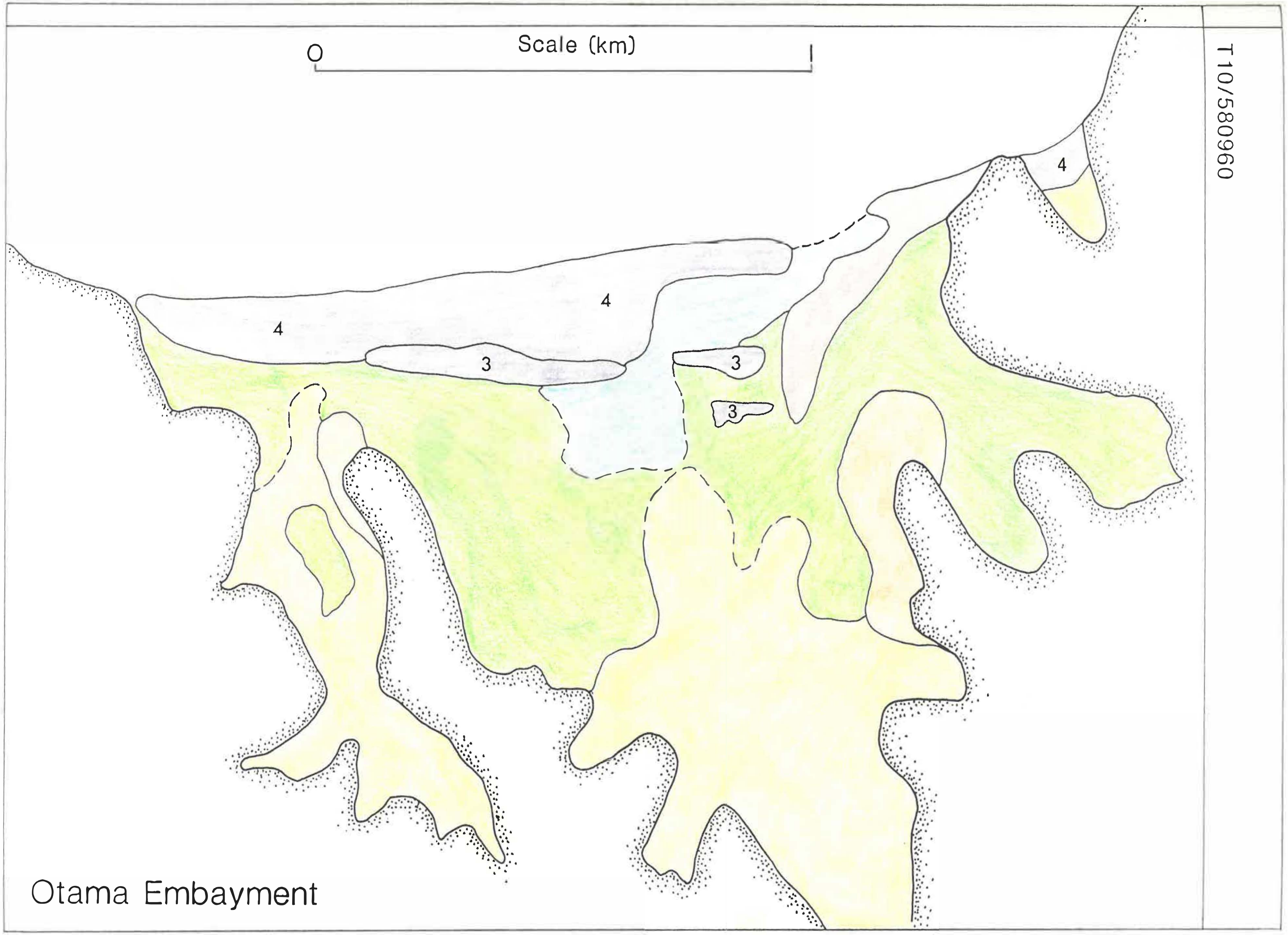
Morphological Key

- Hinterland
- 20-30 m Terrace
- 10-15 m Terrace
- 1-2 m Terrace
- Coastal Platform
- Dune Ridges
- Rock Bluffs
- Pine Trees
- Dune Scrub
- Low-lying Grassland
- Reeds
- Swamp Scrub
- Salt Marsh
- Mangroves
- Lagoon
- Shell Bank

Sub-ash Surfaces

- Waihi Beach
- Ocean View
- Athenree
- Tauranga

Map 1A



Map 1B

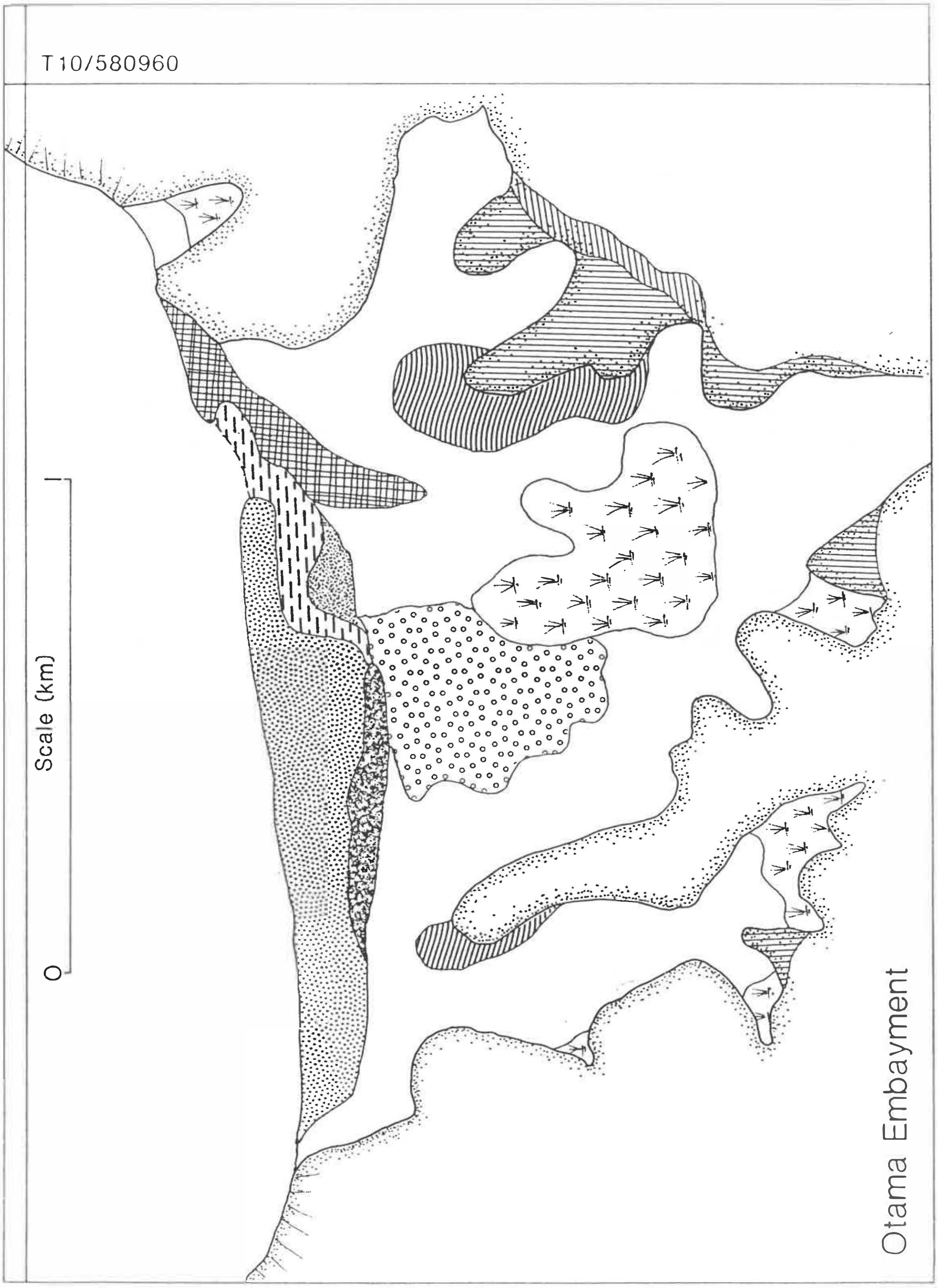


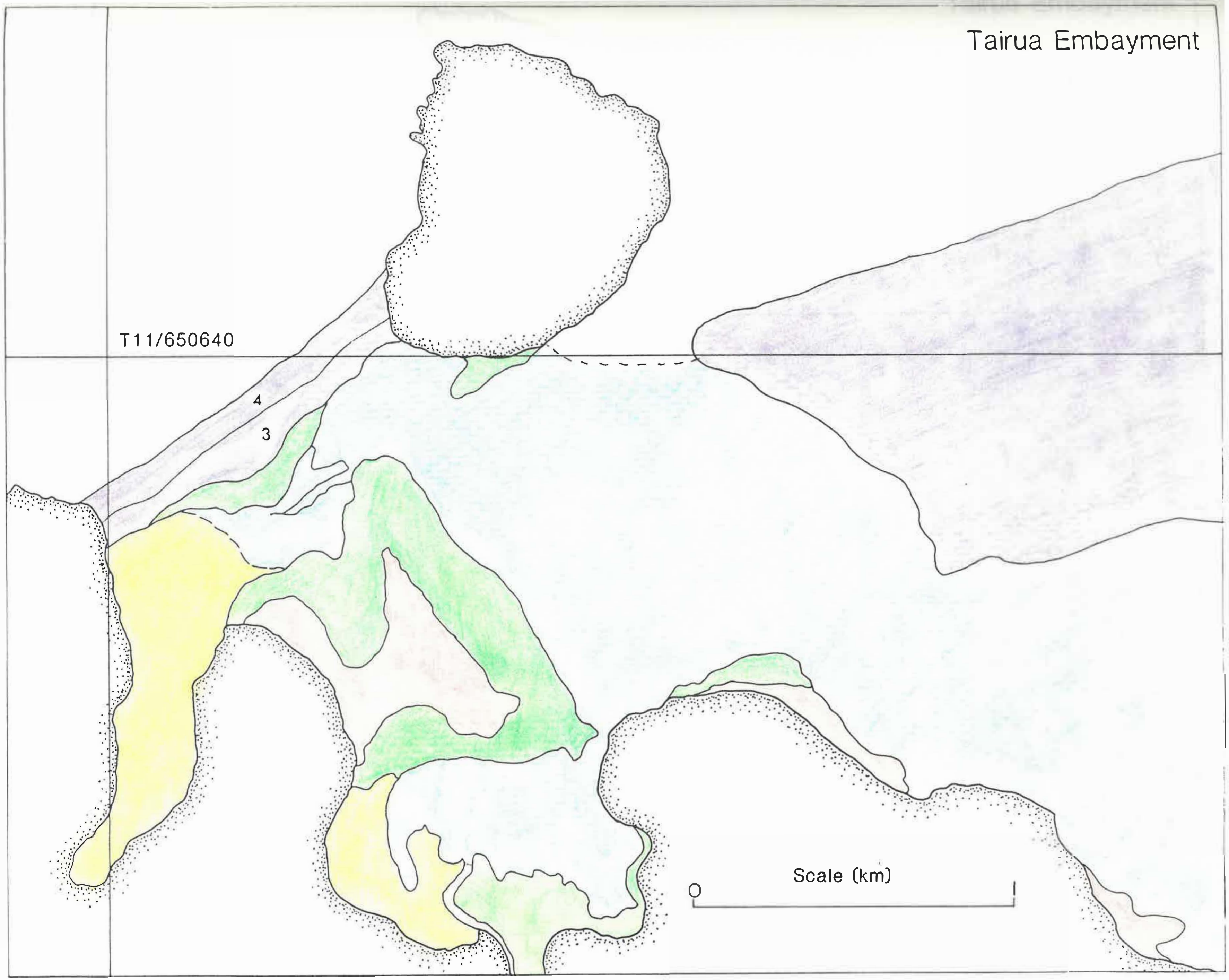
Figure 3.2 Aerial view of Otama embayment looking southwest. Pleistocene cliffs outlined by pohutakawa trees, parallel and immediately back the eastern end of the beach and lagoon. Extensive low-lying flats are fronted by a sparsely vegetated Holocene barrier system impounding a small inlet. Mahinapua Andesite in the lower left terminates the eastern end of the beach.

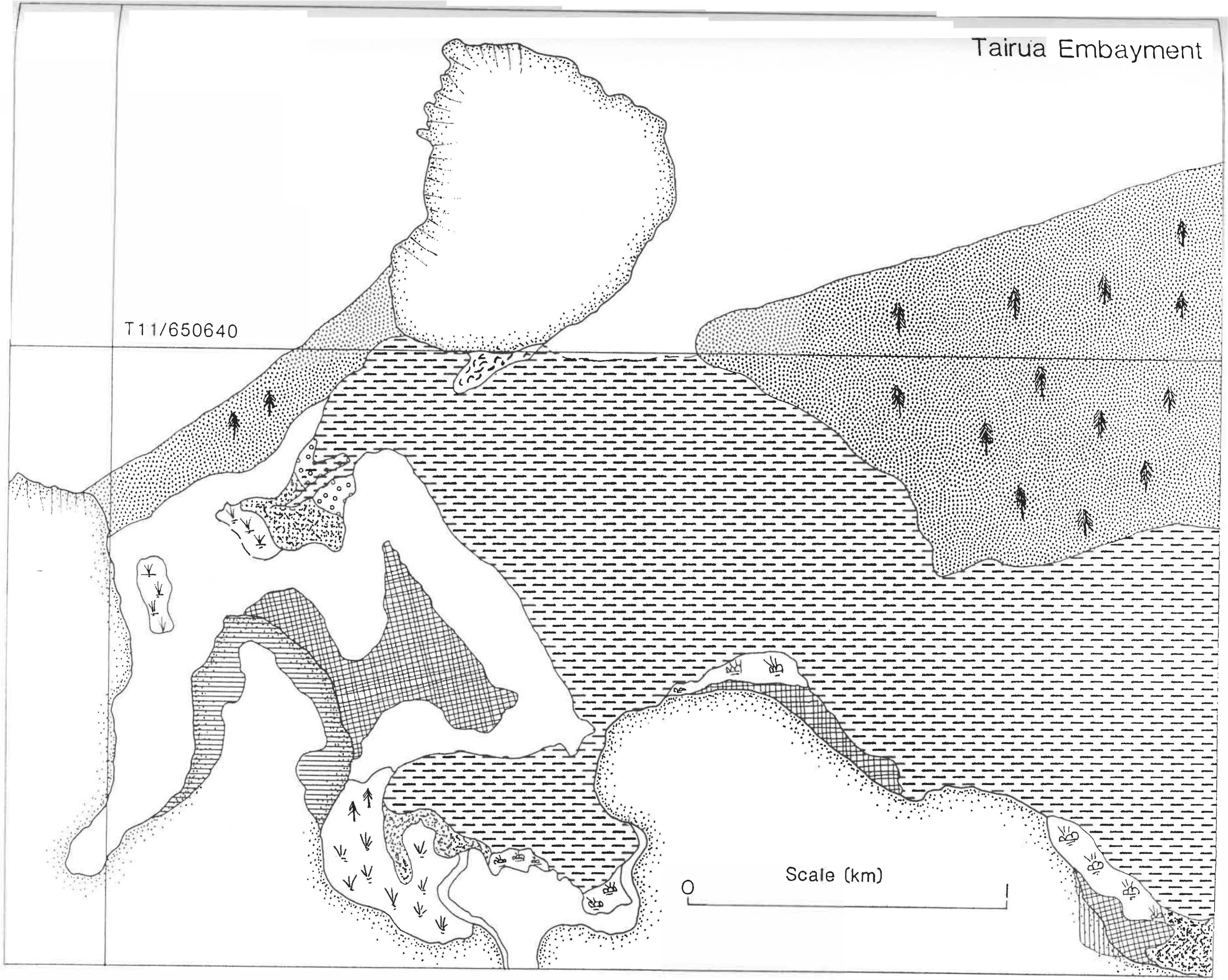
Tairua (refer to maps 2 a,b)

Tairua embayment contains a largely sand-infilled harbour enclosed by a Holocene barrier spit known as Pauanui, consisting of approximately 60 parallel dune ridges. In the north, a Holocene barrier tombolo bridges Paku Island and the northern volcanic headland. Fronting this system is the 1.2km exposed ocean beach of Tairua, frequently exhibiting good berm and cusp development (Healy et al. 1981). Dune ridges of the outer barrier are partially stabilised by vegetation, although several blowouts break their parallel continuity. Impounded behind the tombolo is a series of alluvial flats reaching up the northernmost valley and cut by a meandering stream. Pleistocene sands fringe the embayed hill country margin for approximately 3km, and suggest a fairly extensive barrier system existed during the Pleistocene high sea level stand, although probably smaller than the current Holocene system.

The hinterland consists of two volcanic lithologies. Paku Island, 179m high is composed of Paku Rhyolite, a subgroup of Minden Rhyolite (Skinner, in prep.) with the surrounding geology chiefly Tapuaetahi Andesite, a formation of the Coromandel Group (Skinner, in prep.) attaining elevations up to 110m.

Map 2A





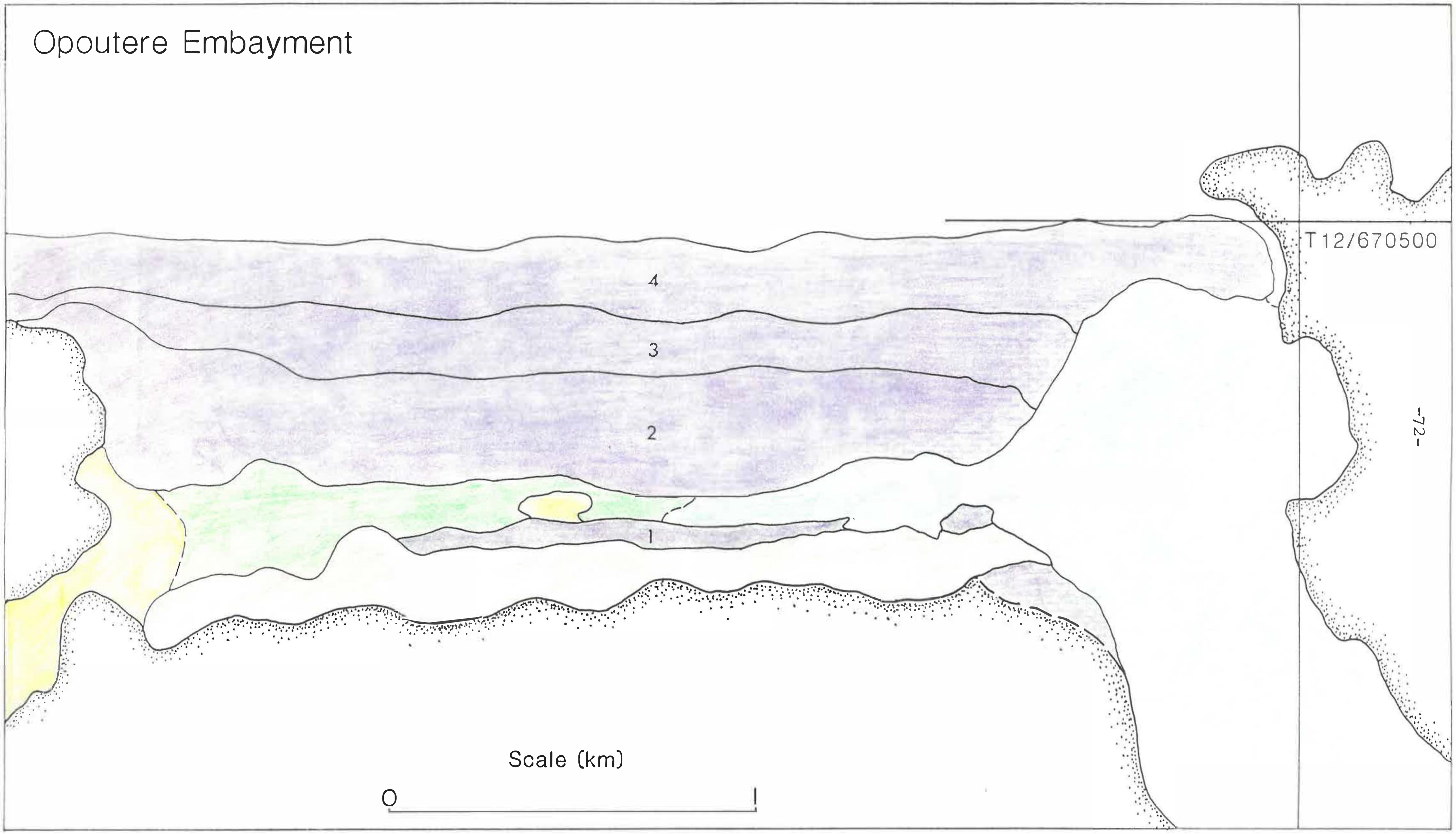
Map 2B

Opoutere (refer to maps 3 a,b)

Dual barriers and swamplands are contained within the confines of Opoutere embayment. A 4.6km long Holocene barrier spit pointing southwards encloses a largely sand-infilled estuary (Figure 3.3). The estuary supports a single channel and well developed sandy tidal flats partially stabilised by mangroves and reeds. The outer barrier is approximately 600m wide and surmounted by extensive transverse dune ridges, semi-transgressive dunes and fronting discontinuous scarped ridges, much of which are covered by a pine plantation (Figure 3.4). It is flanked on the seaward side by an active foredune up to 8m high. The continuity of this foredune is interrupted by several blowouts and public access paths. The wide beach has a fairly flat gradient in the north, which steepens to the south. Behind, an interbarrier depression occupied by swamps and a small stream separates the Pleistocene inner barrier. The inner barrier extends landward to the margins of bush-clad hills.

The surrounding relief confining the estuary and inner barrier is Minden Rhyolite, a subgroup of the Whitianga Group (Schofield 1967). Beeson Island Volcanics form the ridges bounding the swampy valley in the north, which is fronted by a large hill consisting of Minden Rhyolite.

Map3A



Map 3B

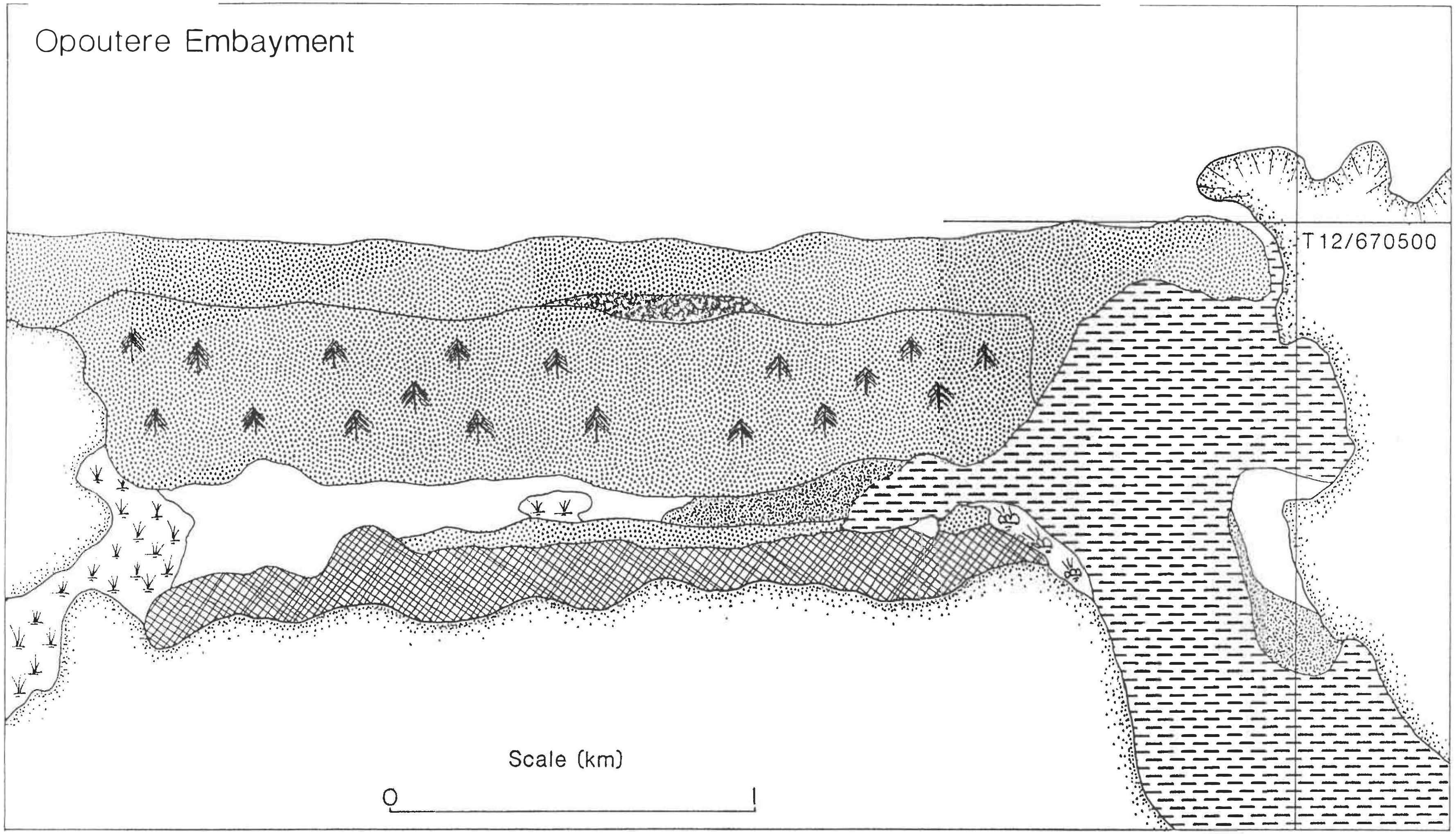


Figure 3.3 The well developed barrier spit covered in pine plantation and the flood tidal delta (foreground) dominate Opoutere embayment. The Pleistocene barrier is covered by much of the green pasture (upper left). View looking north.

Figure 3.4 Spinifex covered foredunes are backed by pine covered dune ridges at Opoutere (looking north).

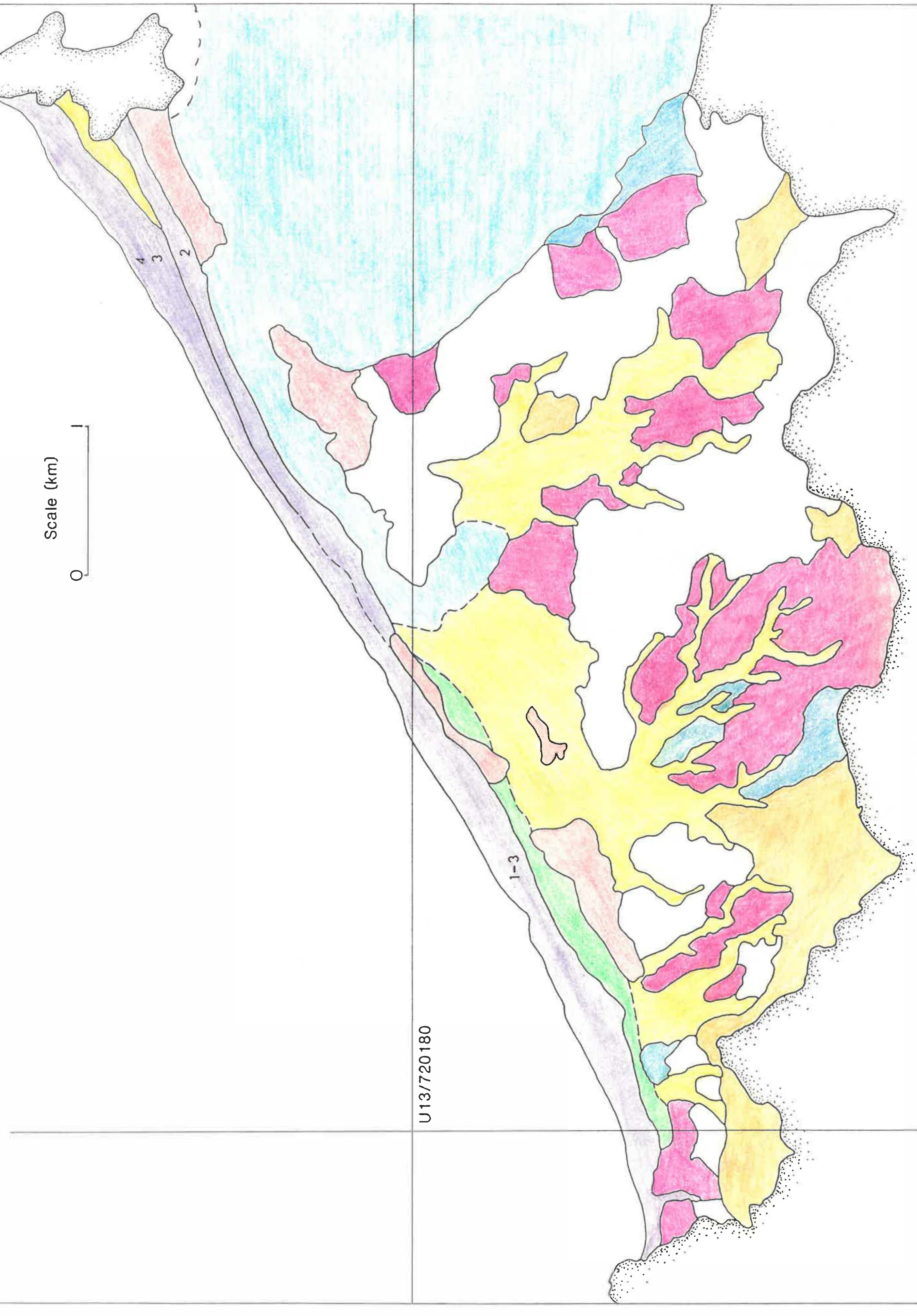
Waihi-Bowentown (refer to maps 4 a,b)

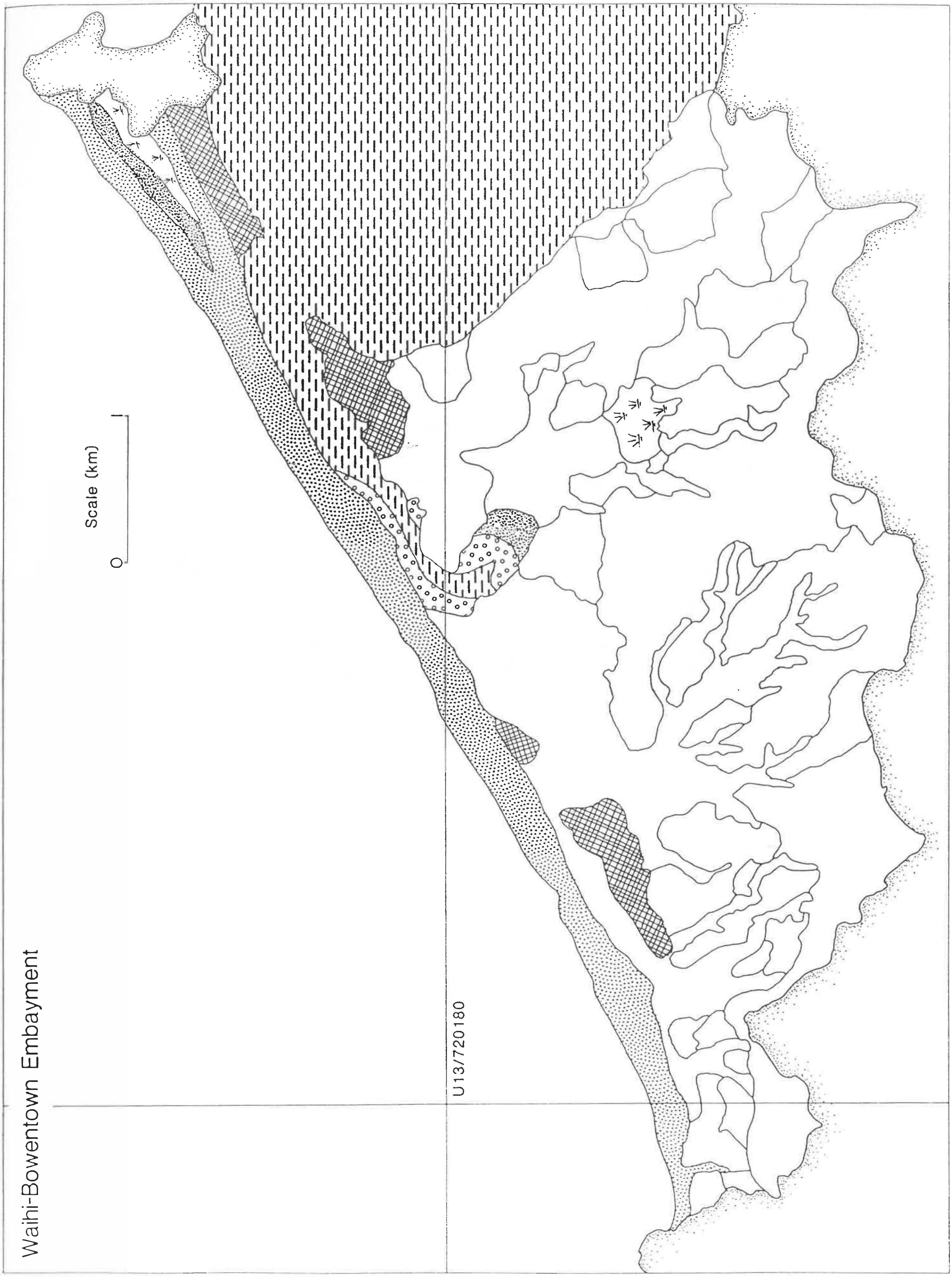
Several coastal surfaces are recognised within the Waihi-Bowentown embayment (Kear and Waterhouse 1961; Selby et al. 1971), namely the Tauranga, Athenree, Ocean View and Waihi Beach surfaces (Table 1.1). The underlying formations, named after the above surfaces, accumulated by aggradation and consist of locally derived clays and sands with angular pebbles near the hills and rounded pebbles in the valleys (Kear and Waterhouse 1961). The terraces fan radially out from the surrounding Tertiary volcanics (Minden Rhyolite and Beeson Island Volcanics), reducing in elevation towards the sea.

Fronting the embayment is Waihi Beach, a 9km long barrier beach, attached as a tombolo to Bowentown Head at the southern end. Bowentown Head, consisting of Minden Rhyolite, is the delimiting headland for the northern entrance of Tauranga Harbour. Waihi Beach varies from a wide gently sloping beach in the north to a steep, short beach in the south (Healy et al. 1977). Backing much of the beachfront is a frontal dune, increasing in height from 1 to 9m southwards. Dune blowouts and public access paths dissect the frontal dunes along the entire length. A prominent second set of Holocene age dunes lies 50 to 80m inland of the frontal dunes, partially vegetated and sometimes modified by subdivision development. These sets of Holocene dunes converge in the lee of Bowentown Head and onlap remnants of Pleistocene paleodunes further inland (Figure 3.5). A cap of Rotoehu Ash immediately overlies these relict dunes. Low-lying interdune regions are occupied by swamps and alluvial and estuarine deposits of the Waihi Beach Formation (Selby et al. 1971).

Map 4A

Waihi-Bowentown Embayment





Map 4B

Figure 3.5 At Bowentown, dual barriers enclose the upper part of Tauranga Harbour. The Holocene barrier in the upper right connects Waihi Beach and Bowentown Head, and remnants of a Pleistocene barrier parallel the coastline. View towards the north.

3.2 Supplementary and Additional Sites

Other locations were investigated to further develop stratigraphic and geomorphic analysis of the eastern Coromandel coast. These sites were mainly chosen because of available access routes; supplementary locations include those sites where stratigraphic columns were drawn, while additional sites consisted of field observations. Stratigraphic columns recording details of sedimentary structures, texture and composition of the depositional sequences at each location are given in Appendix 3. Geomorphological features are summarised in Table 3.1.

Waikawau: Pleistocene and Holocene barrier systems occur separated by a low-lying, partly swampy, interbarrier depression (Figure 3.6).
Kennedy Bay: Holocene progradation consists of a barrier spit and a series of dune ridges in the south. The distal portion of the spit is seperated by a small stream, forming an island.
Whangapoua: The sedimentary fill of this embayment includes four dune ridges: the first of these is a well developed frontal dune; followed 40m inland by a vegetated second set, 4m high; the third ridge, still of Holocene age and up to 9m high, lies seaward of a low-lying region containing estuarine deposits and which separates the innermost Pleistocene barrier.
Matarangi: Matarangi beach is situated on the seaward side of Omaro barrier spit which is composed of 15-18 Holocene dune ridges, and encloses Whangapoua Harbour.
Rings Beach: Is a Holocene bay barrier, and consists of a cuspate beach and a dune system showing evidence of ancient blowout and parabolic dunes, now stabilised (Healy et al. 1981).
Kuaotunu: Kuaotunu beach is divided by a headland and reef into two sub-systems. The west system is a bay barrier presently suffering erosion, while Kuaotunu east is a bay barrier consisting of two major dune ridges fronting Pleistocene alluvial terraces and an infilled estuary (Healy et al. 1981).
Opito: Drainage basins carved into the volcanics and now partially infilled by alluvial sediments are blocked by Holocene dunes in the north and Pleistocene dunes near the centre of the bay.

Table 3.1 Geomorphological attributes of supplementary sites.

Embayment name	Pleistocene Barrier	Holocene Barrier	Dunes	Beaches	Flats	Inlets	Headland	Other
Waikawau	remnants	well developed	active, hummocky sand blowouts	steep, mod. berm	marshes, swamps	partially infilled estuary	prominent	
Whangapoua	poorly developed	moderately developed	3 established sets	steep, well developed berm	swamps, estuarine	partially infilled	bounding	
Opito	moderately developed	moderately developed	hummocky high	low, poor berm	alluvial		bounding	
Wharekaho		poorly developed	eroding, low	cuspate	backbarrier alluvial swamps	2 small streams	prominent	extensive Pleistocene terrace
Whitianga		well developed, 2 km wide bay barrier	sand ridge plain	narrow cuspate		large estuary	prominent	
Cooks Beach		well developed bay barrier	sand ridge plain	narrow moderate berm	alluvial backbarrier	small inlet, Purangi estuary	bounding	low lying flats, separate dunes
Hahei		poorly developed	incipient, eroding	shelly veneer over wave-cut platform	alluvial freshwater marsh	infilled, alluvial region	prominent	Pleistocene terrace
Hotwater Beach	remnants	well developed	high blowouts semi-transgressive	good berm, wide	backbarrier, estuarine alluvial	infilled estuary	bounding	
Whiritoa		moderately developed	stabilised, faceted	steep, good berm	coastal marshes, alluvial	small, swampy lagoons	bounding	sand extraction subdivision modified
Mataora		poorly developed	low, active	narrow, shallow		small		low (6m) Pleistocene terrace

Figure 3.6 Waikawau embayment (T10/360080) is typical of the sandy bays common along the eastern Coromandel coast. View looking west.

Wharekaho: Is situated within the greater Mercury Bay, so that it is relatively protected, open only to moderate swell waves (Dell and Healy 1982) and fronted by a curved beach frequently cuspated and dominated by heavy minerals (Figure 3.7).

Whitianga: An extensive beach ridge plain that averages 2m above mean sea level and is near 2km wide consisting of ridges commonly 25m apart and 1m high is contained in Mercury Bay. Buffalo beach fronting the large bay barrier is strongly cusped and narrow and is low energy, resulting from refracted and diffracted swell waves (Smith 1980).

Cooks Beach: Is a headland controlled, semi-enclosed embayment where several hundred metres of Holocene parallel dune ridge progradation extends between two small inlets (Figure 3.8).

Hahei: A Pleistocene terrace forms a backing faceted cliff for much of the beach (Figure 3.9).

Hotwater Beach: The partially vegetated dune complex, including stabilised and active dune blow-outs, has blocked off and encroached upon an infilled estuarine basin consisting of swamp, estuarine and alluvial deposits (Figure 3.10).

Whangamata: Is a complex Holocene barrier dune ridge progradation, enclosing the Otahu estuary and Whangamata Harbour. Wave difraction and refraction around offshore islands has caused the barrier system to develop as a large cuspate foreland (Healy et al. 1981).

Whiritoa: The site of sand extraction activities for the past 40 years contains a sequence of dune sets enclosing a low-lying depression and two small lagoons at either end, between themselves and the forested hills behind.

Mataora: Is blocked by a small barrier, podzolised dunes and a low pleistocene terrace capped by Rotoehu Ash.

3.3 Geomorphic Discussion

Geomorphologically, the embayments of eastern Coromandel have a very similar late Quaternary depositional record. In each, the coastal deposits include freshwater swamps, coastal marshes, dune ridges, estuarine deposits, sand flats and beaches, and are usually terminated at the landward margin by an essentially eroded volcanic

Figure 3.7 Wharekaho embayment (T11/540860) is characterised by two valleys, and a curved beach dominated by heavy minerals and cuspates at its northern end. (Photo: T. Healy).

Figure 3.8 Cooks Beach (T11/560800) consists of a long bay barrier beach fronting close to 1km of parallel dune ridges which converge and are cut by the sand-infilled Purangi estuary in the east (left). View towards the south.

Figure 3.9 The embayed nature of the east Coromandel coastline is evident. Sandy beaches, including Hahei in the foreground, and Cooks and Whitianga beaches further north, are terminated by prominent headlands composed of Minden Rhyolite.

Figure 3.10 View of Hotwater Beach looking north (T11/620750). Volcanic complexes abut the embayment in the north, centre and south. The vegetated Holocene barrier is seen in the centre of the photograph.

landscape. In general, the embayments are small, moderately embayed and less than 5km in length where Holocene and Pleistocene barrier systems extend between rocky headlands. Significant differences in the degree of estuary infilling suggest a series of stages in estuary development (see Chapter 6). The occurrence and relative extent of the morphologic and stratigraphic units in the mapped and supplementary embayments, and additional bays not studied in depth, are shown in Table 3.2. The extent of each unit is assessed on relative areal exposure within each embayment, and not from embayment to embayment.

Table 3.2 Extent of the stratigraphic units in the Eastern Coromandel embayments[1].

Location	Pleistocene Barrier (PB)	Holocene Barrier (HB)	Holocene Sand Flat (HSF)	Fluvial (F)	Estuarine (E)
A. Mapped					
Otama	C	A	A	R	R
Tairua	C	A	A	C	A
Oputere	C	A	R	R	A
Bowentown	C	A	C	R	A
B. Supplementary					
Waikawau	R	A	A	C	R
Whangapoua	R	C	R	X	R
Opito	R	C	R	C	R
Wharekaho	R	C	C	A	R
Whitianga		A	X	X	A
Cooks Beach		C	C	R	A
Hahei		R	C	X	R
Hotwater	R	A	C	C	R
Whiritoa		C	R	X	R
Mataora		R	R	X	R
C. Additional					
Kennedy Bay	X	A	X	X	C
Matarangi	X	A	A	C	A
Rings Beach	X	C	C	X	X
Kuaotuna	X	C	X	C	R
Whangamata	X	A	X	X	A

1. Extent: A - abundant, C - common, R - rare, X - unknown.

CHAPTER FOUR

SEDIMENTOLOGY OF THE LATE QUATERNARY DEPOSITS

In this chapter, three aspects of the sedimentology of the eastern Coromandel units are described. First, sand and clay mineralogy of the deposits has been determined to ascertain if specific eastern Coromandel deposits could be uniquely identified by their mineral assemblage, or if the mineralogical data enabled any interpretative trends in terms of littoral systems, littoral drift directions and sediment provenance. Second, the general chemical composition in terms of the calcium carbonate and organic matter content was analysed, to further characterise the sediments. Third, textural data are reported and the sediments classified into major textural groupings.

4.1 Compositional Studies

Compositional studies are here separated into two main divisions; mineralogical and chemical analyses. Mineralogical investigations concerned detrital mounts and thin-sections of sands (<4ϕ), and X-ray diffraction of clays (>4ϕ). Furthermore, 'heavy mineral' separates and calculated percentages were obtained via the Frantz isodynamic separator. Chemical investigations undertaken were carbonate content by acid digestion, and organic matter percent by loss on ignition. Laboratory methodology is presented in Appendix 1, some results are shown on stratigraphic columns (Appendix 3), and the remainder are available on request.

4.1.1 Sand Mineralogy

Previous mineralogical studies have been generally limited to localised coastal systems (Christopherson 1977, Harray and Healy 1978, Marks and Nelson 1979, Healy 1981, Willoughby 1981) and have shown a dominance of quartz and feldspar, with small amounts of shell fragments, hypersthene, hornblende and magnetite in decreasing order of abundance. On a broader scale, Healy and Dell (1982) examined only the quartz and feldspar contents along the entire eastern coastline by bulk XRD analysis.

4.1.1.1 Light Minerals

Quartz: Quartz phenocrysts appear as hexagonal crystals with highly polished surfaces under reflected light. Straight extinction, single-grained volcanic quartz is the dominant variety. Minor amounts of slightly undulose single-grained quartz and traces of fine polycrystalline quartz with sutured contacts are also present. The quartz grains commonly are sub-rounded to angular, anhedral to euhedral crystals. Large rounded corrosion embayments are not uncommon. Red-brown goethite rims occasionally coat grain surfaces. Clear crystals with no inclusions are ubiquitous, and only rare microlites are seen.

Feldspar: Subrounded, subhedral feldspar is common within the eastern Coromandel sediments. Crystals range from large tabular grains (up to 1.0mm long) to small rounded and corroded grains with both smooth and irregular edges. The feldspar exhibits polysynthetic twinning (plagioclase), and Carlsbad twinning (sanidine) in minor (10%) proportions. Plagioclase feldspar compositions, determined using the Michel-Levy method of maximum extinction angles (Cox et al. 1974), range from An_0 to An_{44}, incorporating albite to andesine compositions. Alteration of feldspars includes common surface fractures, minor limonite staining and rare vacuolisation where fluid-filled vacuoles have a whitish appearance under reflected light (Blatt 1982).

4.1.1.2 Heavy Minerals

Opaques: The opaque minerals occur in minor proportions, commonly from 3-5%. The grains are consistently small, averaging a 0.1mm maximum axis. They occur as euhedral to anhedral crystals, well rounded to angular grains with irregular to straight edges. Dissolution cavities or embayments are common with occasional red discolouration. The magnetic proportion (<25% of total heavy minerals) consists of magnetite and titanomagnetite grains.

Hornblende: Hornblende occurs in proportions from 2-5%, as a pale green to dark green pleochroic variety and a pleochroic green to brown type. The crystals are usually prismatic subhedral to euhedral, and commonly about 0.5mm long. Irregular outlines show well developed hacksaw terminations, dissolution pits or embayments and abraded chips. Brown alteration rims are well developed on several grains.

Hypersthene: Pale green to pale pink pleochroic lozenge-shaped hypersthene crystals occur (commonly 2-5%) in the sands of eastern Coromandel. The prismatic phenocrysts, up to 0.8mm maximum axis, commonly contain opaque euhedral phenocryst inclusions, suggested by Hogg (1979) to be magnetite. Irregular crystal edges (Figure 4.1) or cockscomb terminations (Birkeland 1984) can be well developed.

The development of etched hypersthene grains was further investigated in this study in an attempt to differentiate the ages of the barrier units. Because mineral weathering is time-dependent, the examination of individual mineral grains for signs of weathering may enable rough age estimates. For example, Birkeland (1984) described variations of hypersthene grains in the Sierra Nevada tills based on age (Figure 4.2). Fresh hypersthene grains are supplied from the erosion of the surrounding Tertiary volcanics (see section 4.1.1.4). Obviously, caution is needed in this investigation where reworking of grains between differently aged coastal deposits is potentially significant, so that some material eroded from the Pleistocene deposits may occur in the younger deposits of the Holocene Barrier.

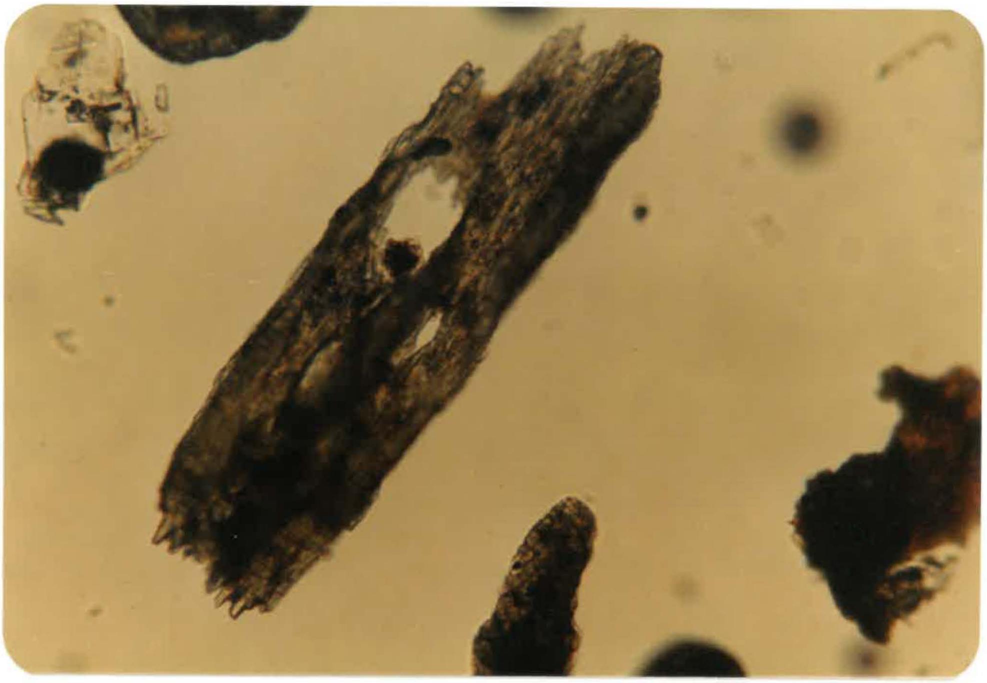


Figure 4.1 Prismatic hypersthene phenocryst containing magnetite inclusions and exhibiting cockscomb terminations (magnification 63x).

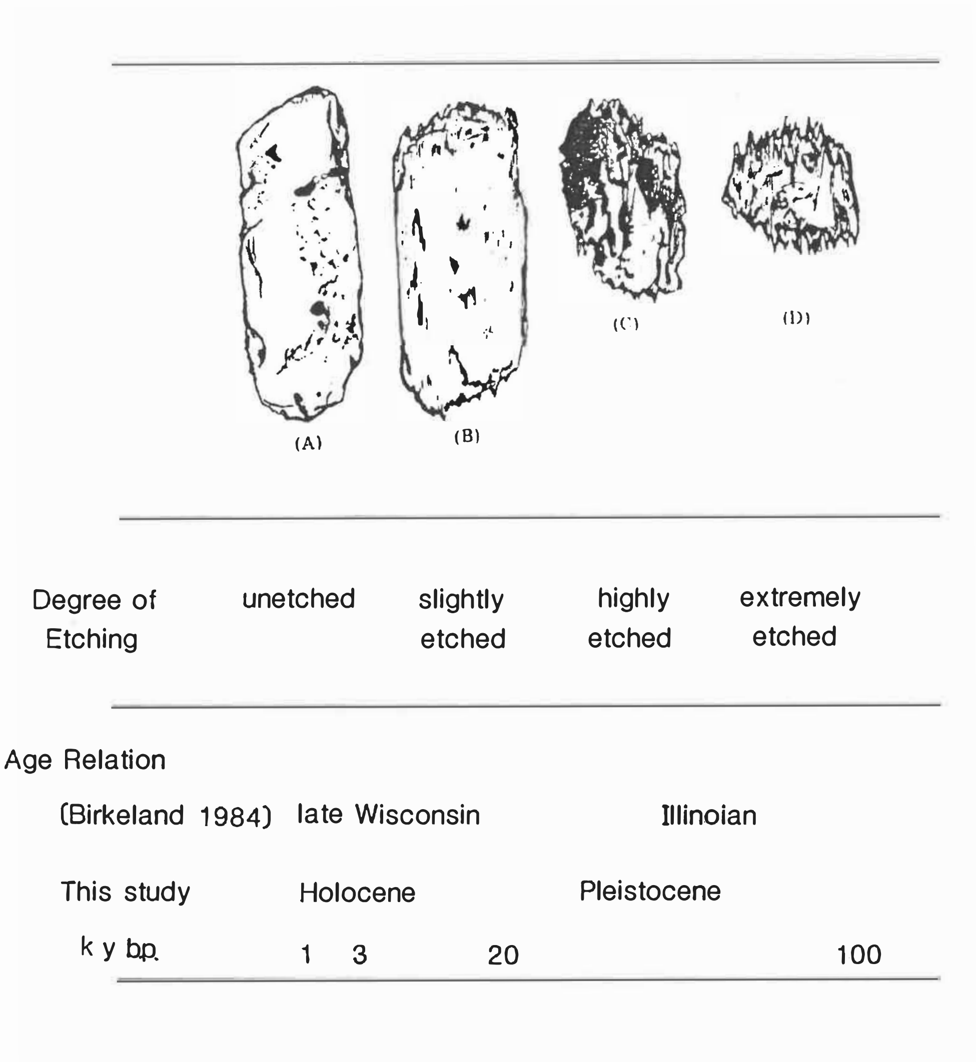


Figure 4.2 Summary diagram showing classification scheme of etched hypersthene grains and estimated ages (modified from Birkeland 1984).

One hundred hypersthene grains from samples of the barrier units were classified according to the scheme outlined in Figure 4.2. Results are summarized in Table 4.1. A greater abundance of moderate to highly etched hypersthene grains is characteristic of the Pleistocene Barrier Unit samples, while slightly etched to unetched grains characterise the Holocene Barrier Unit. The greater development of etched hypersthene in the older barrier unit samples reflects a Pleistocene age whereas the fairly unweathered grains of the younger barrier unit range through the Holocene time scale. Although potentially erroneous age reconstructions may arise from redeposited sediment, the broad relationships between degree of grain etching and age of deposit occurring in this study parallel those observed by Birkeland (1984).

Augite: Subhedral irregular prismatic crystals of augite are recognised in accessory proportions (<2%). The pale brown sub-rounded phenocrysts can be up to 1mm in length. Grain modification includes irregular etched edges, fractured surfaces and brown rim alteration.

A study of heavy mineral abundances in the Pleistocene Barrier, Holocene Barrier, Holocene Sand Flat and Estuarine Units from four embayments was undertaken (Figure 4.3), to investigate percentage trends across the units and across the embayments. Studies by Sherwood (1973), Richmond (1977), and Willett (1982) showed no significant trends of percentages between depositional environments. Alternatively, consistent trends have been reported by several investigators (Bradley 1957, Reid 1978). For example, Reid (1978) found that estuarine harbour samples from Mangatawhiri Spit, contained a higher percentage of heavy minerals than dune samples, and that beach samples contained the lowest values.

Highest concentrations of heavy minerals were recorded at Wharekaho, whose beach is usually dominated by heavy mineral concentrates. Similar concentrations occurred between particular units within each embayment. Pleistocene and Holocene eolian units contain comparable abundances, as do the sand flats and tidal flats.

Table 4.1 Hypersthene etching results.

Sample	Unit	Etching[1]			
		UE	SE	ME	HE
OG1	HB-4	93	7	0	0
OE1	HB-4	80	18	2	0
OE4	HB-4	75	22	3	0
OE3	HB-4	83	17	0	0
WGB1	HB-3	69	22	9	0
OF1	HB-3	58	37	5	0
OPA1	HB-2	56	41	3	0
BB2	HB-2	61	32	7	0
CA2	HB-1	17	75	8	0
OP7	HB-1	11	47	42	0
OD2	PB	17	50	10	23
OI1	PB	6	44	26	24
HW2	PB	16	58	11	9
CC2	PB	6	47	28	19
OI1	PB	0	24	49	27
OD3	PB	22	49	24	5

1. Degree of etching: UE - unetched
SE - slightly etched
ME - moderately etched
HE - highly etched

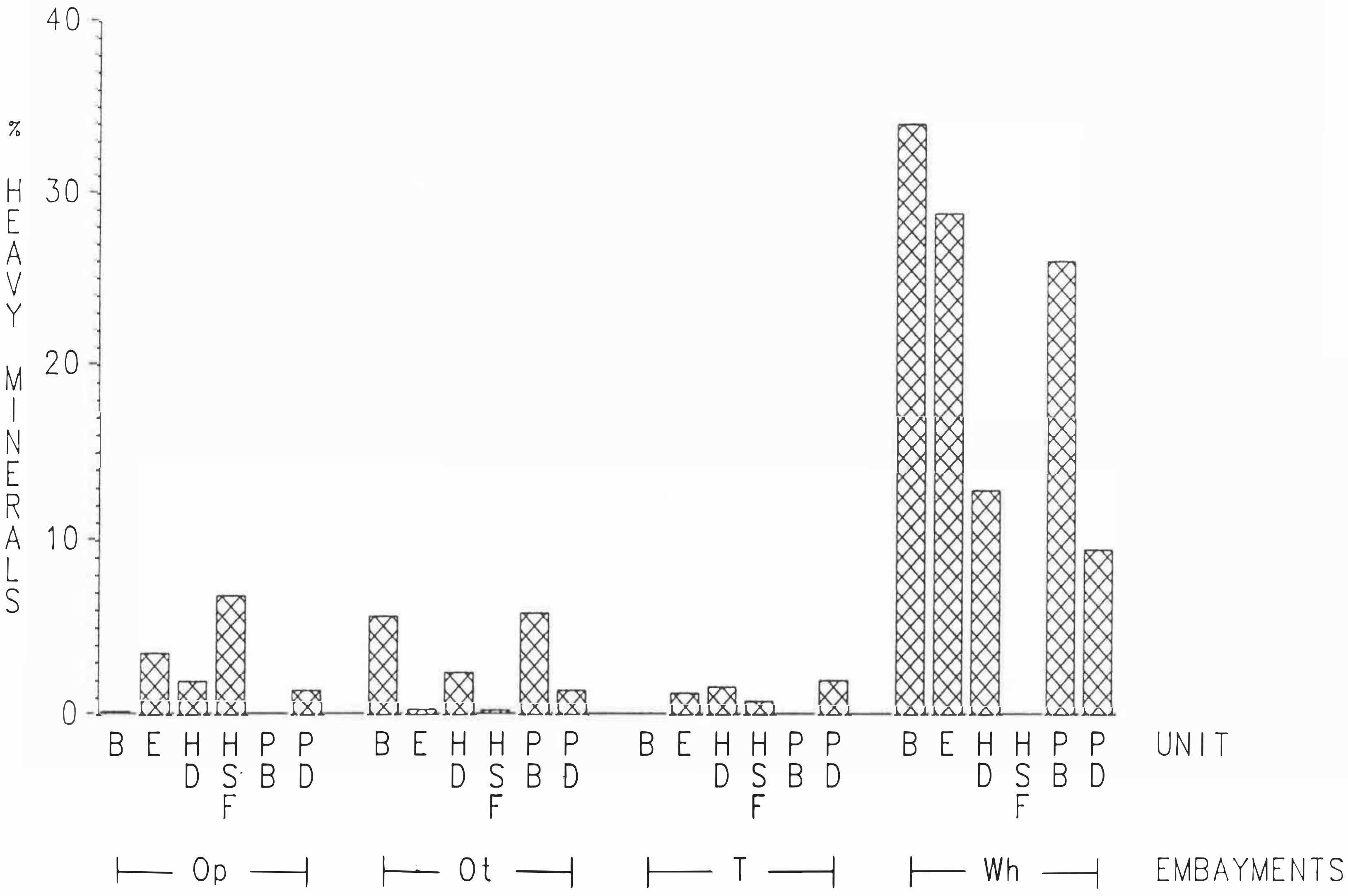


Figure 4.3 Heavy mineral percentages of total sediment for embayments along eastern Coromandel; Opoutere (Op), Otama (Ot), Tairua (T), Wharekaho (Wh). Abundances are shown for specific deposits; modern beach (B), estuarine unit (E), Holocene dunes (HD), Holocene sand flat unit (HSF), paleo-beaches (PB), Pleistocene dunes (PB).

In this study, beach deposits preserved in the late Quaternary depositional record were uncommon, but where heavy mineral contents were analysed, reasonable correlation was obtained between them and current modern beaches of the region. Unlike Reid (1978) at Mangatawhiri Spit, no consistent trend in abundance of heavy minerals percentages occurs between dune, beach or harbour environments in a general sense.

4.1.1.3 Accessory Minerals

Lithic Fragments: Red-brown rounded to sub-angular rock fragments are common in all units and include andesitic and rhyolitic volcanic fragments. The andesitic fragments consist predominantly of large feldspar and straight to slight undulose quartz crystals set in a groundmass of felsitic crystals. The quartz and feldspar and minor hornblende phenocrysts are normally euhedral and can be up to 0.3mm size. The groundmass is commonly fine-grained feldspar and quartz containing lesser amounts of opaques and hornblende and often forms a trachytic texture. The acid volcanic fragments are generally buff-coloured and consist mainly of devitrified glass. Textures may be vitrophyric, spherulitic and trachytic. Phenocrysts are not common and consist mainly of quartz and feldspar. The rock fragments are up to 4mm in size, show well developed clay cutans and brown alteration rims.

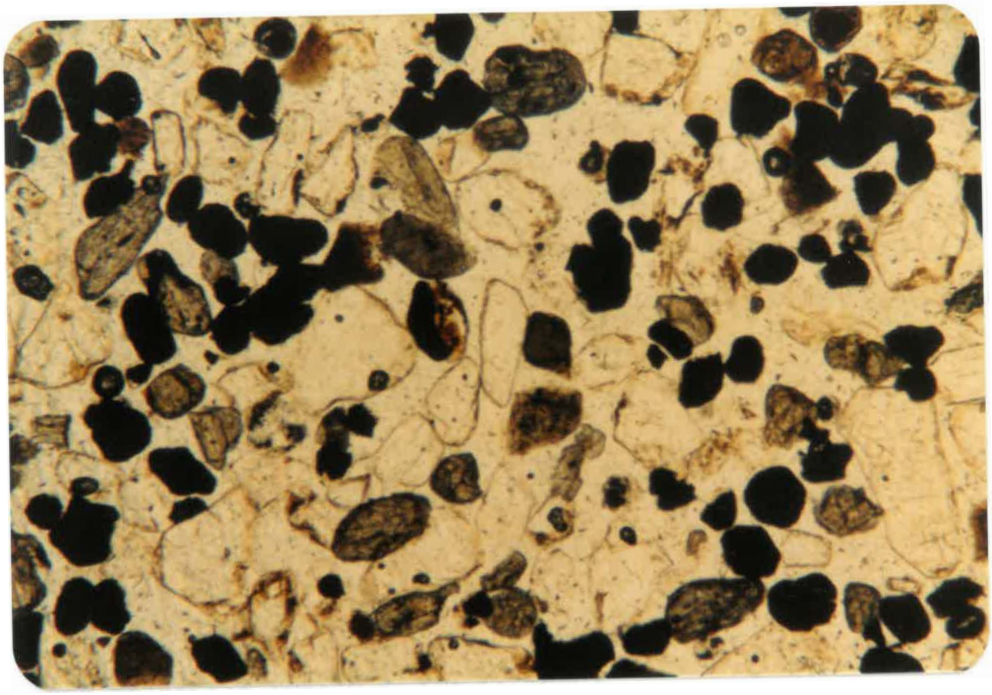
Volcanic glass occurs as fresh and altered fragments. Unaltered particles appear isotropic and have shard-like forms. The altered glass maintains the curved shard forms, but exhibits a recrystallised fine-grained mosaic of feldspar and microcrystalline quartz. Brown material, probably clays, is closely associated with the volcanic glass.

Shell Fragments: Shell fragments appear as yellow-brown rounded to angular fragments. Prismatic shell growth patterns may be evident sometimes interrupted by dissolution embayments or borings.

Trace Minerals: Brown pleochroic biotite flakes with irregular wispy outlines occur in trace (<1%) proportions in southeastern Coromandel dune sediments, particularly in a buried horizon at the Holocene dunes at Whiritoa. Traces (<1%) of aegirine and riebeckite minerals were contained in modern beach samples. Aegirine occurs as apple-green angular prismatic crystals, while blue riebeckite crystals have an acicular habit. A third trace mineral cummingtonite, usually occurs as euhedral, elongated prismatic crystals, often twinned and commonly with euhedral magnetite and occasionally hypersthene inclusions (Hogg 1979). It has a cloudy green colouration and very weak pleochroism from pale orange green to pale green.

4.1.1.4 Discussion

Mineralogically, the coastal sands along eastern Coromandel Peninsula are broadly similar composed chiefly of quartz, plagioclase feldspar, heavy minerals, rock and shell fragments, yet two main sediment suites are recognised (Figure 4.4). The first suite occupies the beach/dune coastal zone and is dominated by (25-45%) quartz and (30-45%) feldspar and minor amounts (<10% total) of heavy minerals mainly hypersthene, hornblende and opaques, rock and shell fragments (Figure 4.4). Located within estuarine basins and associated depositional environments are the second type of sands composed predominantly (>40%) of feldspar, and significant proportions of volcanic glass (10%), heavy minerals (~10%), locally derived shell fragments (5-10%), eroded rock fragments and minor (<15%) quartz (Figure 4.4). A similar sediment distribution trend was observed in the New South Wales coastal zone by Roy et al. (1980), who referred to them as 'marine' and 'fluvial' sediment provenances. These names are adopted in this study. Marine sediments are generally mature sands, and occur as a result of marine and eolian reworking in the coastal zone. Fluvial sediments are angular gravels, sands and muds transported by rivers from the hinterland and trapped within estuarine sinks.



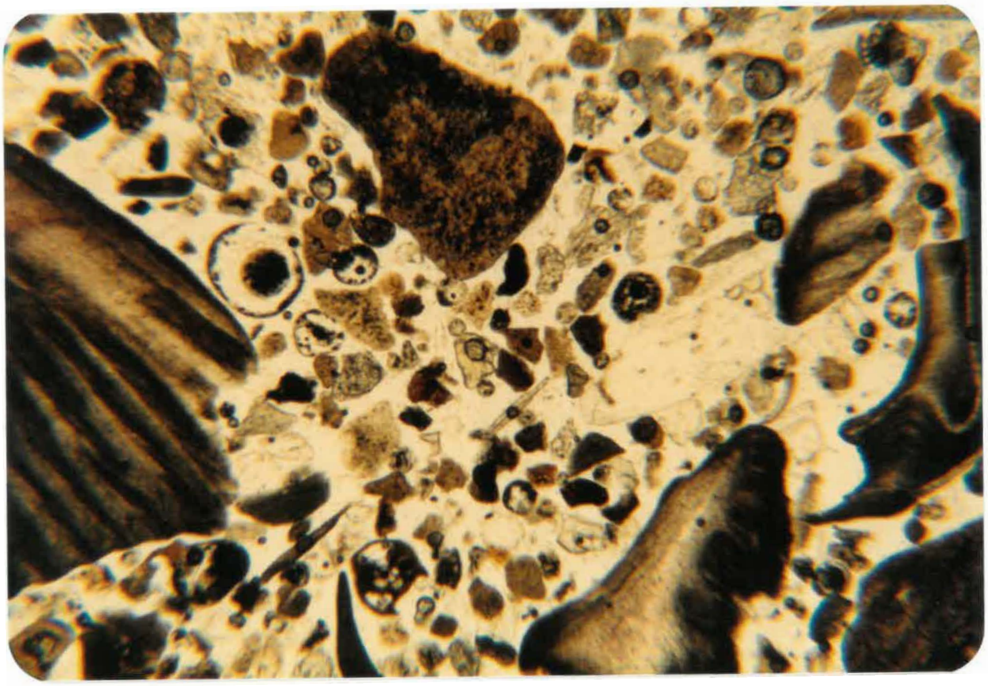


Figure 4.4 Two mineral suites: A marine' sands, rounded quartzofeldspathic-rich and significant proportions of hypersthene, hornblende and opaques, B 'fluvial' sediments are characterised by increased amounts of shell fragments, rock fragments, volcanic glass and smaller amounts of quartz (magnification 16x). Plane polarised light.

In general, the contents of quartz, feldspar and rock fragments in marine sediments fluctuate between localities along the coast (Figure 4.5), suggesting a series of individual or isolated beach systems, not nourished by a regional littoral drift. Healy and Dell (1982) reached the same conclusion from bulk XRD data carried out on dune, berm and offshore sands of the eastern Coromandel embayments, although emphasising bulk XRD mineralogical analyses should be used as a first approximation only. Widely fluctuating quartz and feldspar percents were recorded from embayment to embayment and from dune to beach to offshore samples within individual embayments. Few consistent interpretative trends concerning littoral drift of sediment could be determined, although quartz-rich beaches (e.g. Opoutere) had large hinterland catchments draining Minden Rhyolites, and feldspar-dominated sands (e.g. Whangamata) had catchments draining Beesons Island Volcanics (Healy and Dell 1982).

The most important control on sediment mineralogy is the source rock mineralogy. In this study the mineral suites suggest mainly volcanic source rocks. Quartz occurs in proportions up to 45% and is predominantly volcanic, as shown by the shape, water-clear appearance and normal extinction of single quatz crystals. Feldspar forms 30-55% of the sediments, plagioclase being the most common variety with small amounts of sanidine. Volcanic source rocks are indicated by an abundance of plagioclase, rather than K-feldspar, and small quantities of sanidine (Folk 1968). Similarly, volcanic source rocks are suggested, based on heavy mineral types. Hornblende and pyroxenes are moderately unstable minerals and an abundance of them as for the eastern Coromandel sediments, suggests volcanic source rocks (Folk 1968). For the eastern Coromandel sands, three sources of sediment are suggested: adjacent Coromandel catchment volcanic rocks; volcanic sediment derived from the Central Volcanic region; and tephras covering much of the hinterland.

The major source of sand is erosion of the Tertiary volcanic hinterland by stream erosion, coastal cliff erosion and possibly onshore creep of shelf sand (Christopherson 1977, Marks and Nelson

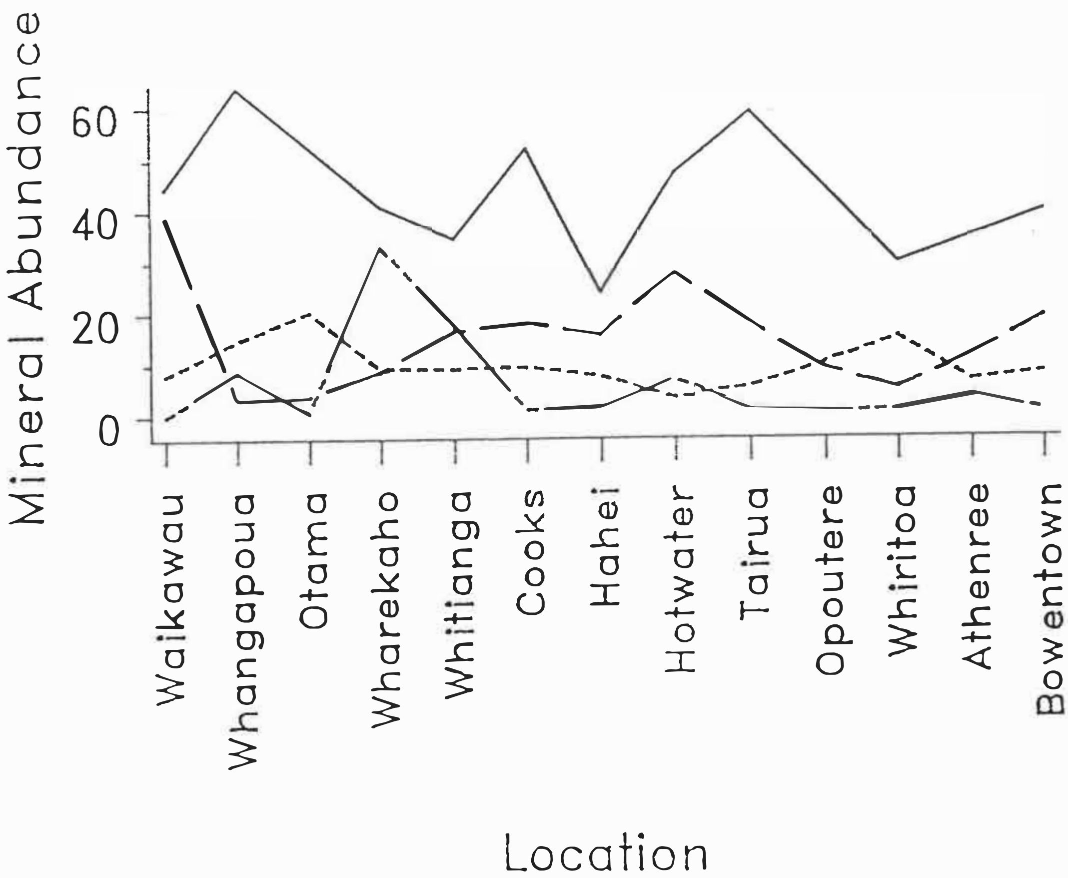


Figure 4.5 Varying mineral abundance (%) in beach samples along the east Coromandel coast.

Quartz ——— Feldspar - - - - - -

Opaques —··— Rock Fragments — — —

1979, Healy 1981, Willoughby 1981). Whitianga Group and Coromandel Group Volcanics are generally classed as hypersthene-hornblende rhyolites and pyroxene-hornblende andesites respectively (Skinner 1986). Whitianga Group rocks consists of corroded plagioclase, rounded quartz, euhedral magnetite phenocrysts, minor phenocrysts of hypersthene and hornblende, and trace biotite and sanidine (Hayward 1974). No potash feldspar or clinopyroxene is present. Coromandel Group rocks in thin section have phenocrysts of abundant plagioclase, hypersthene and augite, and minor opaques and quartz (Hayward 1974). Mineral suites of the volcanics and of several beaches from this and other studies are compared in Table 4.2. It is evident that the mineral assemblage of most of the east Coromandel sands with the exception of Waihi Beach points to these Tertiary volcanics as being the major source rocks of the sediments. Harray and Healy (1978) found the Waihi Beach mineral assemblage to be consistent with an ultimate origin from the erosion of the Quaternary pyroclastics of the Taupo Volcanic Zone. Waihi beach forms the northernmost section of the long, sandy littoral system of the Bay of Plenty which has a present net littoral drift south eastwards. Harray and Healy (1978) suggest that TVZ-derived sediment deposited during glacial times at lower sea levels, would have moved onshore normal to the shelf under a rising sea level and into the Waihi nearshore system.

Although the mineral types between the volcanic source rocks and coastal sediments correlate closely, abundances or importance of minerals differs. The increased importance of quartz and lesser contributions from feldspar and heavy minerals in the coastal sands is accounted for by mineral stability. Quartz is one of the most durable or resistant grains, capable of retention within a beach system, while most other grains are more susceptible to abrasion and size reduction in the surf zone. Thus allowing for mineral abrasion and weathering, it seems reasonable that the Tertiary volcanics are the major source rock for the sediment, whether by stream erosion, coastal cliff erosion or movement onshore of shelf sands during the post-glacial marine transgression.

Table 4.2 Mineral abundance of selected beach sediments and potential sources.[1]

Location/ Rock Type	Mataora Beach (Christopherson 1977)	Whiritoa Beach (Willoughby 1981)	Whangamata Beach (Christopherson 1977)	Opoutere Beach (This Study)	Otama Beach (This Study)	Waihi Beach (Harray & Healy 1978)	Whitianga Group Rocks (Hayward	Coromandel Group Volcanics 1974)
Quartz	-	25-40	-	66	65	19	0.4-5	-
Plagioclase	-	15-40	-	16	20	50	3-12	-
Hypersthene	54	37-47	25-38	47	37	44-66	20-70	43-82
Hornblende	5-16	20-35	25-50	28	25	21-43	20-33	0-12
Magnetite (plus opaques)	2-5	15-35	8-30	17	18	1-11	26-80	5-10
Cummingtonite	<1	2-3	3-11	1	2	4-14	rare	8-43
Augite	4	<1	21	3	6	0	-	-

1. Quartz and plagioclase expressed as a percentage of the total sediment. Hypersthene, hornblende, magnetite, cummingtonite, augite expressed as a percentage of total heavy minerals.

Secondary contributions of sediment were probably also derived from the Central Volcanic Region. For example, Schofield (1970) reports a distinct coastal-inner shelf sand facies around northern Coromandel Peninsula, underlying the mud deposits within the Hauraki Gulf and partially up the Northland east coast. It contains pumice and rhyolitic rock fragments and was almost certainly deposited when the Waikato River flowed into the Hauraki Gulf, through the Hinuera Gap during the last glacial (Schofield 1970). A large supply of sand was deposited at the river mouth, at a time when there was extensive volcanic activity in its catchment. The volcanic detritus was probably forced shoreward by currents and waves during the subsequent sea level rise to form widespread coastal deposits from Whangarei Heads, east Northland to Matarangi Spit, east Coromandel (Schofield 1970). The higher content of volcanic rock fragments (upto 20%) in coastal deposits at Waikawau, northern east Coromandel may possibly indicate this additional source.

An additional indirect Central Volcanic Region source comes from the mantle of tephras on the Coromandel hinterland and coastal deposits. The Quaternary tephras (Hogg 1979) decrease in total thickness northwards, from as much as 2m near Bowentown and to about 0.2m at Waikawau Bay. Denudation of the rugged landscape would allow these moderately friable layers to contribute to the sediment load of the many tributary streams and thence to the coastal sediment budget. Constituent heavy minerals of the late Quaternary tephras erupted from the Central Volcanic Region are presented in Table 4.3. In this study trace proportions of several marker minerals were identified, delineating specific tephra units, along with ubiquitous hypersthene and hornblende crystals, common ferromagnesian minerals of the late Quaternary tephras (Hogg and McCraw 1983). Biotite is a useful marker mineral of the Kaharoa Ash (Pullar et al. 1977, Howarth et al. 1980), a constituent ash of the late Quaternary tephra sequence south of Tairua (Hogg and McCraw 1983). Both aegirine and riebeckite crystals are derived from the Tuhua Tephra. Aegirine confined to the Tuhua Tephra is derived from Mayor Island (Hogg and McCraw 1983). Another useful marker mineral occurring in trace proportions is cummingtonite

Table 4.3 Ferromagnesian mineral assemblages of the Coromandel late Quaternary tephra sequence (2-4ϕ) (modified from Hogg and McCraw 1983).

Tephra	Field Class (Hogg 1979)	Hypersthene (%)	Cummingtonite (%)	Hornblende (%)	Augite (%)	Aegerine (%)	Additional Ferromagnesian Minerals
Kaharoa Ash Taupo Pumice Tuhua Tephra	4	23-49	14-32	8-34	0-24	7-36	cossyrite, riebeckite, olivine, oxyhornblende
Rotorua Subgroup tephras	3	32-47	25-52	8-24	2-8	-	-
Hauparu and Rotoehu Ash	2	21-33	50-72	4-16	0-2	-	vermiculite
Rotoehu Ash	1	7-14	81-91	1-7	-	-	-

(derived from the Whakatane Ash, Rotoma Ash and Rotoehu Ash, Hogg and McCraw 1983). Rotoehu Ash is dominated by cummingtonite, which makes up 30-70% of the total heavy mineral suite. Thus very small proportions, taking into account mineral breakdown, would be anticipated in the eastern Coromandel sands younger than 50 ky BP (post-Rotoehu Ash deposition). Quantitatively, only small amounts of sediment can be attributed to the mantling tephras, as suggested by Kohn and Glasby (1978) for the Bay of Plenty, which has experienced thicker sequences of Quaternary ashes.

Hence, the unconsolidated sands which comprise the late Quaternary sedimentary units of the eastern Coromandel embayments are separable into two main sediment provenances; Marine and Fluvial sand. Ultimately the sediment is derived predominantly from stream and coastal cliff erosion of surrounding Whitianga and Coromandel Group Volcanics. Marine sands reflect mature sediments which have undergone reworking on the continental shelf. Fluvial sediments are typically immature, poorly sorted gravels, sands and muds transported from the hinterland by rivers and normally trapped in estuaries. Further sources may include sediment derived from the Central Volcanic Region deposited in the Hauraki Gulf region by the Waikato River, and finally direct contributions from airfall tephras erupted mainly from the Central Volcanic Region. Tentative conclusions are drawn from this, which support previous research views (Christopherson 1977, Willoughby 1981, Healy and Dell 1982) concerning littoral systems along the coastline, namely that since the modern hydrodynamic regime has been established, a series of disparate beach systems has existed which are not nourished by a coast-long littoral drift system, but undoubtedly support localised embayment littoral systems.

4.1.2 Clay Mineralogy

Studies of clay mineralogy ($>4\phi$) were undertaken to aid the description and interpretation of coastal sequences, and to determine and confirm relative age sequences. The above intentions arose because the clay species present are normally controlled by three factors: (a) primary composition of parent material plays an initial role in the type of clays produced; (b) environmental controls have an important role in determining the clay mineral types and as such may hint at paleoenvironmental conditions of older sequences; and (c) clay minerals may change with time and thus enable some interpretation of the ages of deposits.

Forty representative samples of the Pleistocene and Holocene Barrier, and Holocene Sand Flat Units were selected for X-ray diffraction analysis (XRD). Relative abundance of the clay fraction for these units ranges up to 20%, but more commonly is less than 10% of the total sediment. Initially, samples representing modern depositional environments were excluded, as were samples containing carbonate material which produced positive results in the Fieldes and Perrott (1966) allophane test. Of the samples subjected to the allophane test, 95% were positive. Appendix 1 gives sample preparation and XRD procedures.

Occurrence and Nature of Clay Mineral Species: The dominant components in the clay fraction of eastern Coromandel deposits are halloysite, allophane, and iron oxides. Examples of diffractograms (Figure 4.6) display poorly defined peaks and high background counts. The traces can be divided into two groups, one essentially X-ray amorphous, dominated by allophane, typical of the Holocene Barrier and Holocene Sand Flat samples and some Pleistocene Barrier samples (75% of all samples analysed), and the other dominated by a conspicuous halloysite peak at about 10Å, moderately to sharply defined. Halloysite occurs only in Pleistocene Barrier samples. Several patterns exhibit poorly defined maxima from between 5Å and 8Å, probably representing short range order iron oxide materials (C.S. Nelson, pers. comm.), which agrees well with the red, iron-stained nature of associated bulk samples.

Halloysite is a kaolinite subgroup 1:1 layer silicate mineral, occurring in two phases (Lowe and Nelson 1983), 10Å hydrated halloysite and 7Å dehydrated halloysite or metahalloysite. Allophane

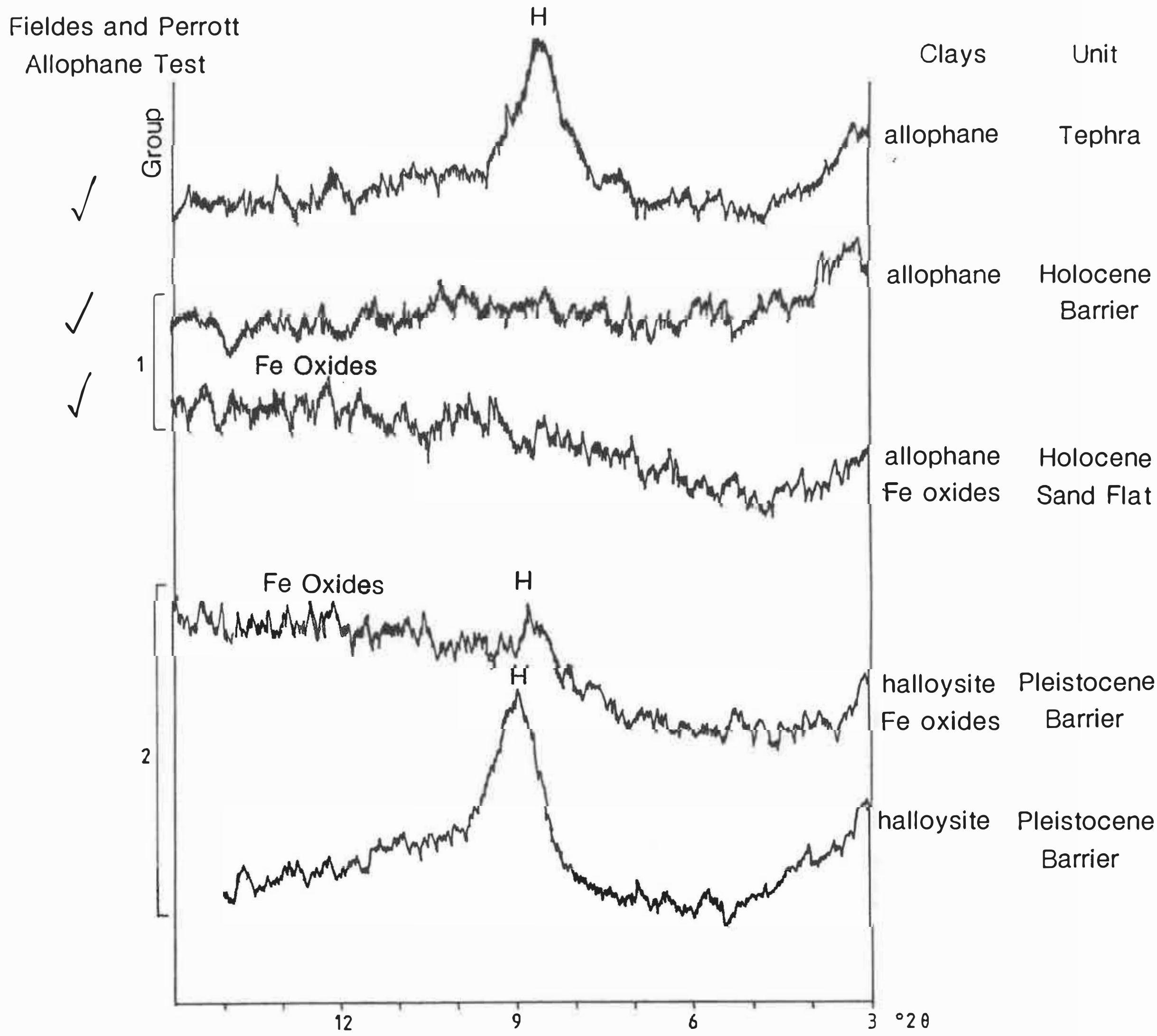


Figure 4.6 Representative x-ray diffractograms for samples from selected stratigraphic units. ✓ positive for allophane test.

is a series of naturally occurring hydrated aluminosilicate clays characterised by short range order and the predominance of Si-O-Al bonds (Lowe and Nelson 1983). Allophane consists of irregular aggregates constructed of hollow, spherically shaped particles and it is essentially X-ray amorphous (Lowe and Nelson 1983). This non-crystalline character is derived from the local, non-repetitive nature of the structural unit (Wada 1979).

The deposits of this study are variably podzolised quartzo-feldspathic sands which are generally overlain by silicic tephras and associated paleosols. The clay minerals are therefore derived from two main sources; the weathering of overlying tephra deposits, and the weathering of sand minerals. Other clay mineralogical studies (e.g. Anderson et al. 1982) with parent material compositions comparable to this study are characterised by the occurrence of allophane. Tephra-derived clay minerals typically have an occurrence of short range order or amorphous clay minerals, in addition to well ordered species (Lowe and Nelson 1983), as well amorphous minerals have been identified in podzols derived from non-tephric and non-vitric materials (Young et al. 1980, Farmer 1982).

Genesis of Clay Minerals: Clay mineral transformations with time have been described in terms of weathering sequences. A widely adopted sequence (Kirkman 1975, Kirkman and Pullar 1978) for rhyolitic tephras is:

glass and feldspar	⟶	allophane (+ imogolite)	⟶	halloysite ± minor silica

Short range order minerals such as allophane were previously thought of as simply short-lived transition products. More recently they have been considered as reaction end points that persist, given favourable conditions, for long periods of time in coexistence with halloysite (Lowe 1986). Conversely, halloysite, previously regarded as a reaction end point, is now thought to form rapidly and directly by precipitation of dissolution products of either primary or secondary minerals, or both (Lowe 1986). Therefore, rather than clay transformations being a direct function of time, other factors such as environmental conditions determine the rates of clay transitions.

The occurrence of clay minerals is also determined by both primary mineral composition and site weathering conditions, past and present (Birrell et al. 1977). However, although the primary composition of parent materials plays an initial role in the types of clays produced by weathering (see Lowe 1986), foremost are the environmental controls operating (Lowe and Nelson 1983, Lowe 1986). Critical environmental contributors to the clay product composition include rainfall, the leaching regime and the organic cycle. Allophane and halloysite tend to occur where rainfall and subsequent silica loss is low (Lowe and Gibbs 1981, Parfitt et al. 1983). The loss of Si and other cations is also minimized in an impeded drainage situation, and similarly favours the formation of halloysite and allophane (Al:Si=1.0) (Lowe 1981, Parfitt et al. 1984). Conversely, good drainage or high rainfall promotes the loss of silica and formation of Al-rich allophane (Al:Si=2.0) (Parfitt et al. 1984, Stevens and Vucetich 1985). Therefore, it is suggested that the concentration of silica in solution appears to be a decisive factor governing allophane and halloysite formation (Parfitt et al. 1983).

Implications: The predominance of allophane across the sandy units (Figure 4.7) probably results from freely draining sands and a high level of silica leaching. Halloysite occurs in several samples of the older Pleistocene Barrier deposits, either in impeded drainage conditions or at increased depths (>4m) in subsurface cores. Both these situations can account for low silica losses, a factor that fosters halloysite formation. Typically, allophane is absent from organic-rich sandy deposits or horizons, explanable through the formation of stable Al-humus complexes which tie up available Al ions (Lowe 1986). Tephra samples are characterised by an expected coexistence of allophane and halloysite clays. Red, iron-stained bulk samples have background noise on their x-ray traces attributed to iron oxides.

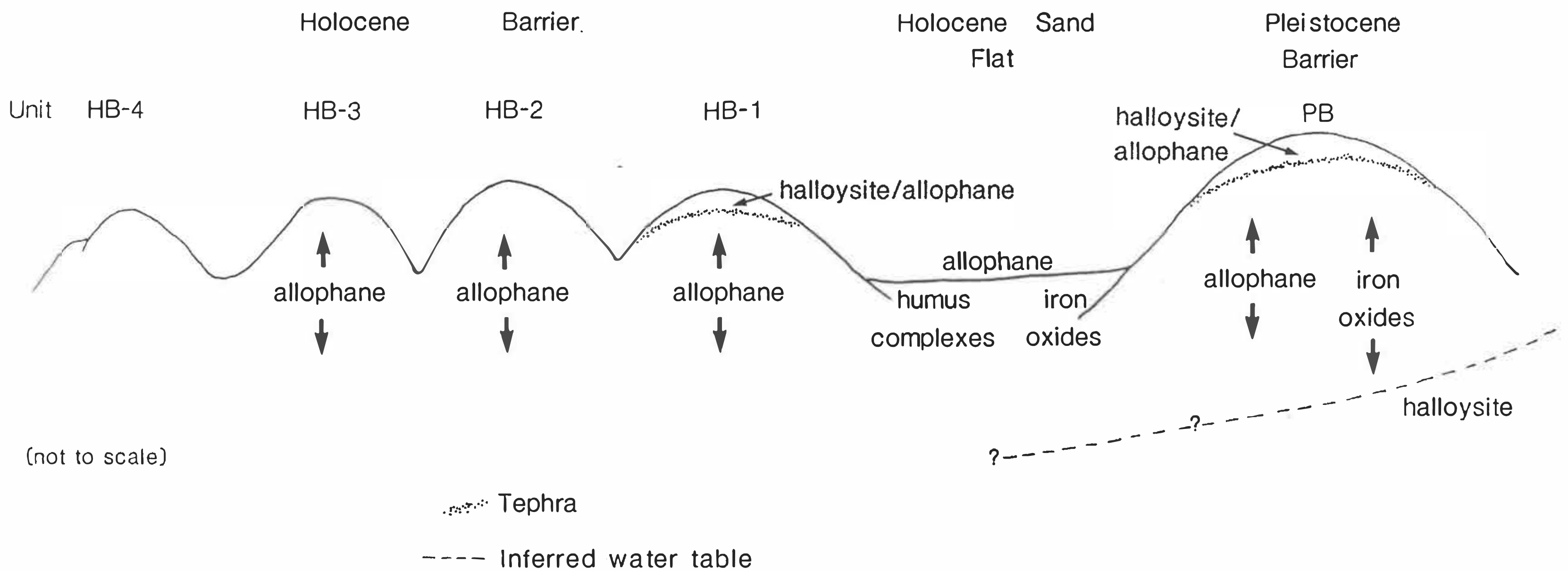


Figure 4.7 Schematic diagram showing clay mineral types across some stratigraphic units and with depth.

Clearly evidence for a clay weathering sequence across the Holocene and Pleistocene barriers of the eastern Coromandel coast is limited, although the presence of halloysite in the older deposits may at first suggest one exists. However, the occurrence of halloysite is more likely a function of site weathering conditions than the age of the deposits.

4.1.3 Chemical Composition

Aspects of chemical composition investigated included organic matter content and carbonate content. The coastal deposits generally contained small amounts of organic matter, typically less than 5% in the Pleistocene and Holocene Barrier Units, up to 15% in some Estuarine Unit and Holocene Sand Flat Unit samples, and an average of 40% in swamp deposits of the Fluvial Unit. Soil horizons and paleosols were identified in stratigraphic profiles by an increase in organic matter (see Appendix 3). Calcium carbonate percentages were analysed to further characterise stratigraphic units, and in addition the degree of carbonate leaching of eastern Coromandel dunes were examined. Weathering effects such as carbonate leaching can alter and modify the mineralogy and composition of sands to varying depths, and with time the depth of 'affected' sand down a profile should increase. Hence, understanding and recognising different weathering stages assists in confirming relative age sequences (Thompson 1981).

The carbonate content of 80 samples was determined by acid digestion. The content ranges from 0% to 30% (Figure 4.8). Overall, the units show an average less than 5% $CaCO_3$ content with only samples from modern tidal flats and beaches having a greater abundance of shell material.

Sand dunes of a coastal system invariably receive a contribution of biogenic carbonate from an adjacent beach source. Normally this carbonate content is only small, much less than 10% (Bird 1971, Thompson and Bowman 1984), and in the form of fine shell fragments. The colonisation of these sand dunes by vegetation provides litter for

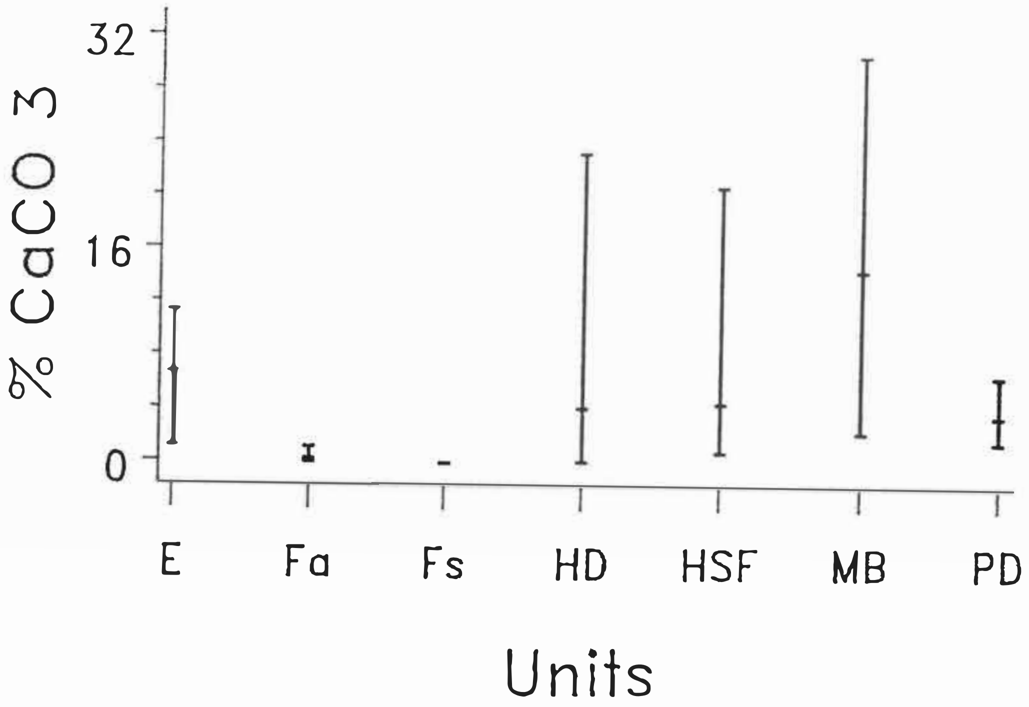


Figure 4.8 Percent calcium carbonate (mean and range) of stratigraphic unit and deposits; Estuarine unit (E), Fluvial unit (alluvial deposits) (Fa), Fluvial unit (swamps) (Fs), Holocene dunes (HD), Holocene Sand Flat unit (HSF), modern beach (MB), Pleistocene dunes (PD).

decay forming organic acids that may leach the shell fragments (Thompson and Bowman 1984). Studies of leaching rates of shell carbonate have estimated that up to 75% of the initial shell content in the surficial 10cm of deposit may be lost in 300 years (Olson 1958, in Bowman 1979), while 1000-1500 years are needed to remove the carbonate to a depth of two metres (Bowman 1979).

Degrees of carbonate leaching were examined in eastern Coromandel dunes (Figure 4.9). The leaching profiles concur with the above mentioned studies, assuming the original shell content was similar to that in the modern dunes of the same embayment. Organic acids leach through the dune decreasing the carbonate content from the surface downward, in effect causing an increase in the carbonate content with depth. Dunes of the Holocene Barrier subunit (HB-3), estimated roughly at 900-600 years old (by radiocarbon dates and possibly Loisels? Pumice) have lost more than 75% initial carbonate content within the upper 2m. The younger HB-4 dunes (<500 y) have experienced a considerable loss of carbonate over the top 30cm, although the increased content of carbonate at the dune surface probably indicates a spurious input of fresh shell carbonate because of the proximity (~20m) to the shoreline and the limited vegetation cover across the unit. Compared with Olson's (1958) research, these data suggest that the dunes of HB-4 could be up to 300 years old, and with caution, relative ages of coastal dunes may be determined through the examination of calcium carbonate profiles.

4.2 Textural Studies

Textural studies have been carried out by several workers on the nearshore beach-dune deposits of eastern Coromandel (Schofield 1970, Marks 1975, Christopherson 1977, Healy 1981, Healy et al. 1981, Willoughby 1981, Healy and Dell 1982, 1987). Further textural analyses were undertaken in this study for three main reasons:

1. to provide additional data to that existing for the late Quaternary coastal sediments; and,

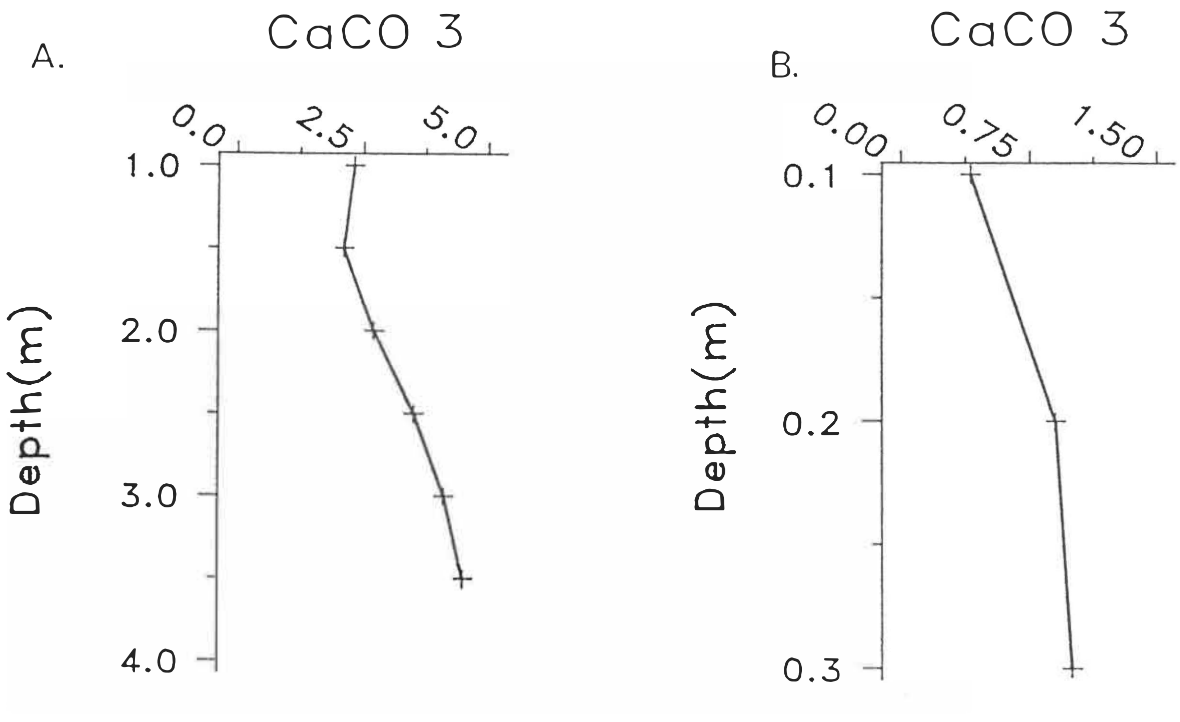


Figure 4.9 Generalised profiles of Holocene dunes showing percent calcium carbonate with depth from dune surface. A. Holocene dunes (HB-3); B. Holocene dunes (HB-4). Note calcium carbonate content increases with depth.

2. to qualify the textural statistics of the stratigraphic units discussed in Chapter two, and possibly group these into particular sedimentary facies.

Textural investigations included the analysis of sand/silt/clay or gravel/sand/mud percentages and the determination of settling tube textural parameters for 130 eastern Coromandel samples.

Grain size analysis is determined by sieve or settling tube analysis. It assesses the transportability of sediments, which is largely determined by weight, rollability and density of the grains (Kuenen 1968). Sieve analysis grades the grains according to their size, accounting for neither rollability or density and only partially for the weight of the grains. On the other hand, settling rate combines all of the above transportability factors and represents more closely the behaviour of sedimentary particles under natural conditions of transportation and deposition. Additional advantages of the settling technique include rapidity of measurement, continuity and permanency of the record and the requirement of only a small amount of sample (Sengupta and Veenstra 1968). One limitation of the settling method is settling convection, currents induced by differences in density of suspension clouds (Kuenen 1968). Denser suspension clouds sink carrying their particle population downwards at higher speeds than individual grains. As this type of convection is especially active with well sorted fine-grained samples, material finer than 50 microns was excluded from all samples analysed in this study.

Sengupta and Veenstra (1968) completed a series of tests to assess basic differences between sieve and settling analysis. Sieving techniques exhibited better reproducibility (1.3% for coarse sediments) than settling methods (5%), although the actual error was commonly much larger (9.2% and 5.6% for sieving and settling techniques, respectively). The total error mentioned includes sample splitting errors, manufacturing, operational and reading errors.

Because of the large numbers of samples analysed in this study, the University of Waikato Rapid Sediment Analyser (settling tube) was used. The settling tube is standardized and calculations based upon the settling velocity equation of Gibbs et al. (1971). Gibbs (1972) evaluated the accuracy of settling tubes, in order to provide some basis for comparison between different settling tube data. A settling tube 25cm in diameter as used, will produce grain size inaccuracies less than 3% with 1g of sample. Bulk sand samples were washed through a 4ϕ sieve, and the finer than 50μm was retained for pipette analysis and clay mineralogy analysis (see Appendix 1).

4.2.1 Textural Classes

The sediment samples ranged from gravelly sands to sandy muds (Figure 4.10). Half of the samples (52%) analysed are composed of more than 90% sand and are those predominantly from the Holocene Barrier Unit. No gravel deposits occur, although gravel clasts occur in 3% of samples. The remaining 45% of samples contain more than 10% by weight but less than 50% by weight of silt plus clay.

Two broad textural groups are defined: those making up the stratigraphic units (70% of all samples analysed); and those samples of soils and tephras overlying the stratigraphic units. Group 1 or unit samples are predominantly sandy sediments, with 61% classified as sands and 20% as muddy sands. The remaining unit samples scatter across most size classes (Figure 4.10). Certain textural classes can be attributed to specific field units: sands characterise the barrier units; muddy sands characterise the Estuarine and Holocene Sand Flat Units; slightly gravelly to gravelly sands make up the Fluvial Unit; and swamps of the Fluvial Unit are classified as muds (Figure 4.11). Tephra and soil samples of group two are generally finer grained, mainly silty sands.

A weathering pattern is recorded by the clay percentages across the coastal dune sequence in eastern Coromandel. There is a gradual increase in clay from <1% in the youngest Holocene dunes to about 12%

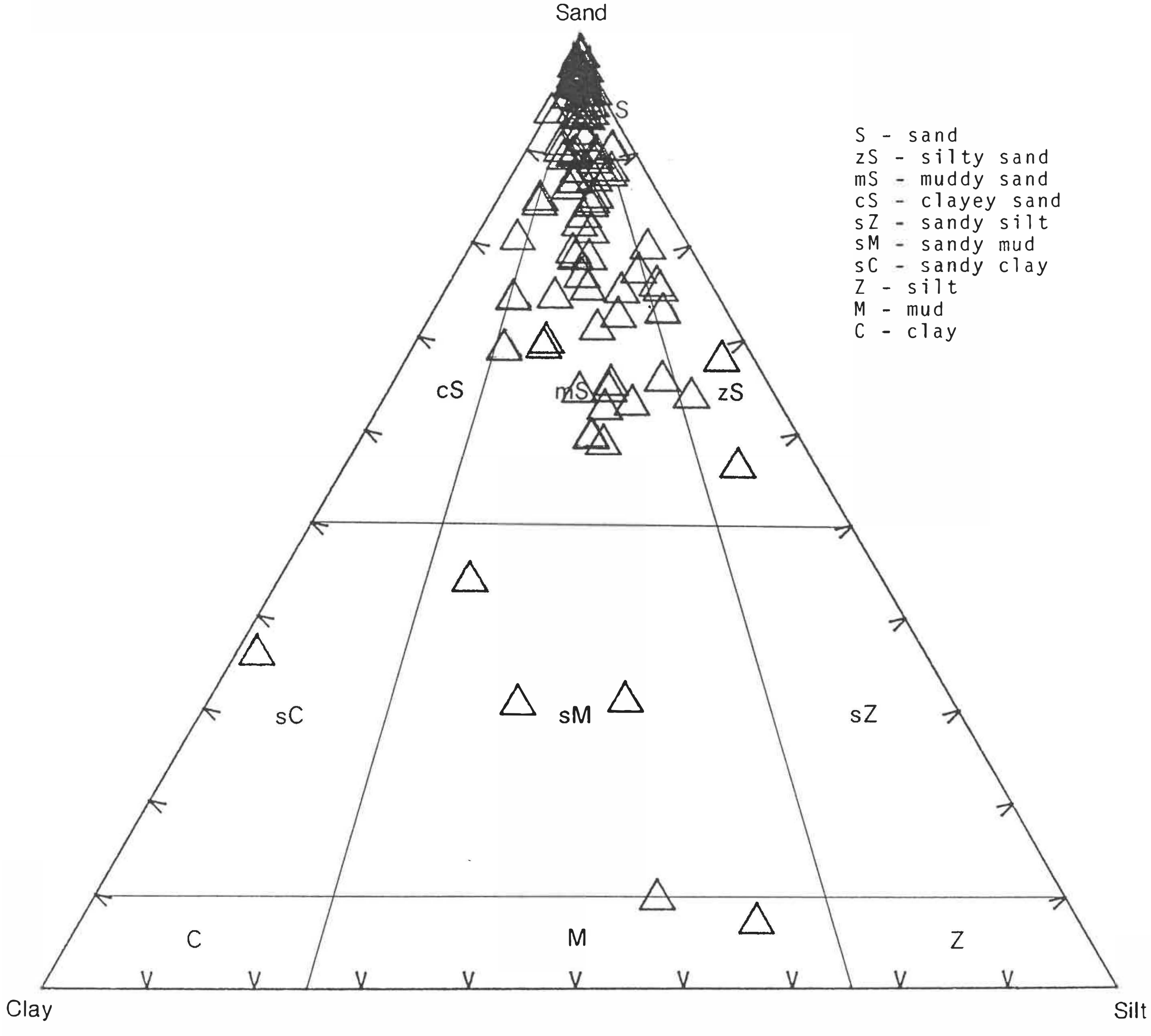


Figure 4.10 Textural classification (after Folk 1968) of east Coromandel samples.

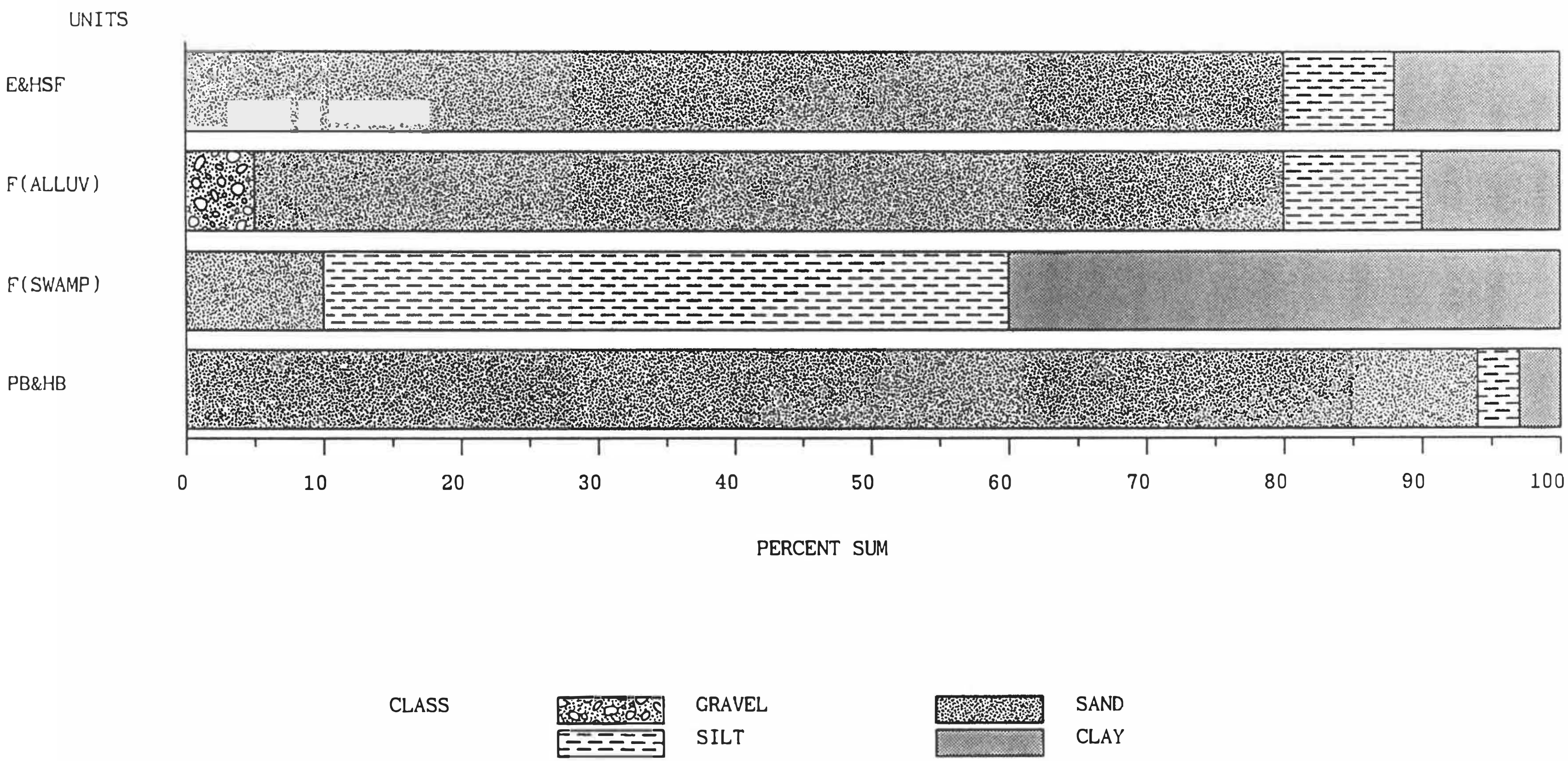


Figure 4.11 Percents of textural classes within the stratigraphic units; Estuarine unit (E), Fluvial unit (alluvial deposits) (Fa), Fluvial unit (swamps) (Fs), Holocene dunes (HD), Holocene Sand Flat unit (HSF), modern beach (MB), Pleistocene dunes (PD).

in the oldest Pleistocene dune. In the older two sets (HB-4, HB-3) of Holocene dunes and the Pleistocene dunes, the clay occurs predominantly in thin zones of accumulation in the upper part of the soil B horizons and is presumably derived and leached from the overlying sand column and tephra deposits. The progressive weathering sequence provides additional evidence for establishing the relative age of a series of dune systems.

4.2.2 Graphical Statistical Parameters

The statistical measures of mean diameter, standard deviation, skewness and kurtosis were determined for the major stratigraphic units along the coast. It was hoped that a particular combination of statistical measures and values might be characteristic of the stratigraphic units of Chapter two.

Mean Grain Size: Grain size depends largely on the size range of available particles, and the amount of transporting energy imparted to the sediment, which depends on the current strength of the local environment (Folk 1968). The mean grain size of the eastern Coromandel sediments ranges from 1ϕ (granule) to 2.4ϕ (fine sand) with the most common values occurring in the medium sand grade (Figure 4.12). Samples from specific units, although widely separated locality-wise, show broadly similar mean grain size characteristics (Figure 4.13). Several points are evident in the mean size data:

1. Mean sizes 1.4ϕ 1.8ϕ are the most frequently occurring for the Pleistocene and Holocene Barrier Units.
2. Finer mean sand sizes (1.7 2.3ϕ) are consistently obtained for the Holocene Sand Flat and Estuarine Units.
3. The Fluvial Unit is characterised by coarser sand sizes, generally less than 1.1ϕ.

Sorting: The sorting characteristics of a sediment depend on at least three major factors: (a) the size range of the original eroded detritus; (b) the current characteristics; and (c) the type of deposition. The Coromandel coastal sediments range widely from poorly

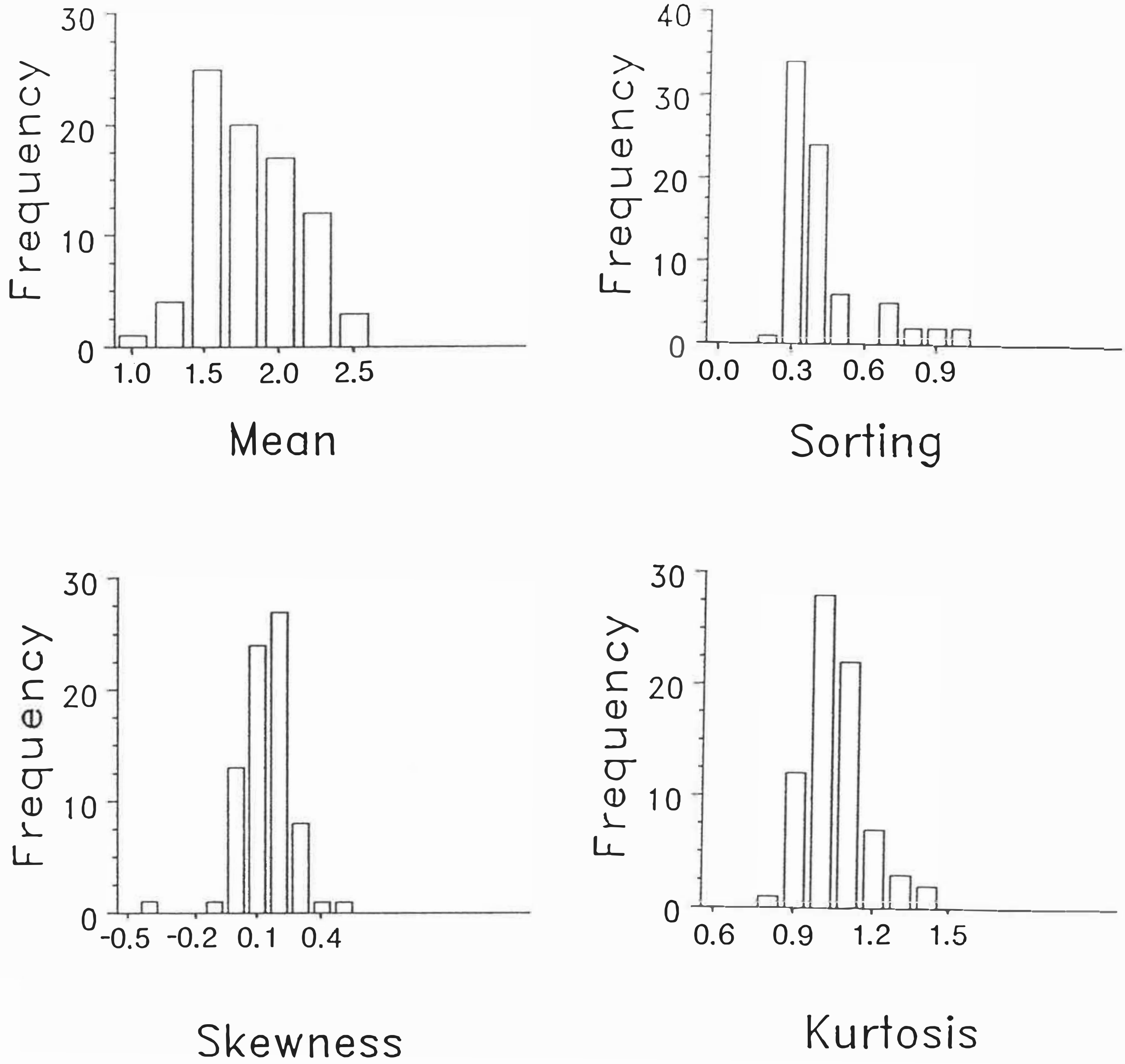


Figure 4.12 Histograms of grain size statistical parameters for the sand fraction of all stratigraphic units, plotted as a function of frequency.

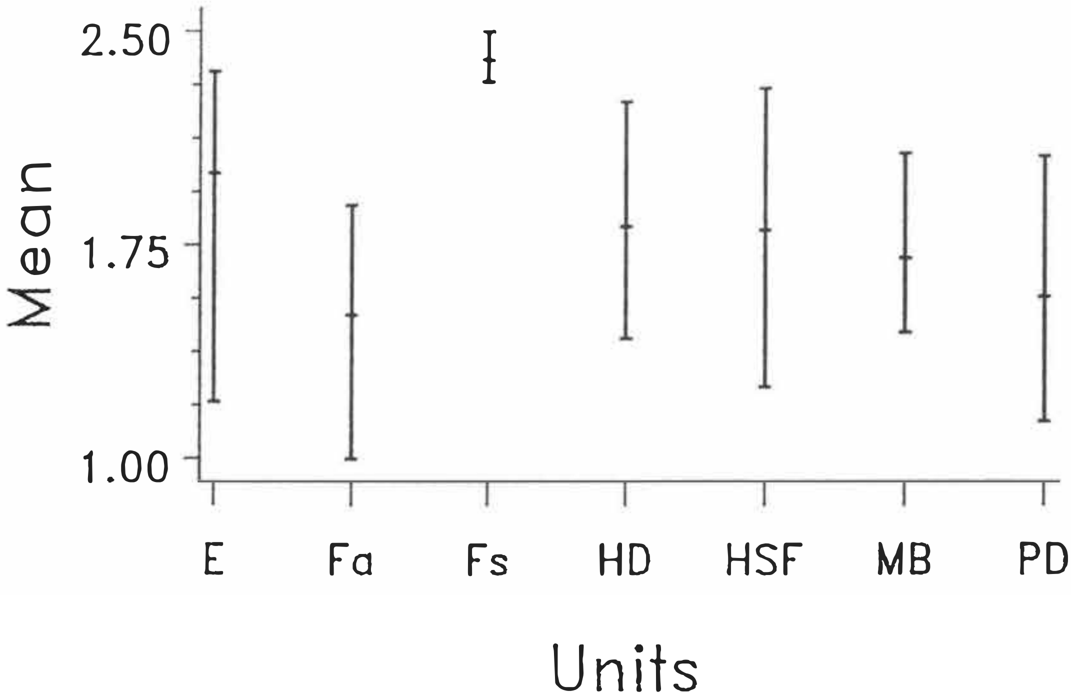


Figure 4.13 Mean grain size (range and mean value) for stratigraphic units and deposits; Estuarine unit (E), Fluvial unit (alluvial deposits) (Fa), Fluvial unit (swamps) (Fs), Holocene dunes (HD), Holocene Sand Flat unit (HSF), modern beach (MB), Pleistocene dunes (PD).

to very well sorted, but predominantly in the well to very well sorted categories (Figure 4.12). Early sedimentological studies (e.g. Folk and Ward 1957, Griffiths 1967) found sorting to be strongly dependent on original grain size and have used bivariate plots to assist delineation of facies, especially when groups plot in distinct clusters. For the bivariate plot of mean grain size versus sorting (Figure 4.14) on the Coromandel sediment data, no inclusive trend is observed. On the other hand, definite cluster occur, the barrier units group together and have a small range of sorting values, the Estuarine unit clusters towards the finer mean size end of the plot, and the Fluvial unit is characterised by poor sorting.

Skewness: Skewness values for the eastern Coromandel sediments tend towards fine-skewed values with a symmetrical distribution about 0.15, ranging from coarse-skewed (-0.2) to strongly fine-skewed (0.5) (Figure 4.12). Previously defined stratigraphic units of Chapter Two have a variable range of skewness values and no typical values characterise any sub-unit or units. Skewness is emphasised as a sensitive indicator of environment of deposition and has been recognised as potentially useful in identifying ancient sedimentary environments (Valia and Cameron 1977). The basis for its environmental sensitivity arises through varying energy conditions of the sedimentary environments producing variations in the sign of skewness (Friedman 1961, 1962, 1967). However according to Folk (1962, 1966) the insensitivity of skewness as an environmental indicator is possibly due to the incapability of the settling tube to discriminate small differences in skewness. However data in Healy et al. (1981) from seiving 56 beach sites along the East Coromandel also showed similar widely fluctuating skewness values.

Kurtosis: Kurtosis is a measure of the spread in the central part of the grain-size distribution to the spread in the tails. The Coromandel sediments range from platykurtic to leptokurtic, but most commonly they are mesokurtic, comprising a single dominant population (Figure 4.12). Like skewness, kurtosis exhibits a wide set of values across the stratigraphic units. Kurtosis values alone, seem not to be

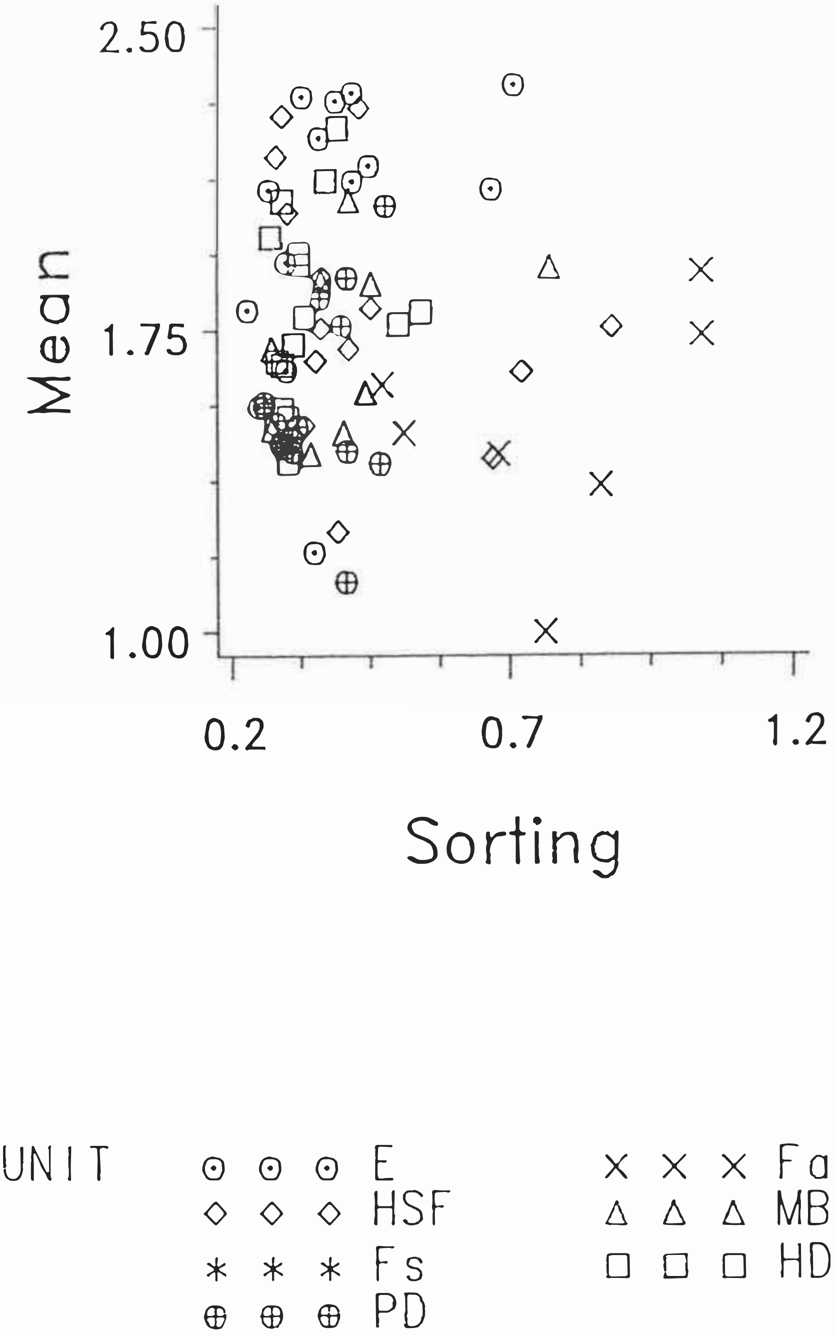


Figure 4.14 Bivariate plot of mean grain size versus sorting for stratigraphic units and deposits; Estuarine unit (E), Fluvial unit (alluvial deposits) (Fa), Fluvial unit (swamps) (Fs), Holocene dunes (HD), Holocene Sand Flat unit (HSF), modern beach (MB), Pleistocene dunes (PD).

environmentally diagnostic, but in combination with other grain-size parameters environmental differentiation may develop (Folk 1968), (see Chapter 5).

4.3 Facies Summary

The compositional and textural laboratory data presented in this chapter can be grouped on the basis of similar sediment properties to define five major sedimentary facies (Table 4.4). The distinction between individual facies is based on criteria such as texture, and the content of shell carbonate and organic matter. **Facies 1** is a well sorted, quartzofeldspathic-rich medium clean sand with minor silt and clay, varying degrees of shell leaching and subordinate organic material and accumulates largely in the eolian environment, and forms the bulk of the barrier units. **Facies 2** consists of organic-rich, medium to fine sand or muddy shelly sand, depending on site, and contains *in situ* plant remains or *in situ* estuarine shells (e.g. *Chione stutchburyi*) and is deposited in the sheltered waters of the estuarine environment. Poorly sorted gravelly sand, no shells and transported plant material characterises **facies 3** and the Fluvial Unit. Peat or organic mud describes **facies 4** and the freshwater swamps of the Fluvial Unit. Facies **5** is identified by well sorted, quartzofeldspathic-rich medium grain size shelly sand, including transported and *in situ* shell material, and is deposited in a wave-dominated marine environment, making up beach deposits of the barrier units.

Table 4.4 Sedimentary characteristics and facies.

Unit	Pleistocene Barrier Dunes	Holocene Barrier Dunes	Holocene Sand Flat	Fluvial Unit (alluvial)	Fluvial Unit (Swamp)	Estuarine Unit	Modern Beach (& Paleobeaches)
Texture	sand	sand	muddy sand	gravelly sand	mud	muddy sand	sand
Mean Grain Size(ϕ)	1.4-1.8	1.4-1.8	1.7-2.3	<1.4	>2.4	1.7-2.3	1.4-1.6
Sorting	0.3-0.4	0.3-0.5	0.2-0.7	0.3-1.1		0.2-0.6	0.3-0.5
% $CaCO_3$	1-5	0.5-5	1-10	0	0	2-10	3-30
% OM*	0.5-2	0.5-2	1-15	0.5-4	>40	1-8	0
Facies[1]	1	1	2	3	4	2	5

1. Facies Description:
   1. Clean sand
   2. Organic-rich sand or muddy shelly sand
   3. Gravelly sand
   4. Peat
   5. Shelly sand

* OM - organic matter

CHAPTER FIVE

DISCRIMINATION OF DUNE AND BEACH SEDIMENTS USING MULTIVARIATE DISCRIMINANT ANALYSIS

A primary consideration of this study involved the attempt to identify a textural "break" in the Pleistocene coastal deposits between eolian and foreshore paleoenvironments. In this chapter, discriminant function analysis is applied to the sediment textural data of the Pleistocene Barrier Unit in an attempt to identify and distinguish between dune and beach sediments. If it is possible to define such a textural boundary then the approximate relative position of sea level at the time of barrier formation may be inferred.

Environmental determination is normally linked to the recognition of characteristic suites of sedimentary structures, body and trace fossils and paleosol development. The general lack of preservation of these features in subsurface auger samples has prompted a second discriminatory technique to be applied, namely multivariate discriminant analysis of textural data. The use of sediment textural data for the recognition and interpretation of depositional environments of modern sands has attracted the attention of a number of investigators (Folk 1966, Valia and Cameron 1977). The identification of depositional environments using sediment textural data depends on three assumptions: (a) that significantly different energy conditions and mechanisms of deposition exist for different environments; (b) that energy conditions are preserved in the sediments at the site of deposition; and (c) that the size distribution of a sediment reflects the mode of transport and the energy of the transporting medium (Sahu 1964). However, grain size is also closely linked to the availability of sediments to an environment which in turn is dependent upon the physiographic setting and nature of the sediment source area. This particular relationship is a crucial factor, and must be borne in mind in any research involving environmental discrimination by grain size distributions.

5.1 Environmental Sensitivity of Textural Parameters

Previous studies (e.g. Mason and Folk 1958, Friedman 1961, Folk 1966, Moiola and Weiser 1968) have demonstrated that certain combinations of textural parameters, such as mean diameter and skewness, effectively differentiate sands from certain environments. In the main, skewness has been recognised as a sensitive discriminator of barrier sedimentary environments (Valia and Cameron 1977), where dune sands are for the most part positively-skewed, and beach sands are typically negatively-skewed (Friedman 1961). Similarly Hails (1967), using moment measures to distinguish sedimentary environments in southeastern Australia, found that if sediments are polygenetic in origin, skewness is the only parameter that may distinguish beach, barrier and dune sands. In dispute, Shepard and Young (1961), Sevon (1966) and Christie (1975), using both sieve and settling tube techniques, questioned the ability of textural parameters to differentiate the deposits of coastal depositional environments.

The initial approach of this section involved sampling modern beach and dune environments to establish (any) textural differences between them, and then to use these differences to help identify ancient equivalents from core samples. Figure 5.1 is a plot of mean diameter versus skewness settling tube data for several modern beach and dune samples from the eastern Coromandel region. Environment grouping is clearly not effective in this case and it therefore does not appear to be a valid means for distinguishing beach and dune sands. This prompted further analysis using a multivariate statistical technique, namely stepwise and canonical discriminant analysis.

5.2 Stepwise and Canonical Discriminant Analyses of Eastern Coromandel Sediments

Discriminant analysis is a statistical classifying technique that differentiates between distinct populations or groups on the basis of a number of attributes or variables (Moiola et al. 1974). The analysis is two-fold. First, a set of sample data derived from known

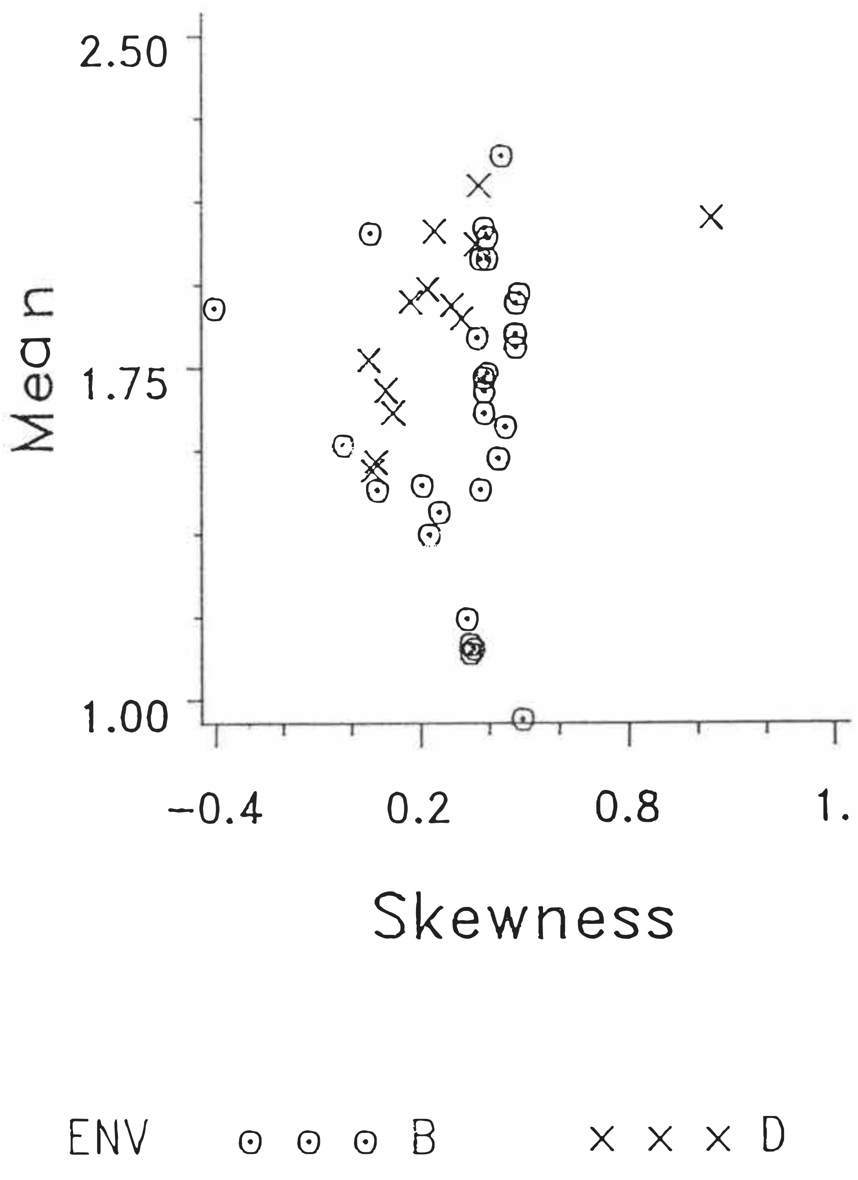


Figure 5.1 Bivariate plot of mean grain size versus skewness for modern beach (B) and dune (D) samples of east Coromandel.

groups or environments (termed a reference set) must be analysed to determine (a) the subset of sample variables which best separate *priori* groups (or environments) within the data set, and (b) weighting coefficients, by which the subset of variables should be combined to produce a single figure (z) which maximises the separation between groups. Second, samples (measured on the same variables as in the reference set) whose group membership is unknown (termed the unknown set samples) should then be weighted by the corresponding weighting coefficients determined in step 1. Thus the unknown samples may then be classified.

Geologically, the technique has successfully differentiated various depositional environments using both sieve-derived (e.g. Sevon 1966, Moiola et al. 1974, El-Ella and Coleman 1985) and sedimentation tube-derived (e.g. Taira and Scholle 1979) textural data.

The discriminant function is a linear combination of variables which maximises the ratio of the difference in means between groups to the variance within the groups (El-Ella and Coleman 1985). The discriminant function is denoted by:

$$Z = C_1X_1 + C_2X_2 + \ldots + C_nX_n + b \quad (5.1)$$

where z is the transformed sample value; $X_1, X_2 \ldots . X_n$ are the original descriptive variables; and $C_1, C_2 \ldots . C_n$ are the coefficients of the discriminant function.

Where the discriminant analysis is linear (involving separation of two populations), the discrimination index R_0, (i.e. the point dividing the two groups) may be calculated by substituting:

$$X_i = \psi_i \text{ for } i = 1 \text{ to } n \text{ into equation } (5.1)$$

where

$$\psi_i = \frac{A_i + B_i}{2} \quad (5.2)$$

and A_i and B_i are the standardised mean scores for any variable i in groups A and B (Davis 1978, Hand 1981).

Sources of the reference set data for this study included both the test information collected from Mangawhai Inlet and dune system, northeast North Island (McCabe 1985) as well as modern beach and dune samples from this study. A prerequisite of the reference data was analysis by the settling tube. Furthermore, because grain size is interrelated to the availability of sediments and, in turn, to the sediment source area and physiographic setting, analogous sediment with respect to source and depositional processes history was preferable. McCabe's (1985) sediments are Holocene beach and dune quartzofeldspathic-rich sands derived ultimately from the Taupo Volcanic Zone, and therefore were particularly suitable as reference data.

The independent variables selected in this study are the commonly used graphical textural parameters: mean, median, standard deviation, skewness and kurtosis. Ideally, a large number of variables should be used in attempting a multivariate discriminant analysis. However, which and how many variables are limited to the data available. Previous effective variables of discriminant models include the mean, standard deviation, skewness, kurtosis and variables related to finer-grained extremes of the distribution (Taira and Scholle 1979, El-Ella and Coleman 1985).

Statistical procedures follow those described by Stokes (1987). The program used combines a stepwise discriminant function and canonical discriminant function (see Joyner 1985 for details). Stepwise discriminant analysis is used to evaluate the variables for discrimination (step 1 above). The procedure STEPDISC (Joyner 1985) begins by choosing the variable that has the highest value on the selection criteria, in this case, the variable that minimises the Wilks' Lambda criterion (Beaudoin and King 1986). This variable is then paired with each of the other variables, and the next variable selected is the one that again minimises Wilks' Lambda. In this analysis three variables were selected as being good group discriminators, namely mean diameter, sorting and kurtosis (Table 5.1).

Canonical discriminant analysis was then performed upon the reference set samples using the variables selected by the stepwise discriminant procedure. Given two or more groups of observations with measurements on several quantitative variables, canonical analysis derives a linear combination of the variables that has the highest possible multiple correlation within groups (or depositional environments) (Afifi and Clark 1984). The maximum multiple correlation is called the first canonical correlation. In this study the procedure CANDISC (Joyner 1985) was used on textural data to derive a series of coefficients or functions by which the selected variables are multiplied and the resultant summed (step 2 above).

The results for the northeastern North Island reference set distinguish well between the environments, with 90% of the samples correctly classified (Figure 5.2). The R_0 value (discriminant index) was calculated, providing the following discriminant rule:

if the canonical variate score is < -0.017 (R_0 value)

THEN depositional environment = beach

ELSE depositional environment = dune.

Errors which may have led to sample misclassification include:

1. Sampling errors;
2. Variability in mineralogy, such as a greater proportion of shell fragments, resulting in an anomalous grain-size distribution;
3. Laboratory analysis errors (e.g. settling tube operational errors);
4. Limitations of the statistical models.

The statistical model, which has effectively classified 90% of the reference set samples correctly, is now applied to the unknown set of Pleistocene barrier samples. This application involves combining the discriminatory variable scores from unknown set samples with the predefined canonical coefficients (Table 5.1).

Table 5.1 Summary (numerical) of the stepwise and canonical discriminant function analyses. Discrimination efficiency is measured upon a number of criterion; including minimisation of Wilks' Lambda and Mahalanobis distance (D^2) which measures the euclidean seperation between group (environment) means. Individual variable discrimination efficiency, in combination with the other entered variables, is measured by its partial R^2. A samples discriminant function score Z is the sum of the products of the selected sample variables and the respective standardised discriminant function coefficients.

Variable Entered	Wilks' Lambda	Partial R^2	Standardised Canonical Coefficients	Eigenvalue	Canonical Correlation	Δ^2
sort	0.6853	0.3147	-0.9316	1.249	0.7452	2.217
mean	0.5984	0.1268	1.2434			
kurt	0.4447	0.2568	1.0070			

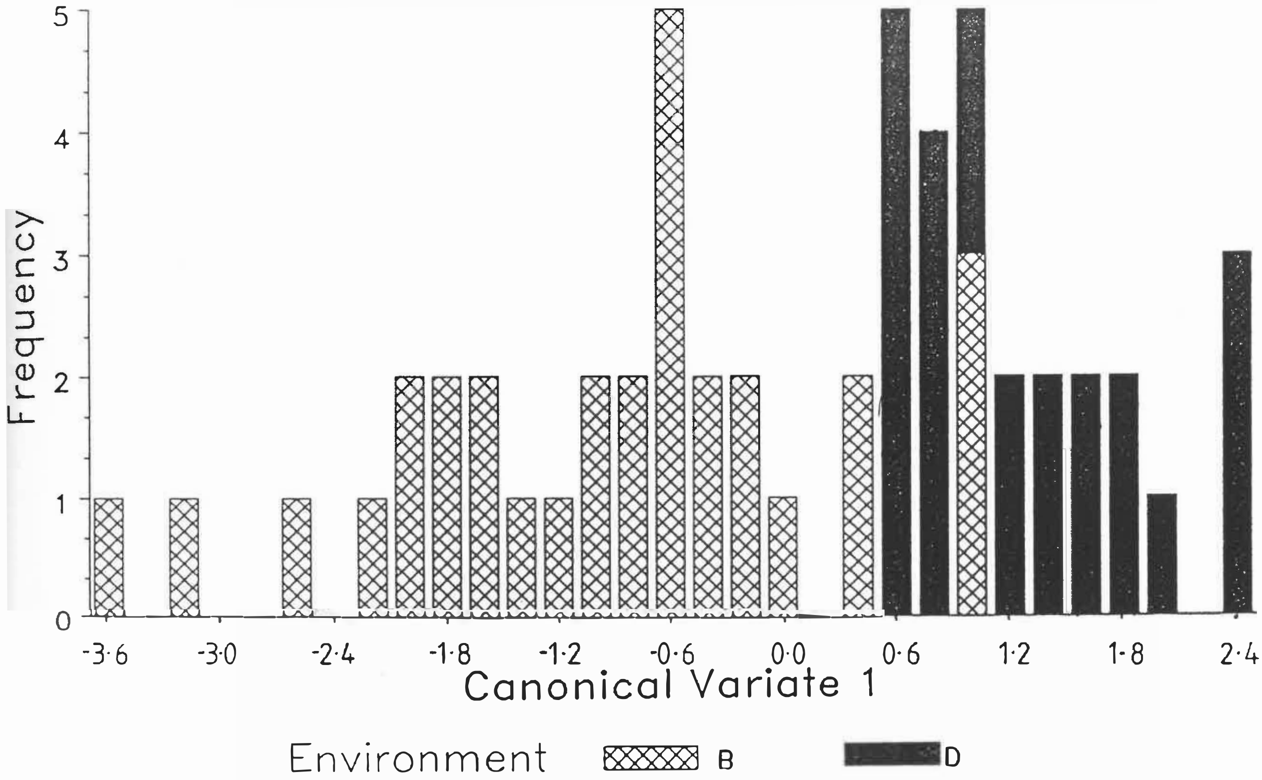


Figure 5.2 Results of discriminant function analysis for the reference data set (comprising sample textural data from McCabe (1985) and textural data from modern beach and dunes in this study). The canonical variate represents the sum of a number of textural variables combined by predetermined coefficients, and delineates beach (B) and dune (D) environments.

Depositional environments for the unknown set samples have been inferred from the discriminant function scores (Table 5.2). An anticipated downhole succession of environments from dune to beach occurs in most sequences. A few auger sequences did not exhibit the expected downhole succession. It is suggested that these anomalous trends may have occurred because: (a) the beach and coastal dune sediments are derived from the same initial sediment population and thus considerable overlapping between groups may result; (b) diagenetic changes may have modified the original grain-size distribution (Taira and Scholle 1979, El-Ella and Coleman 1985); (c) inherent facies variability in the dune environment (e.g. washover and interdune deposits); and (d) additional environments, such as tidal flats and channels, not included in the initial reference set, may be present in the auger sequences.

5.3 Implications

Downcore sequences were plotted with respect to present MSL, from north to south along the coast (Figure 5.3). It is assumed that the discriminated textural break within the ancient Pleistocene barrier between eolian and foreshore deposits approximates the position of sea level at the time, which was presumably near-synchronous along the coast. Assuming a past synchronous level along the coast, faults and relative fault movement are implied from the juxtaposition of this boundary (Figure 5.3). Support for differential fault movements is provided from plotting the lower boundary of the Rotoehu Ash. However, tephras mantle the topography during deposition and, in the case of a dune field, which has a very uneven topographic surface, tephras may be located at variable elevations within a small area. Therefore, where possible, the crest elevations of ancient dune ridges were identified and the Rotoehu Ash measured and plotted at this level.

Faulting is a prominent feature of Coromandel geology. The regional fault pattern consistently trends NNW and NE (Figure 5.4). Satellite imagery has revealed major northeast- trending lineations

Table 5.2 Inferred environment and discriminant function scores for the unknownset (Pleistocene Barrier samples).

Borehole	Sample	Discriminant Function Score	Inferred Environment
1	WT22667	0.3462	D
1	WT22669	0.4485	D
1	WT22671	-0.4686	B
1	WT22673	-1.0590	B
1	WT22675	-1.1889	B
1	WT22676	-1.5588	B
3	WT22703	0.7005	D
3	WT22705	1.7188	D
3	WT22707	1.8452	D
3	WT22709	0.8107	D
3	WT22711	-0.6749	B
3	WT22713	-0.6537	B
8	WT22794	0.8535	D
8	WT22795	-0.4342	B
8	WT22722	0.7952	D
8	WT22723	0.2931	D
5	WT22620	2.2669	D
5	WT22622	1.4077	D
5	WT22624	1.2480	D
5	WT22626	0.8735	D
5	WT22627	1.4793	D
7	WT22570	2.0038	D
7	WT22571	1.3566	D
7	WT22576	3.3943	D
7	WT22572	1.6893	D
7	WT22577	1.9367	D
7	WT22573	-0.9510	B
7	WT22574	-2.0881	B
7	WT22575	-0.6195	B
10	WT22518	-1.8392	B
10	WT22519	-1.3197	B
10	WT22520	-1.5186	B
10	WT22521	-1.7067	B
10	WT22522	-0.7656	B
9	WT22509	-1.6861	B
9	WT22511	-1.5622	B
9	WT22512	-1.6814	B
9	WT22513	-2.0963	B

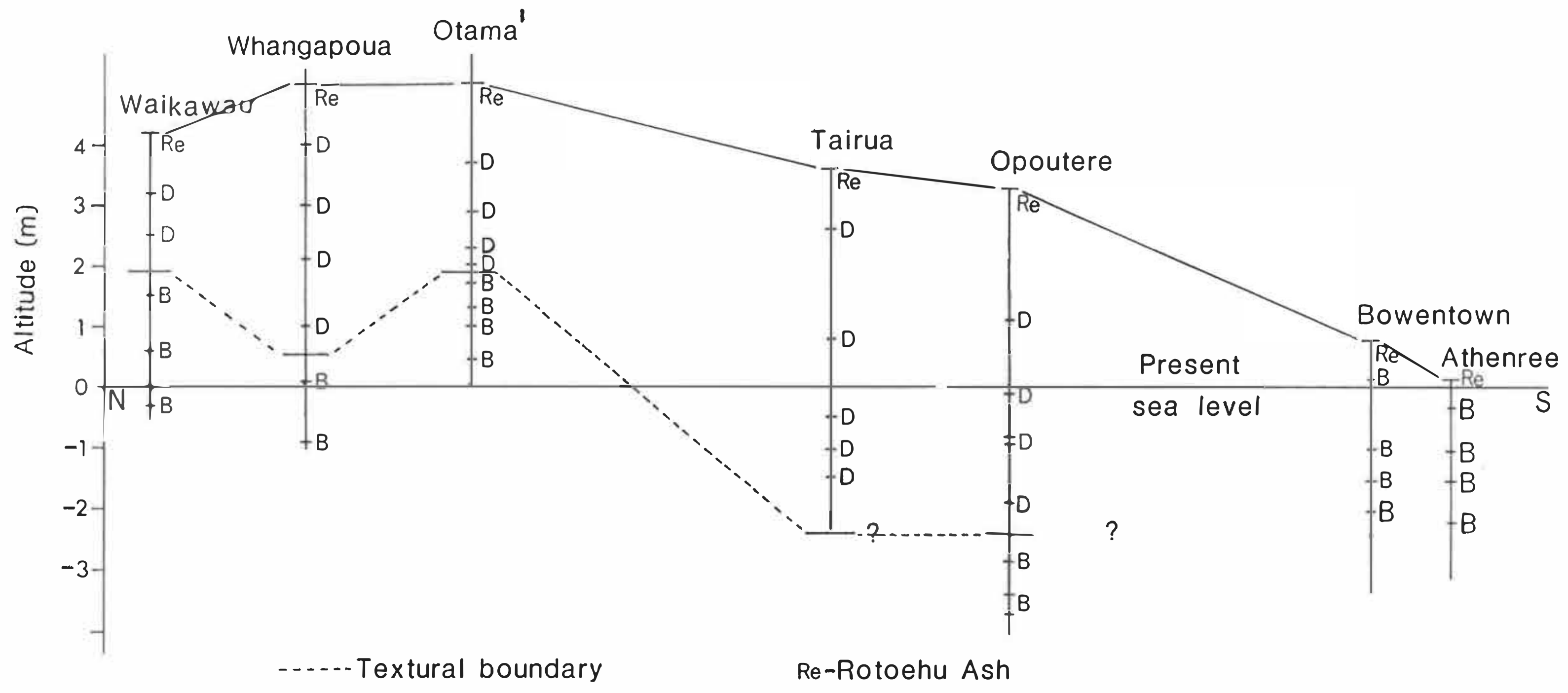


Figure 5.3 Pleistocene Barrier auger sequences and identified textural break (B - beach sediments, D - dune sediments) are plotted with respect to present mean sea level (PSL). Re - Rotoehu Ash. These levels in relation to PSL were obtained through dune surveys (Appendix 4). Sequences are plotted north to south. Note: 1 - environments inferred from sedimentary structures.

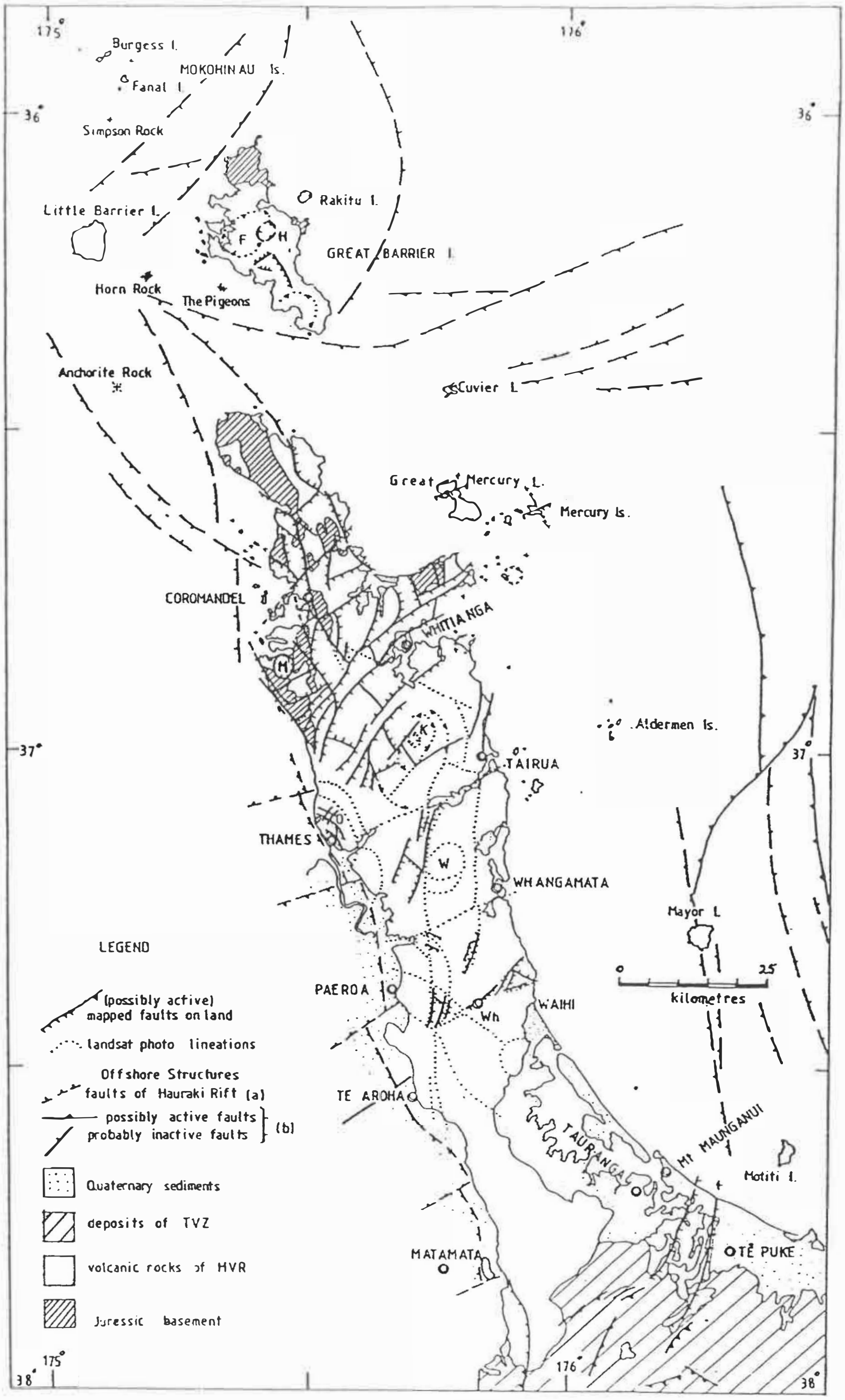


Figure 5.4 Structural and tectonic map of the Coromandel Peninsula (after Skinner 1986); (a) after Hochstein and Nixon (1979), (b) from seismic interpretation by Thrasher (1986).

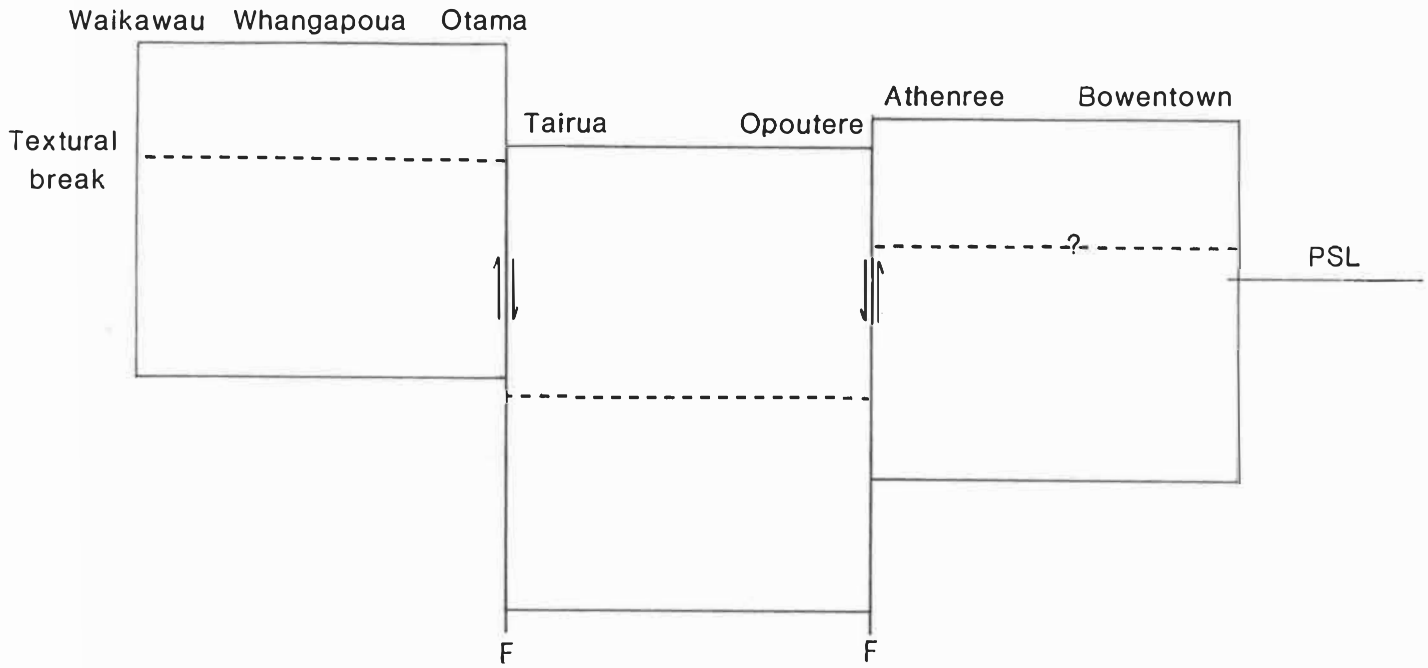
which parallel known faults (Skinner 1986). Analysis of the fault patterns suggests that the fault trends in the Neogene rocks are inherited from, and controlled by, pre-existing fractures formed in the Jurassic basement rocks during the Rangitata Orogeny (Skinner 1967, 1976, 1986). The fault positions and relative movement suggested by the plotted auger sequences of this study agree reasonably well with those structures previously mapped and those inferred from landsat photography. Skinner reports Cenozoic fault movements have been largely normal-dip slip and left-lateral slip on east-northeasterly faults, with downthrow mainly to the south. Furthermore, Skinner suggests active faulting has continued through the late Pliocene and Quaternary following previous ENE and NW trends, although fissuring predominated because of tensional conditions produced by the onset of acidic and later basic volcanism. The Quaternary tectonics of the Waihi Beach - Bowentown region has been a matter of contention (Chappell 1975, Cole 1978). In general, there is agreement on depression of the Tauranga Harbour - Waihi Beach area throughout the Pliocene, and continued warping in the Pleistocene. This warping is considered as most probably associated with active faults that extend between Mayor Island and the Tauranga - Te Puke area (Skinner 1986).

The coastline is divided into three main fault sectors (Table 5.3) based on relative fault movements, position of the textural boundary and Rotoehu Ash. Assuming that the relative position of sea level at the time of Pleistocene barrier formation, was probably near that of present sea level, relative rates of late Quaternary uplift can be estimated for sections of the coast, using present sea level as a reference (Table 5.3). Allowing for minor faults and movements within the sectors, differential sector movement either side of the inferred faults can be calculated (Figure 5.5).

From the discriminant data, the Tairua-Opoutere block has been downthrown to the south relative to the Waikawau-Whangapoua block, similarly suggested by Skinner. However, the lower Athenree-Bowentown sector contradicts this southwards downthrown trend if we accept the

Table 5.3 Relative vertical discplacements for the last 125 ky for each coastal area with respect to present sea level.

Uplift	Embayment						
	Waikawau	Whangapoua	Otama	Tairua	Opoutere	Athenree	Bowentown
ΔH (from textural break to present msl) (m)	2	0.5	2	>-2.0	-2.5	-	-
Relative uplift calculated using 50 ky Rotoehu Ash date (mm/y)	0.04	0.01	0.04	>-0.04	-0.05	-	-
Relative uplift using 125 ky (last interglacial high sea level) (mm/y)	0.016	0.004	0.016	>-0.016	-0.02	-	-
Sector		1		2		3	



ΔH between sectors (m)	4.0-4.5 m	> 2.5 m
Differential sector displacement	0.032-0.036 mm/y	>0.02 mm/y

Figure 5.5 Schematic diagram summarising the main fault (F) displacements between the three main sectors. PSL - present mean sea level.

discriminant analysis classification of samples from that area as beach. This places the eolian-beach textural break above present MSL, and suggests it is part of an uplifted block. Field observations of high-angle cross-bedding and podzolised sands are suggestive of dune deposits at the surface of Athenree and Bowentown Pleistocene Barrier deposits. Trough cross-bedding occurs in the exposed banks and forms scalloped shapes protruding from the bank below and at water level (Figure 5.6), implying a dune depositional environment for at least the upper 2m of sand. Based on field evidence, it is the writers view that at least some upper samples of Athenree-Bowentown were incorrectly classified in the discriminant analysis as beach sediments. This may be because of the proximity to, and the greater thickness, of Rotoehu Ash at these sites, and that all except the top 1m of the ancient barrier sediments are below MSL. Thus, the greater influence of Rotoehu Ash may have provided additional material, or perhaps diagenetic changes induced by constant wetting may have modified the original grain-size distribution to produce anomalous results in the discriminant analysis.

Reasonably successful classification of environments in modern coastal sediments by multivariate discriminant function of textural data, has enabled inferences to be made concerning late Quaternary faulting in the Coromandel region when applied to textural data of Pleistocene barrier dune and beach depositional environments. The analysis supports a southward downstepping trend along northeast-trending faults at rates of up to 0.04mm/yr for the last 125 ky, and that tectonically the northern Coromandel Peninsula is elevated with respect to the southern portion.

Figure 5.6 Poorly visible trough cross-bedded Pleistocene barrier sands grading up into podzolised sands and late Quaternary tephras at Athenree (U13/727132).

CHAPTER SIX

ASPECTS OF BARRIER DUNES AND BEACHES, EMBAYMENTS AND ESTUARIES

Sand barriers of various types are preserved along the east Coromandel coast within bedrock-confined embayments. The wide variety of Holocene barrier types reflects different modes of sand accumulation on a headland-bay coast since sea level attained its present position, some 6500 years ago. The coastal barriers provide an excellent opportunity to study embayment depositional histories reflecting the interaction of sea-level change, embayment configuration, sediment supply and wind and wave regimes.

Using Thom's (1974) models (Figure 6.1) from the south Australian coastline, the east Coromandel barriers are categorised into depositional types on the basis of their geomorphology and stratigraphy. Three basic types of barriers occur, namely prograded, stationary and receded types (see Section 6.2).

In this chapter, reasons for the formation of barrier types along east Coromandel will be reviewed, in an attempt to define several embayment types. The estuaries behind the Holocene barriers are also briefly discussed. Before doing so, the theory of coastal barrier dynamics is reviewed.

6.1 Coastal Barrier Dynamics

The primary control for barrier progradation is sediment supply, where there must be a sediment supply for barrier formation, and the greater the supply probably the greater the degree of progradation. However, other controlling factors include (1) the environmental parameters operating (e.g. wind and wave regime), and/or (2) coastal physiography (e.g. shelf gradient and width, and embayment form) which may in turn govern to a degree (1).

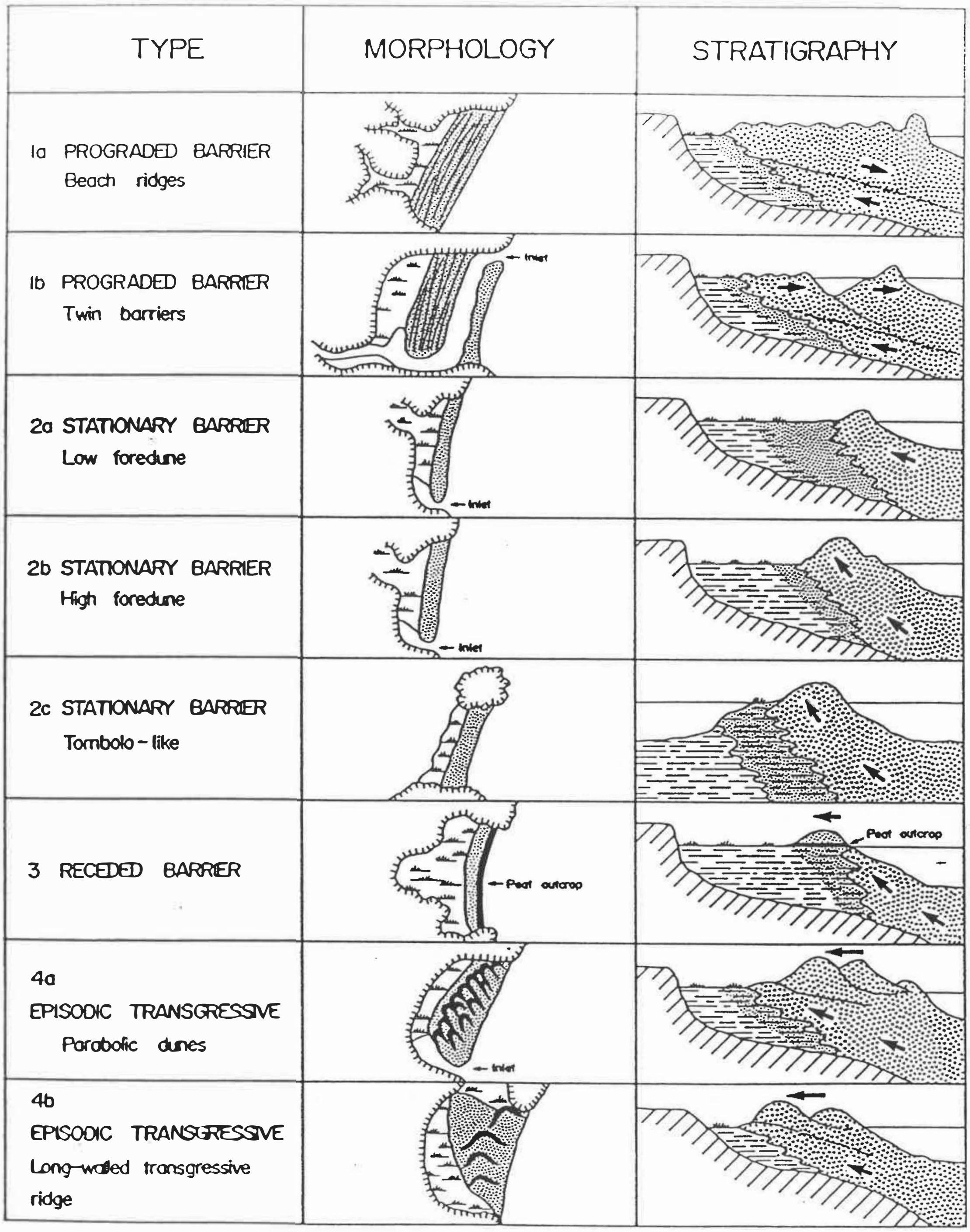


Figure 6.1 Holocene barrier types in New South Wales, Australia, showing generalised morphologic and stratigraphic patterns (after Thom 1974). Arrows indicate directions of sand accumulation.

South Australian literature has reported numerous studies of wave-dominated sandy beaches in low, moderate and high wave energy environments and discussed the relationship between barrier morphology and surf zone-beach behaviour (e.g. Wright et al. 1979, Short and Wright 1981). Recent research has (a) described a range of beach morphodynamic states from steep, reflective beach systems to flat dissipative systems (Short and Wright 1981), (b) emphasised the interaction of deep-water characteristics and shelf and inshore morphology (Short 1979, Short and Hesp 1982) in producing the series of identifiable beach states, and (c) discussed how foredune morphology is dependent on these beach morphodynamic states.

The degree to which a beach is reflective or dissipative is determined by the surfscaling parameter (ϵ) which is a function of the beach and surfzone gradient in conjunction with the incident waves (see Short 1979, Wright et al. 1979).

Reflective systems are characterised by low ϵ values, well-developed berms and cusps, narrow surf zones and steep linear beaches from which wave energy is reflected (Wright et al. 1979, Short and Wright 1981). Such systems are evident where refraction substantially reduces the height of waves, and tend to favour strongly indented embayments, the protected lee of headlands, the presence of relatively coarse materials, and following prolonged accretion (see Short and Wright 1981). On the open coast they occur as pocket beaches bounded by rocky headlands. Available sand is stored primarily on the subaerial beach rather than in the surf zone. Waves break at the beach face.

The dissipative morphodynamic extreme is normally found on the open coast, with wide surf zones, high breaking wave heights and high ϵ values. The waves break well seaward of the beach thereby dissipating energy in the surfzone where sand is stored (Wright et al. 1979, Short and Wright 1981). These systems are characterised by concave upward nearshore profiles and wide flat surf zones and are produced either by a high wave energy environment, an abundance of sand in the surf zone, and by fine-grained sediment in a shallow embayment (Short and Wright 1981). The large sediment storage accompanying this situation offers the greatest potential for net subaerial accretion, but is also more likely to experience local foredune erosion with an increase in wave height (see Wright et al. 1979).

Both reflective and dissipative conditions act to produce a range of intermediate beaches, characterised by pronounced rhythmic longshore variation, including alternating rip channels and bars, cusps and berms (Short 1979, Short and Wright 1981). Sediment storage occurs in both the surf zone and on the beach, enabling rapid sediment exchange during increases and decreases of wave heights. Intermediate beaches are further subdivided into three levels dependent on the modal wave height, beach form and zones of sediment storage (Figure 6.2) (Short and Hesp 1982).

The wave dynamics of a region are largely dependent on the transformation of deep water wave energy as it crosses the shelf and nearshore. Initially, wind strength, duration and the fetch over the sea surface determine the height of deep water waves (Komar 1976). Nearer shore, the wave height is further affected by wave attenuation and refraction (Short and Hesp 1982), more wave energy being expended on wider and shallower shelves. For the south Australia coast, Short and Hesp (1982) have found that with steep shelf slopes (1:150) more than 75% of deep water wave energy reaches the shore producing high energy dissipative and/or intermediate beaches. Moderate slopes (1:300) receive 40-75% deep water wave energy and are dominated by moderate energy intermediate beaches. Low energy reflective beaches are most common where shallow slopes (1:800) allow only 25-40% of the deep water wave energy to reach the surf zone. Hence, the type of beach state, whether reflective, intermediate or dissipative, although related to the type and degree of wave energy, is chiefly a function of embayment form and more importantly the nearshore and shelf slope.

A) MODAL WAVE HEIGHT	B) MODAL MORPHO-DYNAMIC STATE	C) MODAL BEACH STAGE (WAVE HEIGHT)	D) BEACH MOBILITY INDEX	E) MODE OF BEACH EROSION	F) NATURE OF BACK BEACH EROSION: TEMPORAL	F) NATURE OF BACK BEACH EROSION: SPATIAL	G) NATURE OF BACK BEACH ACCRETION: POTENTIAL AEOLIAN SEDI-MENT TRANSPORT	G) NATURE OF BACK BEACH ACCRETION: FOREDUNE SIZE	H) POTENTIAL FREQUENCY (> 100 YRS) OF TOTAL FOREDUNE DESTRUCTION	I) GIVEN E, F, G AND H - NATURE OF LANDWARD DUNES
HIGH (> 2.5m)	DISSIPATIVE	6, 5' PARALLEL BAR/S CHANNEL/S SURF ZONE, WIDE, LOW GRADIENT BEACH.	LOW	LOW FREQUENCY WAVE SET-UP (SWASH BORES)	LOW (1:10yrs) DUNES : ALONGSHORE SCARPING OVERWASH: AT TOPOGRAPHIC LOWS	LATERALLY CONTINUOUS	HIGH	LARGE (15 - 30 HIGH) (> 100m WIDTH)	MODERATE	LARGE SCALE TRANSCRESSIVE DUNE SHEETS
		5 (2 - 2.5m) CRESCENTIC BARS, LOW-MODERATE GRADIENT BEACH.	LOW-MODERATE		MODERATE DUNES: SCARPING IN RIP EMBAYMENTS. (SPACING 1 km). OVERWASH: IN LEE OF RIP EMBAYMENTS.	DISCRETE	HIGH-MODERATE	HIGH-MODERATE	MODERATE HIGH	LARGE SCALE PARABOLICS TO DUNE SHEETS.
MODERATE (1 - 2.5 m)	INTERMEDIATE	4 (1.5 - 2m) CRESCENTIC BARS -MEGACUSPS. VARIABLE LOW-MODERATE GRADIENT BEACH.	HIGH	RIP EMBAYMENT EROSION	MODERATE (1:3-5 yrs) DUNES: SCARPING IN RIP EMBAYMENTS. (500m - 1km). OVERWASH: IN LEE OF RIP EMBAYMENT.	DISCRETE	MODERATE	MODERATE (10 - 20 m HIGH) (< 100 m WIDTH)	HIGH	LARGE SCALE PARABOLICS - LARGE BLOWOUTS.
		3 (1 - 1.5 m) RIP CELLS MODERATE-HIGH GRADIENT BEACH.	MODERATE LOW		MODERATE DUNES: SCARPING IN RIP EMBAYMENTS (< 500 m) OVERWASH: IN LEE OF RIP EMBAYMENTS.	DISCRETE	MODERATE-LOW	MODERATE-SMALL	MODERATE LOW	DISCRETE BLOWOUTS
LOW (< 1m)	REFLECTIVE	2, 1 BARLESS NARROW SURFZONE, HIGH GRADIENT BEACH.	LOW	HIGH FREQUENCY WAVE RUN-UP	HIGH (1: 1-2 yrs) DUNES CONTINUOUS SCARPING. OVERWASH: AT 'LOWS'.	CONTINUOUS	LOW	SMALL (< 10 m HEIGHT) (< 50 m WIDTH)	LOW	FOREDUNE SCARPING, OCCASSIONAL SMALL SCALE BLOWOUTS

Figure 6.2 Wave, beach and dune interactions in southeastern Australia (after Short and Hesp 1982).

Variable foredune morphology has been the product of considerable discussion (e.g. Wright 1970, Bird 1976, Hesp 1984, Hesp 1986). Factors influencing such variations include beach state (Wright 1970, Short and Hesp 1982), the rate of shoreline progradation (Thom 1965, Bird 1976), magnitude of wave erosion (Wright 1970, Bird 1976), and plant-aerodynamic interactions (Hesp 1983, 1984). Short and Hesp (1982) and Hesp (1986) have suggested that foredune morphology is indicative of surfzone-beach behaviour and that foredune dimensions can be related to beach morphologic states. Landward eolian sand transport is a function of the volume of beach sand available for transport, the shape and width of the subaerial beach, and the nature of the aerodynamic flow across the beach (Short and Hesp 1982). For the latter process the flatter the surface, the less the velocities fluctuate or are reduced and the greater the potential for continuous sand transport across that beach (see Short and Hesp 1982). Consequently, the subaerial morphologies of beaches have a direct effect on the volume and rate of eolian sand transport, thereby influencing the adjacent foredune morphology. Dissipative beaches have a maximum potential onshore wave-induced sand transport (Hesp 1986), and display wide, low gradient beaches, suggesting a high potential for landward eolian transport of beach sand. The reflective beach extreme normally features a narrow mean beach width, often a high gradient and steep berms or cusp faces, producing a low potential eolian sand transport, and subsequently low backing foredunes.

Furthermore, observations by Hesp (1986) indicate that foredune ecological status and topography reflects beach behaviour and as the degree of wave- or wind-induced erosion increases, foredune asymmetry increases. Stable, accreting coastal conditions produce topographically continuous foredunes fronted by pioneer plants commonly creating incipient dunes (Hesp 1984), which display a systematic landward increase in vegetation species diversity and cover. Conversely, the less the vegetation cover and species richness and the more disrupted the dune topography, the greater the likelihood that medium to long term erosion is taking place. Hesp (1986) has distinguished five types of Australian established foredunes on the basis of morphological and ecological variations. These range with increased wind and wave erosion from continuous dunes and 90% vegetation cover, to pronounced topographic variability including sandsheets, remnant knobs and deflation basins, and only 5% vegetation (Figure 6.3).

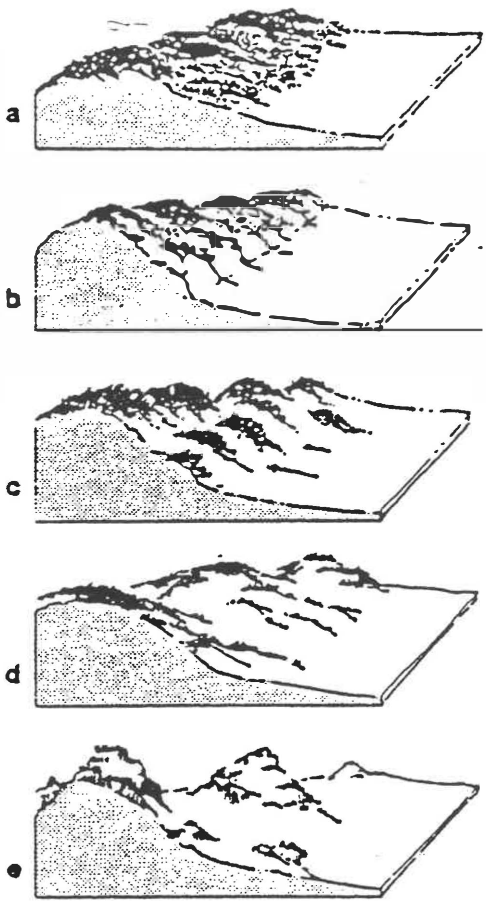
6.2 East Coromandel Barriers

The distribution of barrier types along the eastern Coromandel coastline is summarised in Figure 6.4.

Prograded Barriers

Prograded barriers contain evidence of extensive progradation, suggesting an abundance of sand, and consist of multiple beach ridges, seen as a parallel ridge and swale pattern on aerial photographs. The low ridges are characteristically 2-3m high separated by low-lying swales 10-20m wide. At Whitianga, an extensive prograded sand ridge plain consists of over 30 low-relief sand ridges. The progradation rate of the strand plain has been rapid as is suggested by the presence of Taupo Pumice, 1km inland from the modern foredune. The sand ridge (T11/503825) contains three distinct layers of Taupo Pumice, dipping 2° seaward. The pumice is light-grey in colour with an average pumice clast size of 10cm and up to 0.5m (Figure 6.5), suggesting a sea-rafted origin. Assuming a uniform rate of progradation, and taking the maximum age at the time of the pumice eruption to be 1800 y BP (Healy et al. 1964), then the rate of progradation is calculated near 0.5m/y for the last 1800 y. Cooks Beach is another example of a prograded barrier; 500m of progradation contains close to fifteen beach ridges which converge towards Purangi Estuary. The stratigraphy at Cooks Beach is established from several auger holes in this study, and along a transect conducted by Schofield (1970) (Figure 6.6).

Further examples of prograded barriers along the east Coromandel coastline include Matarangi, Pauanui, Whangamata and Bowentown.



Type a: Topographically continuous, well vegetated (90-100% cover), gently undulating.

Type b: Scarped type a foredune. Small scale unvegetated troughs, minor vegetation cover variation (75-90%)

Type c: Hummocky topography. Small to moderate size blowouts, vegetation cover 45-75%

Type d: Pronounced topographic variability. Mod.-large blowouts, sandsheets; partially vegetated ridges (cover 20-45%)

Type e: Remnant knobs, large scale deflation basins, blowouts and sheets. Vegetation cover 5-20%.

Figure 6.3 Schematic illustration of the range of Australian foredune types (from Hesp 1986).

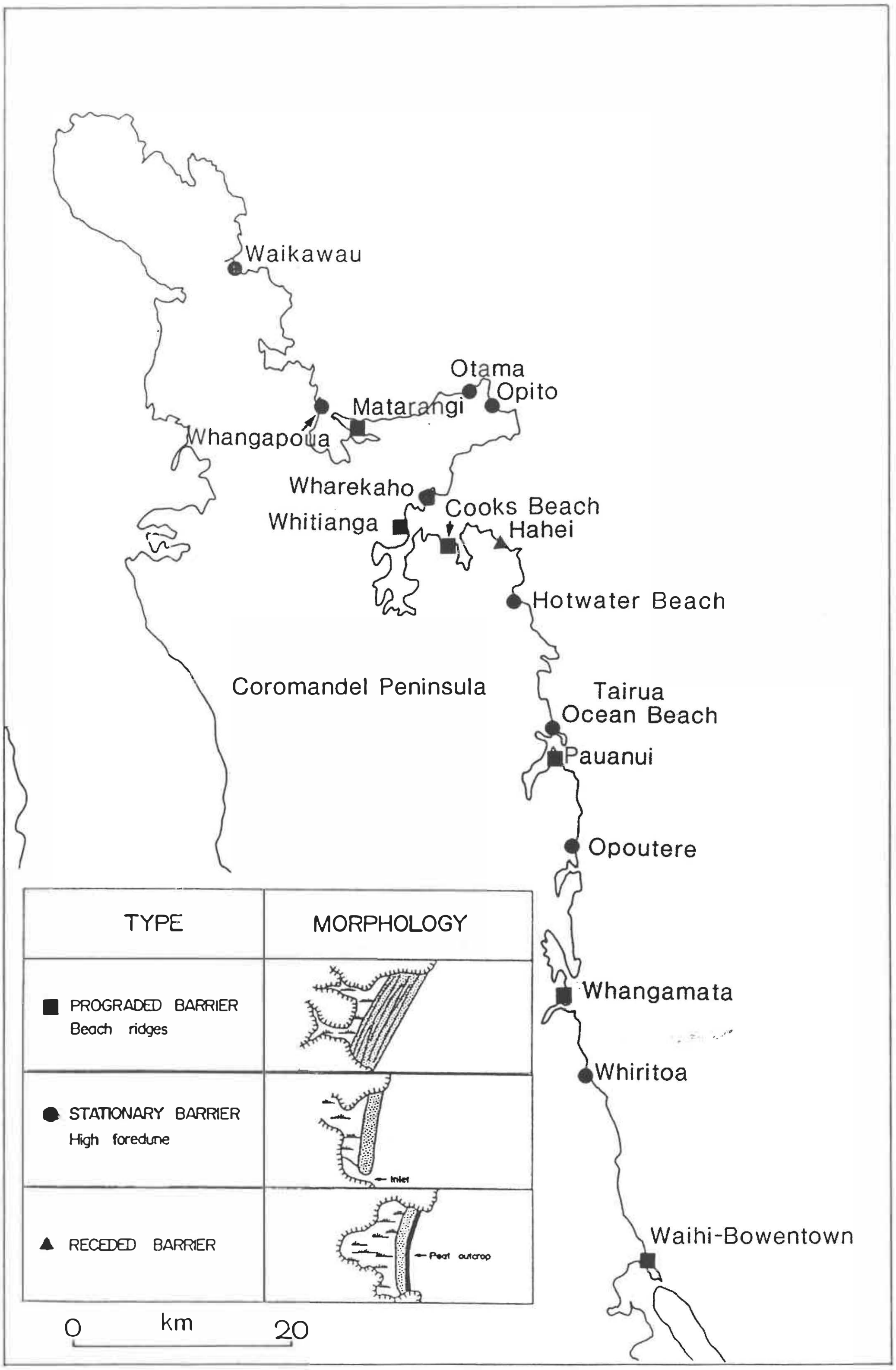


Figure 6.4 Distribution of Holocene barrier types along the east Coromandel coast.

Figure 6.5 At Whitianga (T11/503825), Taupo Pumice lies within a sand ridge in three main layers (one shown). Pumice pieces average 10cm in diameter.

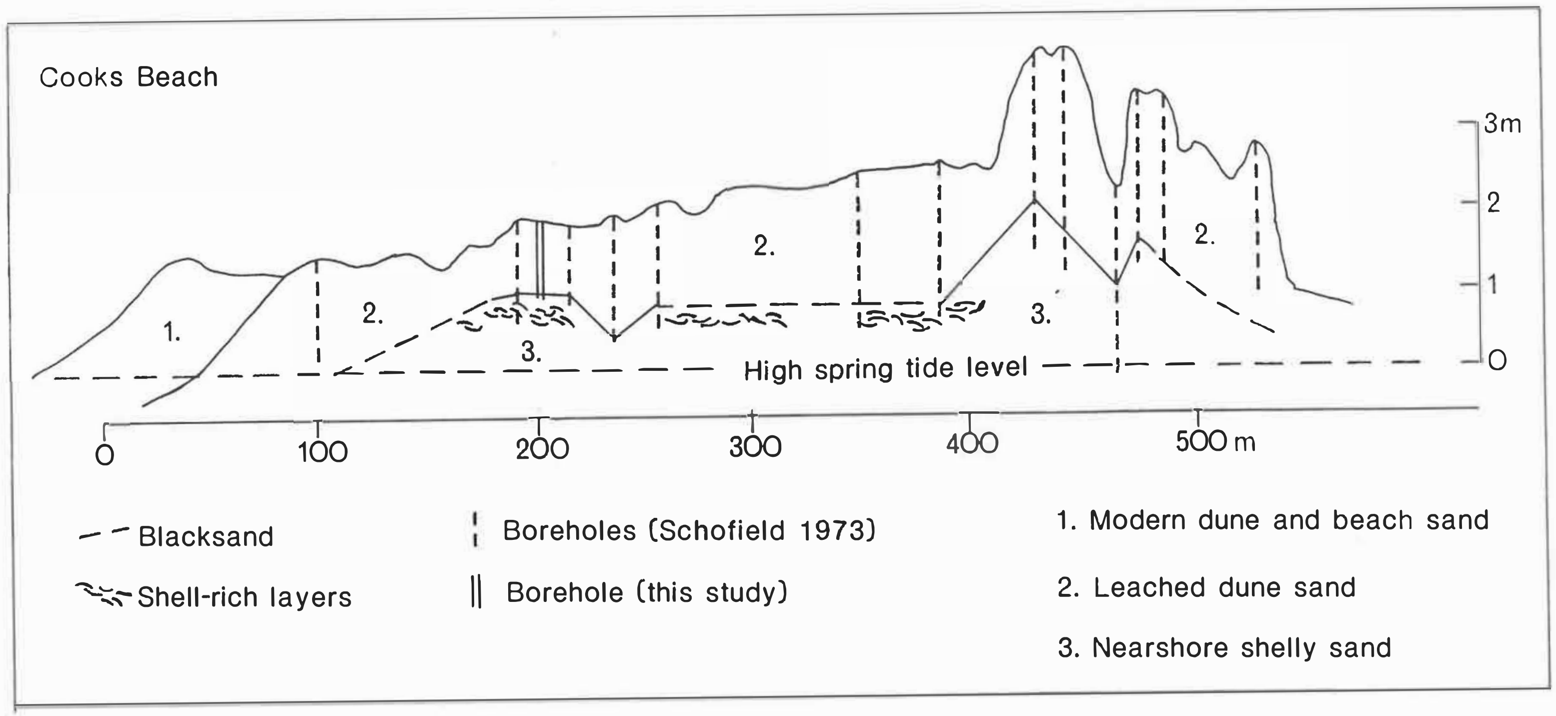


Figure 6.6 Shore-perpendicular cross-section of Cooks Beach embayment (after Schofield 1973).

Although Matarangi, Whangamata and Pauanui barrier spits were not studied in detail, a pattern of Holocene barrier evolution occurs in these embayments. Each is a barrier spit, characterised by a series of dune ridges, impounding an infilling coastal lagoon at one end and often fronting a shore-parallel backbarrier facies. On the seaward side the beach ridges are terminated by a relatively high, frontal dune complex. These barriers all occur across embayments which occupy large incised valleys.

Stationary Barriers

Stationary barriers reflect only limited seaward dune ridge progradation, relative to the larger prograded sand ridge plains. This type of barrier is common along the east Coromandel, including at Waikawau, Hotwater Beach, Otama, Opito, Whangapoua, Opoutere, Whiritoa and Tairua Ocean beaches, and is characterised by a large semi-vegetated sand body, no greater than 150m wide. On the landward side the sand body normally abuts a backbarrier flat.

A striking feature of the stationary barriers is the dune ridges which, although only few in number attain relatively high elevations (av. 10m) in comparison with the low-relief prograded barriers. Often the dune ridges have a hummocky topography induced by sand blowouts and transgressive sand movement. Extensive eolian redistribution has caused dunes in some areas to transgress and encroach upon the backbarrier flat, as at Hotwater Beach. Thom (1974) recognised three subtypes of stationary barriers; low-dune, high-dune and tombolo-like barriers.

High-dune ridges are the most common along the eastern Coromandel coast, and consist of large foredune complexes, up to 30m in height, partially stabilised by vegetation. Examples include Waikawau, Otama, Opito, Hotwater Beach and Opoutere.

Low foredune stationary barriers are relatively uncommon along the Peninsula, well-vegetated examples occurring at Whangapoua, Whiritoa and Wharekaho. Most of Wharekaho beach is backed by small dunes which in parts are presently undergoing erosion causing several faceted dunes, exposing bedrock at low tide along the shoreface. Significantly, the northern end of Wharekaho beach is normally mantled by heavy minerals, a condition regarded as typical of an eroding beach (Komar 1976). Sediment starvation at Wharekaho beach, is suggested by offshore profiles (Healy et al. 1981).

The third subset, called tombolo-like, are described as sand-bodies which link bedrock "islands" (Thom et al. 1981). Tairua Ocean Beach provides an excellent example where partially stabilised high dune ridges bridge Paku Island and the mainland.

Receded Barriers

The third category of barriers recognised by Thom, the receded barriers, are relatively rare on the Coromandel coast. Receded barriers are commonly associated with eroding shorelines and are normally characterised by estuarine, lagoonal and backbarrier sediments cropping out at the present foreshore (Thom et al. 1981). Hahei beach essentially fits this type. At its eastern end the limited barrier foredunes are at present undergoing severe coastal erosion. The rest of the beach is delimited, in the sense that it is backed and underlain by a Pleistocene terrace, and as such cannot retreat any further. Such barriers are usually associated with rising sea levels or a shore-zone deficiency in sand relative to energy conditions (Thom et al. 1981). Healy et al. (1981) has reported that the sediment volume of Hahei beach appears to be very limited.

Barrier Formation

The occurrence of prograded systems along the east Coromandel is consistent with a large sediment source. Each prograded barrier partially encloses an extensive estuary which contains large volumes of sediment and drains a large catchment area. The Whitianga estuary drains a catchment of hill country with an area of 441km^2 (Smith

1980). The rivers and catchment areas supply a large volume of sediment to the estuary and nearshore beach system, via tidal deltas and extensive tidal flats. Gibb (1986) showed the Tairua River is the major supplier of sand to the prograded barrier at Pauanui, with small amounts also supplied from the nearshore seabed and from biogenic sources from within the harbour and along the adjacent coast.

However large volumes of sediment are also contained within the high dune stationary barriers of east Coromandel. The reasons for development of this type of barrier rather than a low relief strand plain (prograded barrier), or other type may be due to the environmental parameters operating and/or coastal physiography. The importance of energy conditions (primarily wind and wave) and coastal physiography can be demonstrated in a comparison of barrier complexes and their dune and beach depositional environments from areas of contrasting inner shelf steepness and energy conditions.

Globally, Short and Hesp (1982) have described the New Zealand east coast swell and trade wind environment as one on which moderate energy intermediate beaches might be expected to develop. Using an approach based on the beach-state model of Short and Hesp (1984) for the southeast Australian coast, a classification of the east Coromandel beaches is given in Table 6.1. These data generally support the findings of Australian research that there is a relationship between shelf gradient and wave energy at the coast, as well as the size of adjacent foredunes. The low energy reflective and intermediate reflective beaches (e.g. northern Wharekaho and northern Buffalo beaches) are characterised by a steep-cusped or bermed beach face, a narrow mean beach width and relatively low backing foredunes. These embayments also have fairly comparable and shallow shelf slopes, and relative low wave energy. The higher energy intermediate beaches (e.g. Hot Water Beach, Waikawau and Opoutere) have steep shelf slopes and often exhibit 'typical' dissipative beach states where there are wide mean beach widths, flat to low gradient beaches and high foredunes disrupted by occassional sand blowouts. Intermediate beaches occupy transition states where beach face gradients, the

Table 6.1 Beach, shelf and wave characteristics of the East Coromandel embayments.

Embayment	Shelf Gradient	Foredune Height(m)	Relative Wave Energy	Beach Grain Size	Beach Class[1] (according to Short & Hesp 1982)	Barrier Type[2]
Waikawau	1:70	15-20	high-mod	ms	interm - dissip	stationary (hd)
Whangapoua	1:180	3	mod	ms	interm	stationary (ld)
Matarangi	1:180	5	mod	fs	interm	prograded
Otama	1:180	13	mod	ms	interm	stationary (hd)
Opito	1:220	7	mod	ms	interm	stationary (hd)
Wharekaho (N)	1:280	0	low	fs	reflect - interm	stationary (ld)
Wharekaho (S)	1:260	3	mod	ms	interm	stationary (ld)
Whitianga (N)	1:400	0	low	fs	reflect - interm	
Whitianga (S)	1:340	2	mod	fs	interm	prograded
Cooks Beach	1:310	4	low	fs	interm	prograded
Hahei	1:300	0-7	mod	ms	interm	receded
Hotwater	1:80	15-20	high-mod	ms	interm - dissip	stationary (hd)
Tairua	1:200	10	mod	cs	interm	stationary (t)
Pauanui	1:200	6	mod	ms	interm	prograded
Opoutere	1:70	8-10	high-mod	fs-ms	interm - dissip	stationary (hd)
Whiritoa	1:180	7	mod	ms	interm	stationary (ld)
Mataora	1:180	3	mod	ms	interm	stationary (ld)
Waihi-Bowentown	1:170	3	mod	ms	interm	prograded

1. interm - intermediate, dissip - dissipative, reflect - reflective
2. hd - high dune, ld - low dune, t - tombolo

degree of dune erosion and accretion, berm development, dune forms, beach width and cusp development vary considerably throughout the year.

From data above a close link between surfzone beach behaviour and foredune morphology is apparent. Interacting parameters include sediment supply and coastal physiography. A sediment supply must be available for barrier formation, but it also influences the type of beach system which develops, which in turn can govern foredune morphology. Coastal physiography partially controls the wave energy regime. Incident wave energy is first affected by the shelf gradient, the wider and shallower the shelf the lower the wave energy. Second, wave energy is influenced by the coastline orientation or embayment exposure relative to fetch. This control may account for the difference in wave energy observed along Wharekaho and Buffalo (Whitianga) beaches, where the northern ends receive relatively low wave energy because they are more protected by headlands.

In the absence of more detailed research, several points are listed below regarding the formation of barrier types within the eastern Coromandel embayments (Table 6.2);

(a) Prograded barriers are associated with an abundant sediment supply, closely linked to large hinterland areas, but are also fostered by shallow shelf gradients and consequent reduced wave energy promoting reflective beach systems and stable continuous foredunes at the shoreline (e.g. Whitianga).

(b) Stationary barriers occur within coastal embayments open to moderate wave and wind conditions (intermediate beach systems) where sand accretion is often vertical forming large dunes (e.g. Otama). Increased energy conditions, often associated with steep shelf gradients, characteristically produce increased dune asymmetry including foredune disruption, sand blowouts and sand mobility (e.g. Hotwater Beach) initiated by vegetation destruction, and wave and wind erosion.

(c) Receded barriers normally have a deficient sediment supply (e.g. Hahei).

Table 6.2 Barrier types and environmental controls.

Barrier type		Embayment examples	Environmental Controls
Prograded	Beach ridge	Whitianga, Cooks Beach	Deeply indented, shallow embayments, large sediment supply
	Barrier spit	Matarangi, Bowentown, Pauanui	Large incised valleys, large sediment supply
Stationary	High dune	Otama, Opito, Opoutere, Whiritoa, Hotwater Beach, Waikawau	Pocket beaches bounded by headlands, open to ocean conditions, moderately high sediment supply
	Low dune	Whangapoua, Wharekaho, Mataora	Pocket beaches as above, decreased wind strength and low sediment supply
	Tombolo	Tairua Ocean	Pocket beaches as above
Receded		Hahei	Pocket beaches with deficient sand supply

6.3 Embayment Classification

It has been suggested that the various barrier types formed in response to specific embayment conditions, including hinterland area, shelf dimensions and coastal configuration. This has enabled the classification of east Coromandel embayments into embayment categories according to environmental controls. The east Coromandel embayments can be classified into prograded barrier spit embayments, bay barrier embayments, and strand plain embayments (Figure 6.7). The extent of depositional environments in the embayment types are shown in Table 6.3.

A similar approach was taken by Roy et al. (1980), who classified the embayments of the high energy southeastern Australia coast into three types; open ocean embayments, barrier estuaries, and ria estuaries. The equivalent classification system is not suitable for the smaller area studied in this project and the near universal dominance of barrier estuaries along the east Coromandel coast.

Embayment Types

Type 1: Prograded barrier spit embayments are where estuarine-lagoons occupy drowned river valleys impounded by prograded barrier spits. They occur within valleys drowned during the Postglacial marine transgression. The embayments characteristically follow the irregular, almost dendritic outline of the valleys they occupy (Figure 6.7). These embayments have large catchment areas (e.g. $280km^2$ for Tairua estuary and Pauanui Spit). Estuary dimensions range from approximately $25km^2$ to $4km^2$, commonly shallow depths (<5m) and narrow tidal inlets, averaging 250m wide. Offshore shelf gradients range from 1:200-1:180. Estuarine deposits dominate the embayments, from shelly sands in the channels to muddy sands of the estuarine basin and flats, and occasional accumulations of shelly debris on the tidal flats. Large volumes of sediment are contained within these estuarine deposits. The barrier deposits correspond mainly to prograded beach ridge types reaching widths of 500m comprising over 60 sand ridges.

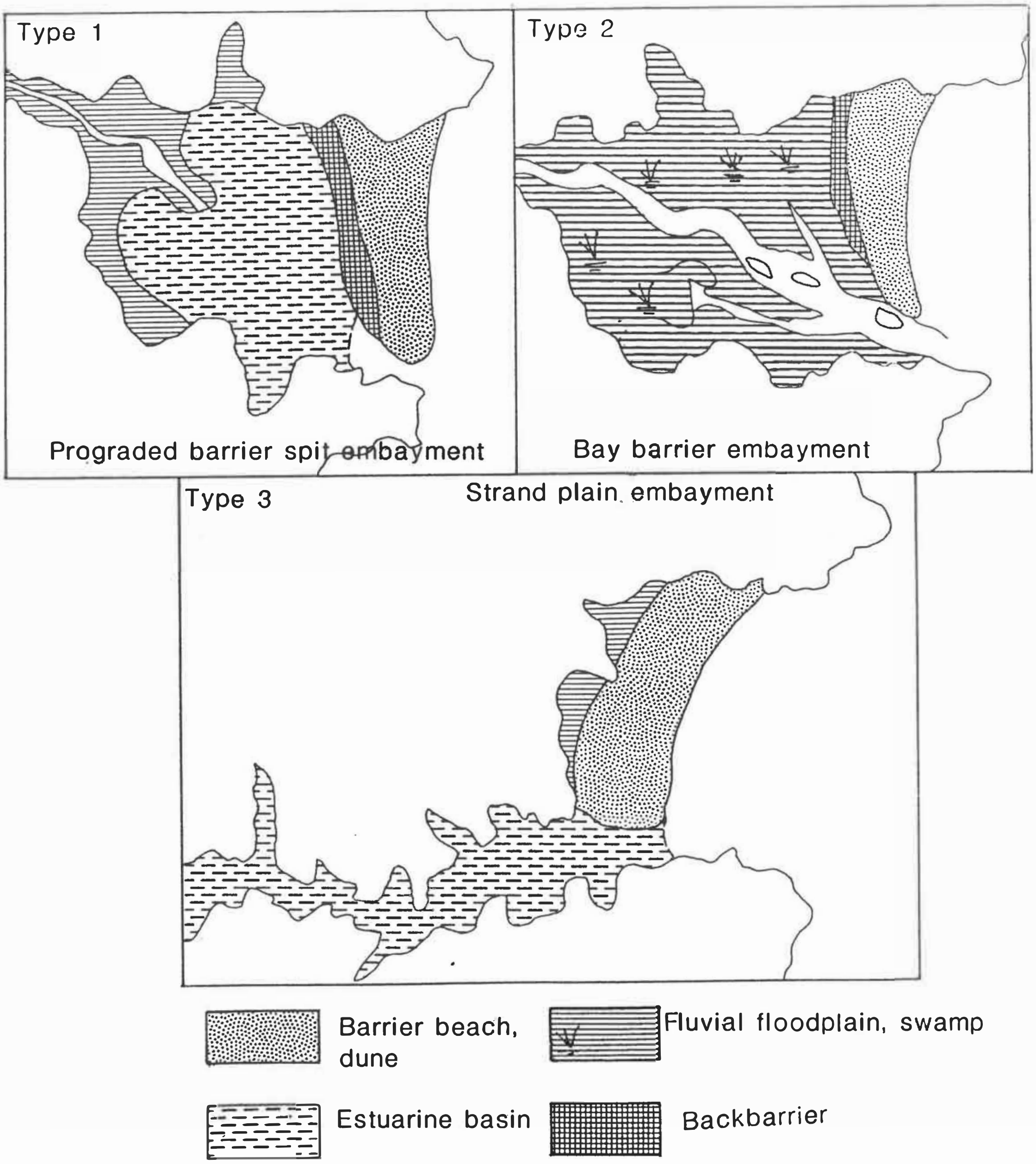


Figure 6.7 Generalised illustrations of the three primary types of embayments, and the extent of depositional environments in each type.

Table 6.3 Extent of Holocene depositional environments within the embayment types.

Unit[1]	Depositional Environment	Lithofacies	Development of Environments in Embayment Types[2]		
			Type1	Type2	Type3
HB	Beach and nearshore	shelly sand	xx	xxx	xx
HB	Dune	clean sand	xx	xx	xxx
F	Fluvial				
	Alluvial	gravelly sand	x	xxx	x
	Swamp	peat		xx	x
E, HSF	Estuarine	muddy sand & organic-rich sand	xxx	x	xxx
HSF	Backbarrier	muddy sand	xxx	xx	x

1. HB - Holocene Barrier, F - Fluvial, E - Estuarine, HSF - Holocene Sand Flat
2. xxx - well developed, xx - moderately developed, x - minor development

Backbarrier flats lie immediately landward of the innermost beach ridge and are up to 600m wide. The barrier deposits occur as baymouth barriers and as such are exposed to ocean swell and wind waves. The dune ridges are continuous and semi-vegetated by dune grasses. The barrier spit embayments include Pauanui, Matarangi, and Bowentown.

Type 2: Bay barrier embayments occur in small irregularly-shaped embayments, normally less than 2km wide, characteristically supporting pocket beaches. The embayment fill is mainly dune, beach and fluvial sediments. Bay barriers are of the stationary type (Thom et al. 1978) reaching widths of 150m, with high semi-transgressive dunes attaining elevations of 15m. Dune asymmetry ranges from scarped dunes with minor vegetation cover, increasing to hummocky topography, moderate sand blowouts and an erratic vegetation cover. This increasing dune asymmetry probably occurs in response to increased energy conditions and steepening shelf gradients. Incident wave energy is moderately high but is dependent upon coastal orientation, coastal configuration and shelf gradient. Embayment orientation varies from north-facing to east-facing. Coastal configuration ranges from semi-enclosed to weakly indented embayments, and shelf gradients vary from 1:80 to 1:200. Generally, the beach systems range through the intermediate states, from more reflective conditions in semi-enclosed bays to partial dissipative situations in more exposed bays. The dune formations enclose low-lying regions containing fluvial flood plains and swamp regions which have progressively infilled estuarine basins. The bay barrier embayments contain infilled estuaries where the tidal prism is confined mainly to the river channel, and as such reflect the mature development stage of an infilling barrier estuary (Type 1). The greater degree of infilling of Type 2 embayments may be attributed to their smaller size relative to Type 1 embayments. Opoutere embayment represents a transitional stage between Type 1 and 2. It contains a barrier spit and partially infilled estuary, is fronted by a steep shelf gradient, while the barrier is surmounted by high dunes indicative of increased energy conditions. Bay barrier embayments include Waikawau, Whangapoua, Otama, Opito, Hahei, Hotwater Beach, Whiritoa, and Mataora.

Type 3: Strand plain embayments are less common, and only occur in the strongly indented Mercury Bay along the east Coromandel coastline. These indented embayments are dominated by prograded multiple sand ridge plains, which have prograded rapidly, up to 1km in the last 2000 years. The sand ridges are commonly 2-3m high separated by lowlying, often swampy swales, up to 15m wide. The semi-enclosed bays are characterised by shallow water depths at their bay mouths, ranging from 5-8m. The incident wave energy is considerably reduced, due largely to wave refraction about offshore islands, and the shallow shelf profile, with rocky headlands becoming the focus of wave convergence. The continuous sand ridges are well vegetated. Narrow estuaries, exhibiting different degrees of infilling, connect catchment rivers to the sea. Whitianga and Cooks Beach are examples of Type 3 embayments.

6.4 Estuary Evolution

As the east Coromandel coast was inundated by the Postglacial sea level rise, estuaries formed behind marine sand bodies depositing in the drowned valleys. During the last 6500 years or so of stable sea level conditions the estuaries have been infilling with sediment and the embayments have evolved through estuarine stages of development. In very general terms, all estuaries follow similar evolutionary paths as they infill with sediment (Davies 1974), with time, water area and depth decrease causing a change in hydrological characteristics and biological communities (Roy 1984).

The east Coromandel barrier estuaries are characterised by narrow elongated entrance channels within broad tidal and backbarrier sand flats. Small tidal deltas occur near the entrance mouths and prograde over sandy muds in the estuarine basins. Further landward, fluvial deltas prograde at river mouths into the muddy estuarine basins. Poorly sorted sands and silts are the dominant fluvial lithology, intersected by channel sands and gravel-dominated levee deposits. Currents have a changing role, with fluvial currents dominating in the upper reaches, wind waves becoming more important in the main estuary body, and prominent tidal currents in the estuary mouth, especially within the entrance channel, as at Whitianga.

Characteristic evolutionary progressions in barrier estuaries are recorded in the eastern Coromandel estuaries. Initially, the estuary is contained behind coastal barriers and has a highly irregular shoreline (e.g. Bowentown). With partial infilling, the estuary shallows and the fluvial delta, tidal delta and backbarrier deposits increase or prograde into the estuarine basin (e.g. Tairua) (Figure 6.8). Continued infilling causes the estuarine channels to bifurcate around broad sandy bars and shoals (e.g. Opoutere, Cooks), and fluvial silts and colonising vegetation aggrade over the estuarine basin. Otama and Wharekaho represent near mature estuaries or essentially filled estuaries where fluvial deltas comprising flood plains, swamps and sinuous streams infill the estuarine basin. Filled estuaries have the tidal prism confined to the river channel by flood plain deposits, as at Hotwater Beach.

Figure 6.8 The partially infilled estuary of Tairua, is enclosed by a Holocene barrier spit (middle left), and a barrier tombolo (bottom). Extensive sand flats are exposed at low tide (shown).

CHAPTER SEVEN

SYNTHESIS

This thesis has described aspects of late Quaternary sedimentation along the east Coromandel coastline. These features, and their implications, are recalled here and synthesised into a general model of late Quaternary coastal sedimentation and embayment evolution for eastern Coromandel.

7.1 Background

The eastern Coromandel coastal deposits have accumulated within valleys and basins carved from a geologically diverse hinterland comprising Jurassic sedimentary rocks derived from an andesitic provenance, non-volcanogenic Oligocene coal measures and marine calcareous rocks, and a Miocene - Quaternary sequence of igneous rocks (Schofield 1967, Skinner 1986). During times of lowered sea level in the late Cenozoic rivers incised these valleys, producing embayments of variable size and orientation and irregular dendritic outlines.

Tectonic influences in this region include active faulting since the deposition of the Tertiary volcanic sequence. Seismic profiles indicate that igneous basement offshore has been faulted into a series of north-south oriented grabens (Thrasher 1986), while northeast-trending faults onshore have divided the peninsula into a series of fault blocks which have downthrown to the south (Figures 5.3, 5.4). Quaternary fault displacements along the northeast-trending faults have been calculated in this study from the different elevations of the Pleistocene barrier formations to be in the range 0.02-0.036 mm/y (Figure 5.5).

The east Coromandel coast is oriented NNW-SSE and as such is a lee shore sheltered from the prevailing westerly and southerly winds and waves that dominate the wave climate of much of New Zealand (Pickrill and Mitchell 1979, Harris 1985). The present wave climate is dominated by northeasterly swell originating from subtropical disturbances north of New Zealand and from depressions moving down from the northwest, typically producing strong northeast winds (Christopherson 1977). The low energy swell environment is considerably lower than on the other more exposed New Zealand coasts (Harris 1985). Incident wave energy at the coast is also reduced locally either by wave refraction about the offshore islands (Smith 1980), or by frictional loss across wider and shallower parts of the inner shelf (Table 6.1).

It has been demonstrated in several local studies (Christopherson 1977, Willoughby 1981, Healy and Dell 1982) that the present coastal sediment is derived mainly from the Coromandel Volcanics via fluvial and cliff erosion. The same conclusion was also reached in this study, although minor amounts of sediment have also come from the Taupo Volcanic Zone (Section 4.2).

Shepherd (1982) described the east Coromandel coast as one supporting embayments where an onshore/offshore mode of sediment transport is likely to be dominant. Recent workers have for several reasons suggsted that the local shelf was a major sediment source. In particular; (i) there appears to be little sediment input from fluvial and cliff sources along much of the coast at the present day (Harray 1977, Willoughby 1981, Dahm 1983), (ii) much of what there is can be trapped within estuary sinks, and (iii) that the Coromandel coastline is not nourished by a regional littoral drift system (Healy and Dell 1982). Despite these generalisations, significant contributions of sediment are derived from some rivers. Gibb (1983) showed that the Tairua River contains abundant sand supplied from catchment erosion and marine sediments transported into the harbour and is the major supplier of sand to Pauanui Beach via the ebb-tide delta. Based on this finding, it is suggested that during lower stands of sea level in the Quaternary, repeated fluvial incision of the Coromandel Volcanics has removed large volumes of sediment offshore. Subsequent rises in sea level have probably mobilised the eroded sediment landward, which has then become available for barrier progradation at the shoreline (Harray and Healy 1978).

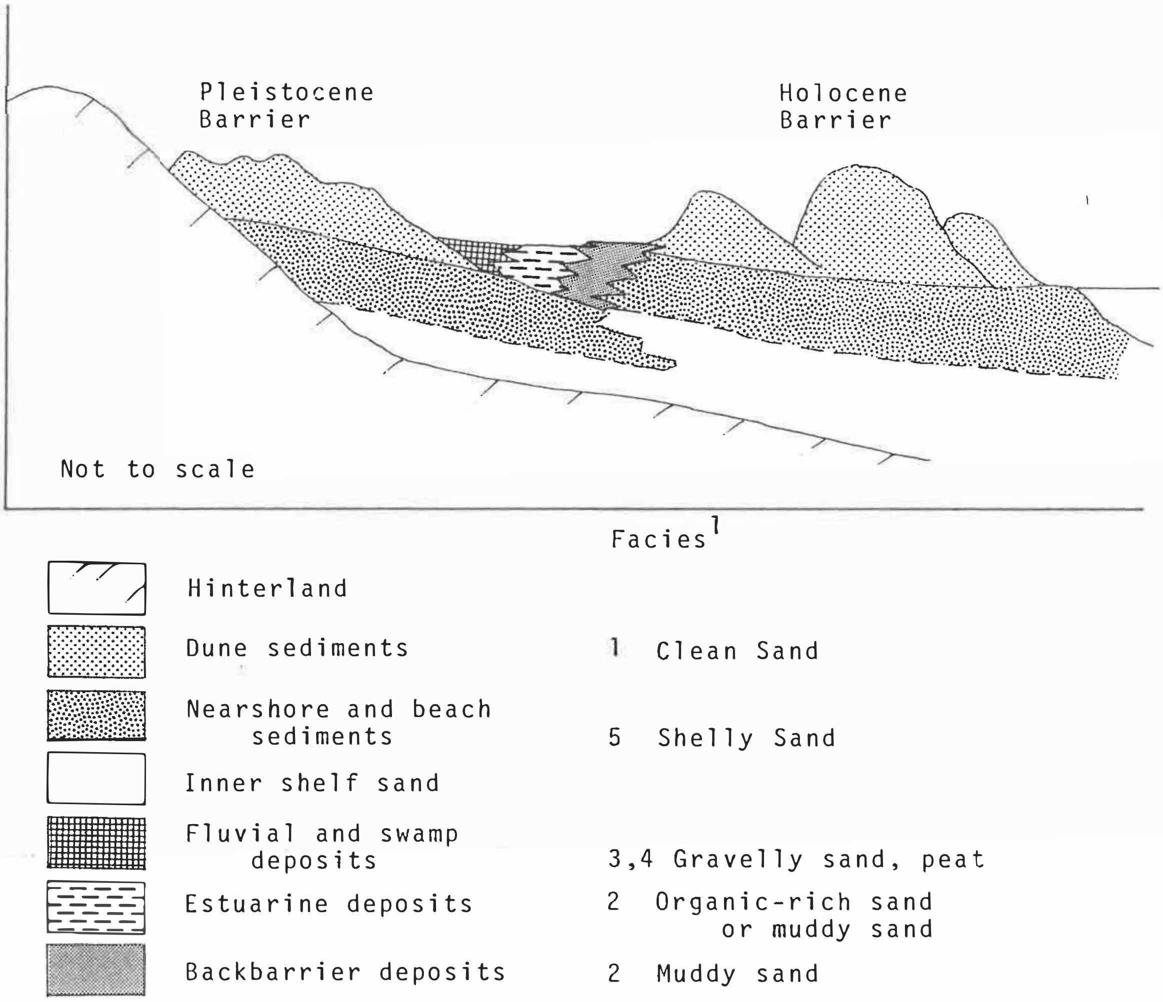
7.2 Late Quaternary Coastal Geology

A basic aim of this thesis was the description of the late Quaternary coastal sequence in the east Coromandel embayments, including the stratigraphic, chronologic and geomorphologic associations.

The eastern coast of Coromandel Peninsula is described by McLean (1978) as a headland-bay coast, comprising a succession of headlands separated by narrow shallow bays. The embayments are small, commonly less than 5km long and 2km wide and backed by a rugged volcanic landscape (Section 3.4). Fronting each bay are sandy beaches, commonly displaying regular geometrical outlines.

The embayment fills consist of alluvial plains, swamps, lagoons and a succession of beach and eolian deposits of late Quaternary age. In several bays, dual barrier systems have been identified (Figure 7.1), and it is likely that these are coeval with the Inner Barrier system of late Pleistocene age and the Outer Barrier system of Holocene age found widely across the Australian coastal plain (Bird 1978, Thom et al. 1981). Pleistocene barriers along the eastern Coromandel coast occur as subdued ridges and are remnants of several different types of barrier systems. For example, at Waikawau and Opoutere the late Pleistocene sand deposits back against the hinterland, suggesting bayhead barriers. Fronting in part Otama embayment and enclosing Holocene deposits are remnant paleodunes of a a baymouth barrier (Figure 3.2).

The Holocene barriers comprise a variety of deposits (Figure 7.2). Well developed, prograded beach-ridge systems occupy bayhead positions in Mercury Bay at Whitianga and Cooks Beach, or enclose estuarine-lagoons forming barrier spits, as at Pauanui and Omaro Spits (Section



1. Facies defined in section 4.4

Figure 7.1 Generalised facies relationship for Pleistocene and Holocene barriers on the eastern Coromandel coast.

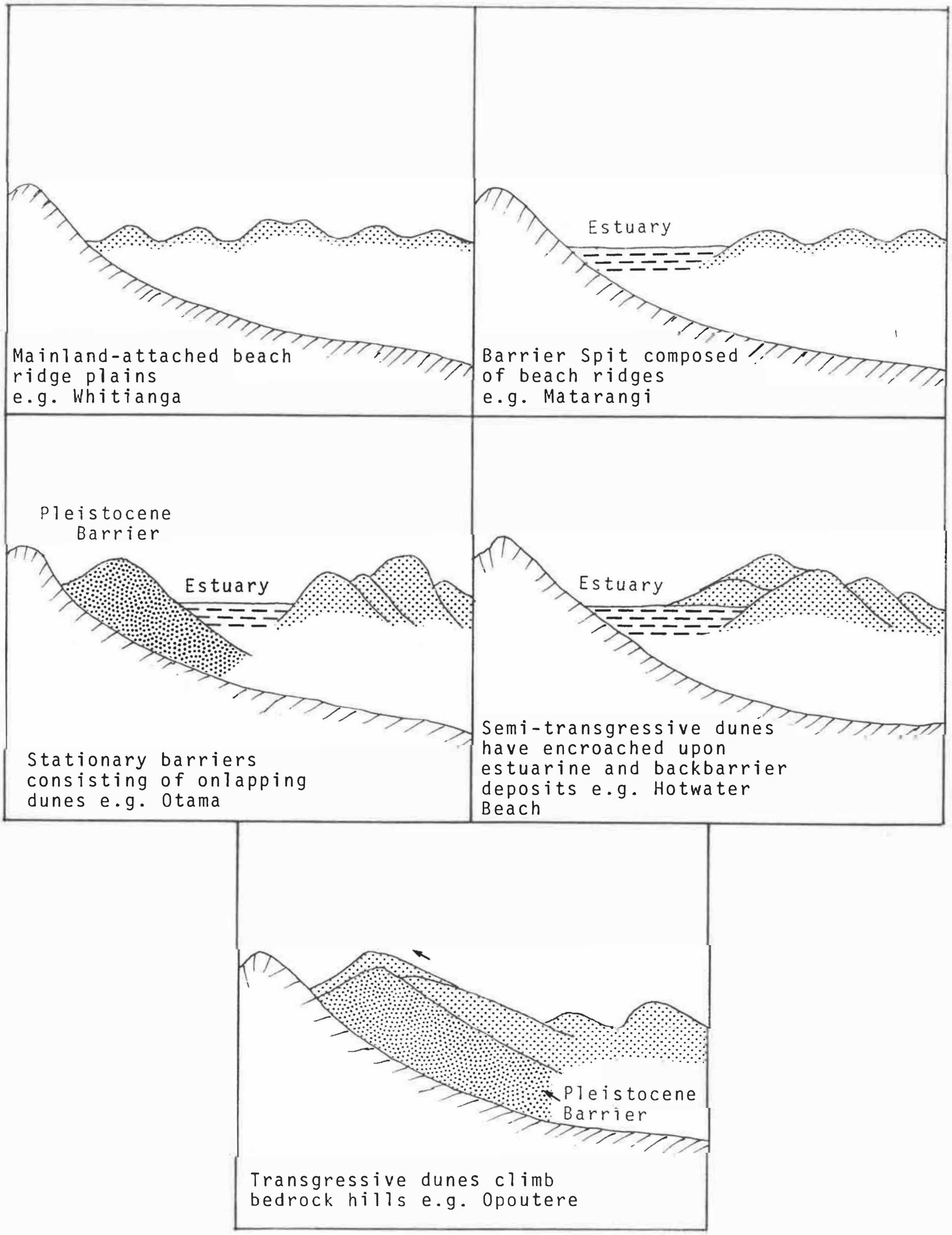


Figure 7.2 Types of Holocene barrier deposits found along the east Coromandel coast.

6.2). Larger dune formations along this coast are normally associated with narrower stationary barriers. Eolian modification of dune ridges has produced onlapping sequences and reworked dune morphologies, as at Otama and Tairua. At Hotwater Beach, semi-transgressive dunes, probably initiated from disturbed vegetation and dune blowouts, have transgressed over backbarrier sequences. Transgressive dunes of presumed early Holocene age onlap bedrock hills and part of the Pleistocene Barrier at Opoutere (Figure 7.2).

A time sequence is recorded across the coastal deposits by differences in soil profile development and associated weathering effects (Table 7.1). The Pleistocene barriers are locally strongly leached, forming thick iron pans and podzol horizons. Evidence for a Pleistocene age is the mantling Rotoehu Ash (*c*. 50 ky, McGlone et al. 1984), which provides a minimum age for the underlying soil and barrier sand. The age of the Rotoehu Ash is a matter of contention, with some research calling for an older age (Kennedy 1984). The Holocene sands exhibit a shallowing soil profile, reduced leaching and become less coherent seaward. Podzolised sands occur only at the most landward position of the Holocene barrier at Opoutere. The presence of Holocene tephras and pumices (Table 2.1), along with some radiocarbon dates (Table 2.4), has enabled predictions of the Holocene barrier time range. Evidence from the prograded beach ridge barriers (e.g. Whitianga) suggests that over the last 5000 y there has been progressive seaward progradation of some sand ridges. At Pauanui, the most landward radiocarbon date records a shoreline position at 5060 y BP (Gibb and Aburn 1986). At Opoutere, the Holocene barrier incorporates the Tuhua Tephra Formation (*c*. 6200 y BP), indicating early stillstand barrier accretion. Stationary barriers record a sequence of dune phases, at 2000-1500 y BP (Taupo Pumice event), 900-600 y BP, and <500 y BP (Section 2.1). In some embayments, it is the writers opinion that barrier sequences (pre-Taupo Pumice) may be exhumed and buried below younger onlapping sand deposits. Clearly, drill holes and more radiocarbon dating are needed to more accurately define the age structure of these Holocene barriers.

Table 7.1 Soil types and weathering characteristics across eastern Coromandel barrier deposits.

Soil Type	1	2	2	4	5	6
Environment of Deposition	Dune Sand	Transgressive Dune Sand	Dune Sand	Dune Sand	Dune Sand	Dune Sand
Age	Last Interglacial c. 125 ky BP	Early Holocene c. 9-6 ky BP	Mid Holocene c. 6-3 ky BP	Late Holocene c. 2-1.5 ky BP	Late Holocene c. 900-600 ky	Late Holocene <500 ky BP
Topography and Drainage	Mod-low relief poor drainage with depth	High relief, free-draining	Low relief, free-mod drainage	High relief, free drainage	Mod relief, free draining	High relief, free draining
Vegetation	Forest and pasture	Native Forest	Forest and pasture	Forest and pasture	Pinus radiata and woodland	Lupin and scrubland
Profile Thickness (m)	A_1 - eroded A_2 - 0.5 B - 5-8	A_1 - 0.4 A_2 - 0.3 B - 3	A_1 - 0.3 A_2 - 0.2 B - 1-2	A_1 - 0.3 A_2 - <0.05 B - 1	A_1 - 0.1-0.2 B - <0.2	A_1 - 0.01
Profile and Weathering Characteristics	Iron pans, leisogang rings and iron mottling	Iron mottling, incipient leisogang rings	Iron mottling	Incipient iron mottling		

7.3 Influence of Eustatic Sea Level Changes on Deposition

Patterns of coastal evolution vary considerably in response to relative changes of land and sea level. Emerged terraces, littoral and marine deposits around the world indicate a changing succession of regressive and transgressive coastal sequences. More recent studies of Quaternary paleoclimates have focused on deep-sea core stratigraphy, documenting significant oscillations in mean sea level of 100 to 120m amplitude, in response to continental glaciations every 100 ky to 150 ky (Shackleton and Opdyke 1973, Nelson et al. 1985). In Chapter Four it was argued that some tectonic movement was occurring along the east Coromandel coast during the late Quaternary. Despite these movements, it is considered that the major control on relative sea level change in the late Quaternary for the east Coromandel, has been the cyclically changing periods of high and low ice accumulation.

The east Coromandel record of late Quaternary coastal sedimentation records two depositional events which can be related to sea level highs. The most recent is the current Holocene stillstand which has promoted a Holocene sequence of shoreline deposits. Sea level oscillations over the last 10 ky has been the focus of considerable attention in many parts of the world. North American and European studies report contrasting trends in relative sea levels to Southern Hemisphere studies where, in the former areas, sea level appears to have reached its present level not earlier than 3.7 ky BP and as late as the present (Oertel 1985). In contrast, Australia and New Zealand the culmination of the postglacial marine transgression is well dated near 6.5 ky, around 3000 years earlier (Thom and Roy 1985, Gibb 1986). The major differences between Holocene sea level curves from the Northern and Southern regions is attributed to global isotatic processes (Thom and Chappell 1975). For New Zealand, Gibb (1986) has produced a regional Holocene eustatic sea level curve where eustatic sea level rose from -33.5 ± 2.5m below present sea level at 10 ky, reaching present sea level at 6.5 ± 0.1 ky.

The only other sedimentary sequence preserved along the east Coromandel coast, suggesting that during the late Quaternary there was only one other sea level higher or similar to the present level, are the Pleistocene Barrier deposits. Although the tectonic stability of the east Coromandel margin of New Zealand during the late Quaternary produced a sedimentary record only dominated by two sandy barriers, other regions of New Zealand record a series of glacial/interglacial events. Marine terraces formed during global eustatic sea level highstands attest to considerable vertical crustal deformation (e.g. Chappell 1975, Pillans 1983, Bishop 1984, Bull and Cooper 1986) and uplift rates of up to 5mm/y. Along the north Westland coast of New Zealand, glacial outwash interbedded with interglacial marine deposits records six Quaternary high sea levels (Suggate 1985).

As mentioned previously, the eastern Coromandel Pleistocene barriers formed during a sea level position very similar to the present. Intuitively, in the absence of accurate dates and given the minimum age of *c*. 50 ky on the overlying Rotoehu Ash, these barriers must have at least formed during the last sea level higher or similar to the present level. Hence, it is suggested that the Pleistocene barriers of east Coromandel are of last interglacial age (*c*. 125 ky) for reasons discussed below.

Elevation data from emergent islands and coastlines around the world indicate that the 125 ky interglacial which corresponds to oxygen istope stage 5e, represents the last time sea level was at least at the present level and possibly several metres higher (Marshall and Thom 1976, Stearns 1976, Harmon et al. 1978, 1981, 1983, Bender et al. 1979, Cronin et al. 1981). In regions where only one terrace or sand barrier is known, it is usually assumed to be *c*. 120-130 ky old (Thom 1965, Pillans 1983) and thought to represent the culmination of a major transgression cycle at 120 ky BP, when sea level lay between 5 to 8m above present (Chappell and Veeh 1978). Ward (1985) describes G11 (Gippsland shore corresponding to the last interglacial shoreline) in Victoria, Australia "an event as great as the postglacial and probably represents a similar, or even greater interval of time. Indeed the initially open coast was rectified, then prograded, before a large enclosing barrier like the postglacial one was developed". In New Zealand, terraces corresponding to oxygen istope stage 5e are best documented in South Taranaki (Pillans 1983) and eastern Bay of Plenty (Iso et al. 1982)

Deep Sea Drilling Project (DSDP) Site 594 in the southwest Pacific has produced a detailed record of sediment texture, calcium carbonate content, and planktonic and benthic foraminiferal oxygen and carbon isotope composition of the deep sea oozes (Nelson et al. 1985). This high resolution (~2400 y) sedimentary record displays a series of glacial-interglacial climate fluctuations and offers one of the best sections cored to date for study of climate change through the latest Cenozoic for the Pacific region (Nelson et al. 1985) (Figure 7.3). For the time framework of interest in this study (last 150 ky), planktonic and benthic foraminiferal $\delta^{18}O$ records at DSDP Site 594 suggest fluctuations in ice volumes and corresponding eustatic sea levels similar to earlier research, where ice volumes and sea level reached similar values to present only during oxygen isotope stage 5e. Preliminary detailed research has produced a higher resolution (~1000 y) calcium carbonate content and benthic foraminiferal $\delta^{18}O$ record from DSDP Site 594, offering an extremely detailed oceanic record of climate change through the last 150 ky (Figure 7.4) (P Cooke pers comm. (University of Waikato), A Cuthbertson pers comm. (University of Waikato)). These early results also suggest sea levels similar to those of today were last reached during and not since oxygen isotope stage 5.

The global stratigraphic dominance of the last interglacial and oxygen isotope records lend support to the assumption that the eastern Coromandel Pleistocene Barrier deposits, which are demonstrated through tephrochronology as older than 50 ky BP, are of last interglacial age.

The time period between the Holocene and Pleistocene barrier events of east Coromandel was characterised by glacial periods and sea

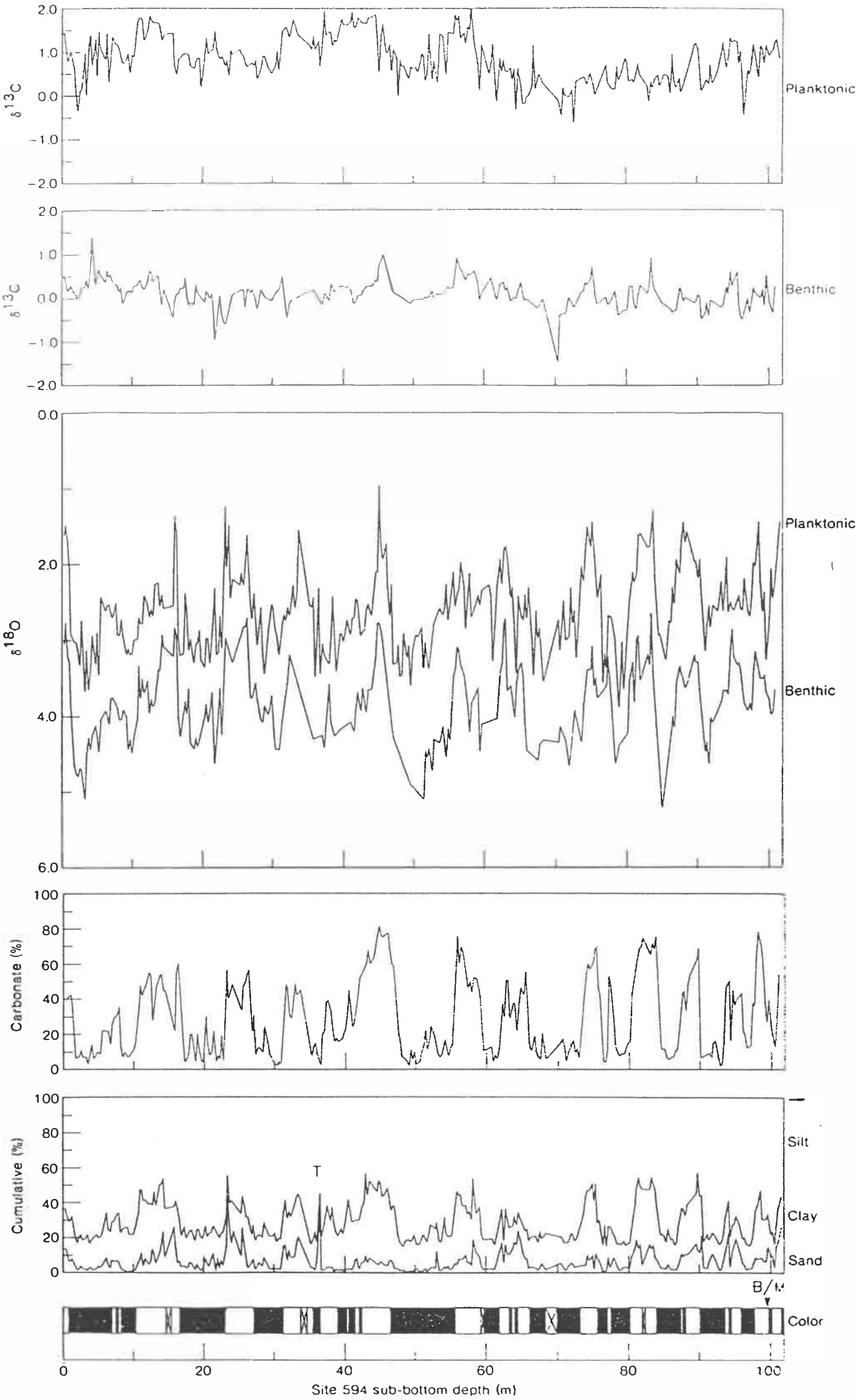


Figure 7.3 Summary stratigraphic logs of the colour, texture, and calcium carbonate content of bulk core samples and of the oxygen and carbon isotope variations of planktonic and benthic foraminifers in the late Quaternary oozes at Site 594 (from Nelson et al. 1985).

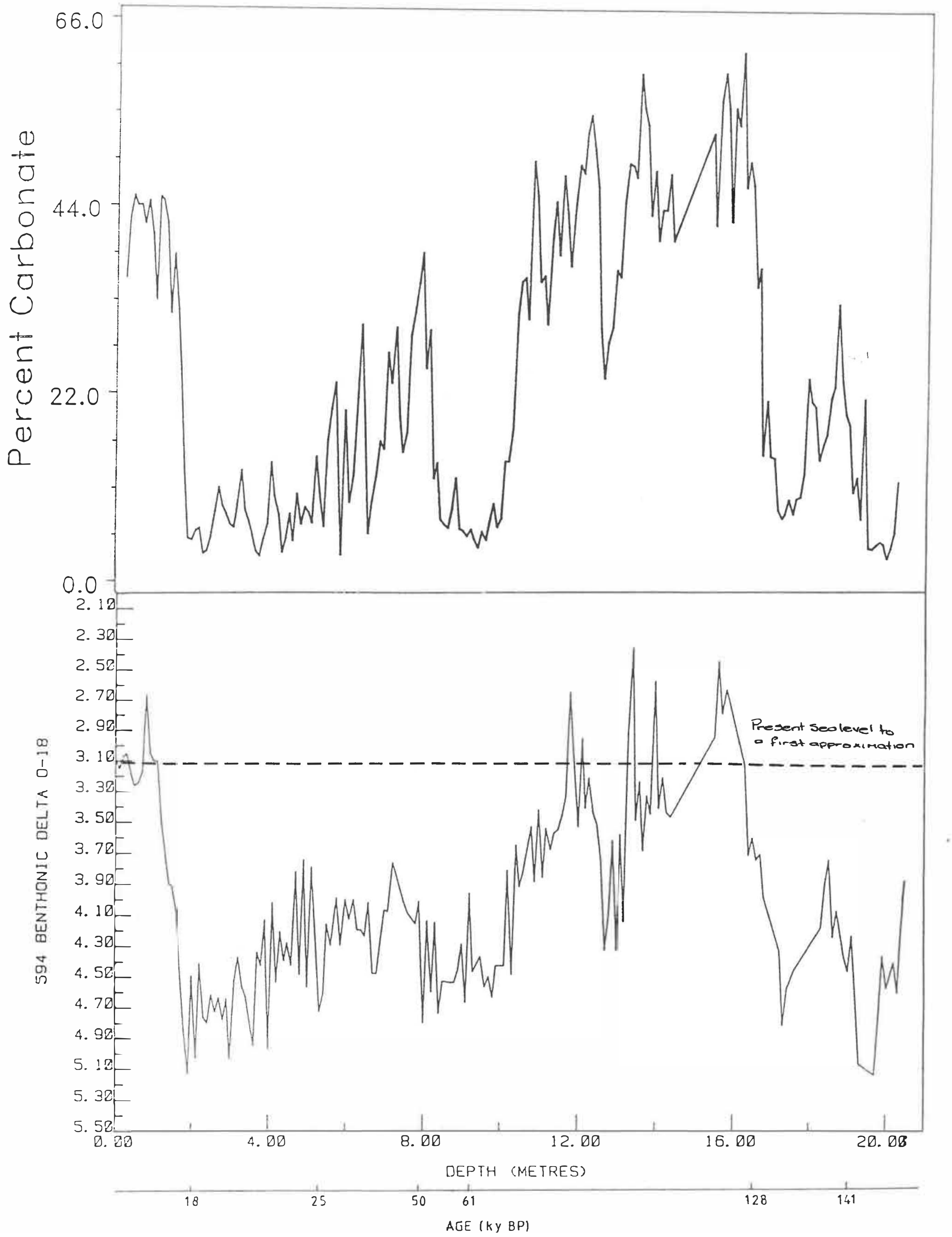


Figure 7.4 Higher resolution calcium carbonate content (A) and benthic foraminiferal $\delta^{18}O$ record (B) for isotopes stages 1 to 6, DSDP Site 594 (P. Cooke, in prep.; A. Cuthbertson, in prep.). Sea level and age conversion shown.

levels lower than present. New Zealand paleoenvironmental data suggest that climate deterioration after the Kaihinu (last) interglacial (Suggate 1985) (revised Oturi interglacial) marking the beginning of the Otiran glacial stage occurred about 70 ky BP (Salinger 1983). At the peak of the glacial period (*c*. 18 ky BP), sea level was located at and beyond the continental shelf edge, at depths of 110-150m. Evidence of eight submergent shorelines on the eastern South Island shelf, New Zealand and Great Barrier Reef shelf, Australia indicate that the postglacial transgression in the Southwest Pacific was episodic, comprising major stillstands punctuated by rapid rises in sea level (Carter et al. 1986). The shoreline migrated from its lowstand position at 20-18 ky BP, in a series of steps, identified at depths and likely ages of -113m/18 ky BP; -86m/17 ky BP; -75m/15 ky BP; -56m/12 ky BP; -46m/11 ky BP; -28m/9.5 ky BP; -24m/9 ky BP; and -9m/7.5 ky BP, finally stabilising at about its modern level at about 6.5 ky BP (Carter et al. 1986, Gibb 1986).

7.4 Model of Late Quaternary Sedimentation for Eastern Coromandel Embayments

The late Quaternary history is summarised in terms of five chronological stages (Figure 7.5). The basis of stage subdivision, namely the glacio-eustatic record, emphasises how sea level movements have exerted the dominant control on late Quaternary sedimentation along the east Coromandel margin, despite minor tectonic movements (Section 5.3).

Pre-Last Interglacial (>125 ky)

Investigation of the sequence of aggradation and cut terraces of the hinterland at Otama and other regions of the coast were beyond the scope of this thesis, but may elucidate earlier (>125 ky) sea level maxima and minima.

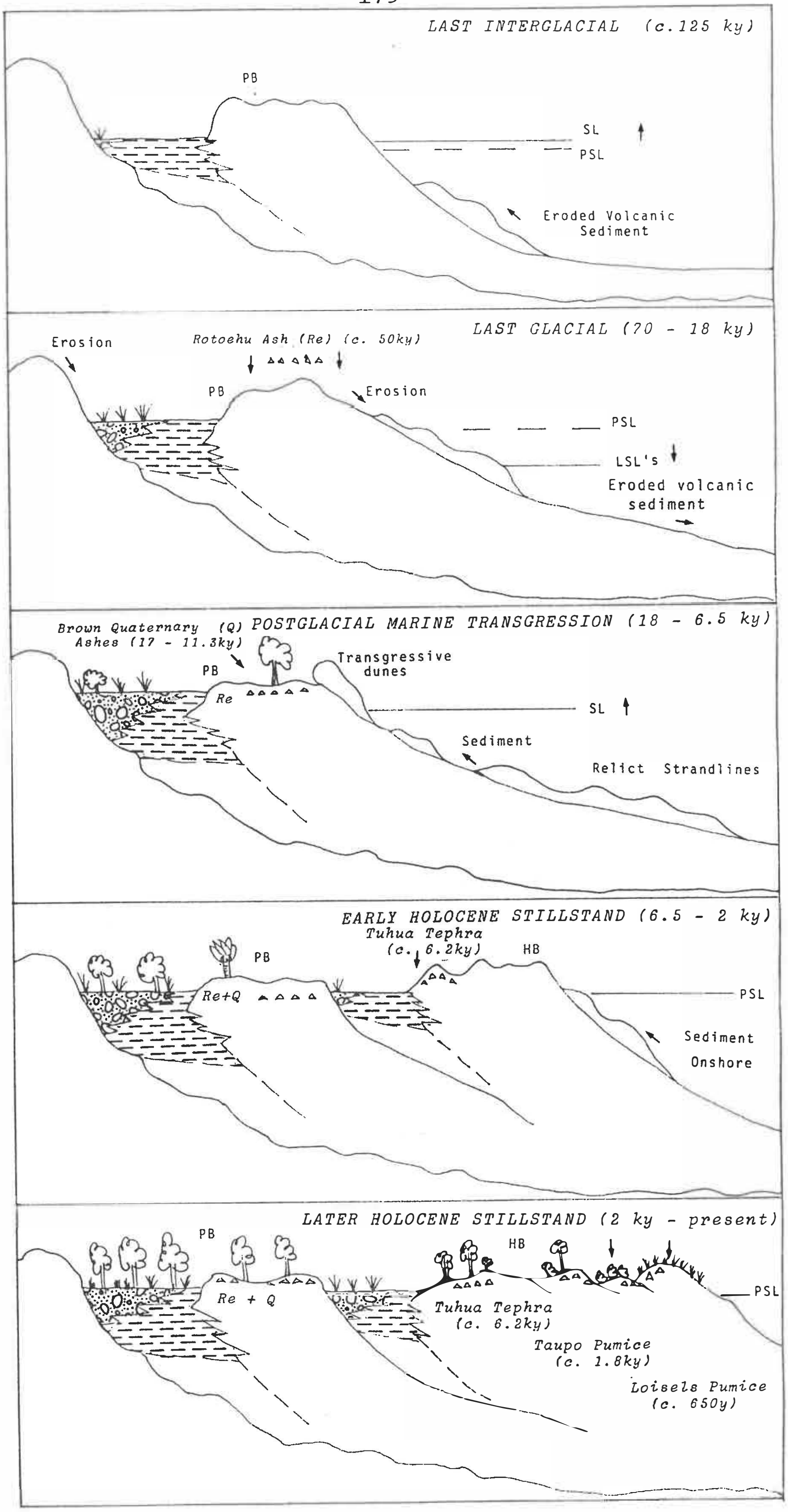


Figure 7.5 Schematic illustrations of coastal sedimentation during the late Quaternary for the eastern Coromandel embayments. SL - sea level, PSL - present mean sea level, LSL - lower sea level(s), PB - Pleistocene Barrier, HB - Holocene Barrier, Re - Rotoehu Ash, BQ - Brown Quaternary Ashes.

Last Interglacial (c. 125 ky)

The Tertiary volcanic bedrock of eastern Coromandel provided a basement for the development of Pleistocene barrier deposits during the last interglacial, globally recognised as a high sea level event (Shackleton and Opdyke 1973, Marshall and Thom 1976, Chappell and Veeh 1978). The surface of the volcanic basement was probably weathered subaerially for an indeterminant period of time, producing an irregular surface. As sea level rose from many tens of metres below its present position it probably reworked a portion of the eroded volcanic sediment shorewards. In each embayment, at a sea level position similar to present mean sea level, barriers formed at bayhead positions or against headlands forming spits and blocking valleys carved into the Tertiary volcanic deposits. Impounded water bodies or estuaries would have followed a similar evolutionary pathway as Holocene estuaries, infilling and eventually becoming swamps. At Otama, estuarine facies underlie paleodunes of the Pleistocene barrier. Three megadune forms onlapping each other can be traced and may represent either (a) coastal dunes, derived from the interglacial shoreline, which in part transgressed landward over estuarine deposits, or (b) reactivated dunes after the interglacial event. The absence of buried soils between the dune units suggests fairly continuous dune accretion or movement.

After the last interglacial high stand, sea level oscillated across the shelf with other reasonably high sea level stands being recorded by elevated reef complexes at 105 ky and 80 ky at Bermuda, New Guinea and Barbados (Bloom et al. 1974, Chappell and Veeh 1978, Harmon et al. 1983), although these did not reach the *c.* 125 ky high position.

With regard to the length of the 125 ky stillstand, it is suggested that sea level remained at this position along the east Coromandel for no longer than 6000y, based upon the size and extent of the depositional units (Section 3.4). In support, Harmon et al. (1983) present a paleosea-level curve that indicates the interglacial high sea stand was relatively short-lived, probably not exceeding 10 ky. Similarly, the detailed foraminiferal $\delta^{18}O$ record from DSDP Site 594 indicates the stage 5e high sea level stand did not exceed 10 ky (Figure 7.4).

Last Glacial (70 - 18 ky)

The last glacial stage corresponds to the time interval from about 70 ky (Salinger 1983) until the beginning of the postglacial marine transgression. Glacial periods dominated this stage, so that sea levels were generally several tens of metres lower than present. At the maximum of glacial cooling between 20 and 18 ky sea level was probably about 113m below present (Thom and Roy 1980, Carter et al. 1986). During this time, rivers were eroding and down cutting the Coromandel Peninsula Volcanic terrane and due to accelerated denudation a large quantity of fluviatile sand sediment probably accumulated at the coastline and across the exposed continental shelf region.

The Pleistocene barrier deposits were affected by `terrestrial' erosion, including fluvial pathways dissecting the linear trending barriers, probably some eolian reworking and the erosion of soil profiles. After formation of the Pleistocene barriers, sand podzols developed locally, probably more rapidly during warmer periods. Absent and disturbed soil profiles suggest reworking of the dune surface. Pre-dating the deposition of the Rotoehu Ash (c. 50 ky), the upper podzol horizons were eroded leaving only remnants of the characteristic silica-rich E horizon and iron-rich horizon. Almost uniform presence of the Rotoehu Ash and associated soil upon the Pleistocene Barrier surface suggests the tephra stabilised the sand deposits, and there has been negligible modification by eolian processes since ash deposition.

Postglacial Marine Transgression (18 - 6.5 ky)

The beginning of the postglacial marine transgression marks the onset of rapid sea level rise to the present position. Carter et al. (1986) indicates an episodic sea level rise from 113m below present some 18 ky ago culminating at its present level at about 6.5 ky ago. The episodic sea level rise comprised major stillstands and barrier formation, punctuated by rapid rises in sea level. Gibb (1986) suggests barrier systems are probably submerged and buried beneath the modern sand wedge on the New Zealand inner shelf, while Carter et al. (1986) have recognised a succession of submerged shorelines across the continental shelf east of South Island, New Zealand.

As the rising sea level drowned the bedrock valleys that had been further eroded and incised during the last glacial, mobilised inner shelf sands flooded into the compartments and were available for coastal progradation. Coastal dunes possibly associated with the postglacial marine transgression, transgressed against bedrock hills at Opoutere, attaining elevations 15m above present sea level. Opoutere is an exposed east-facing embayment, open to high wave energy and strong onshore winds, is fronted by a steep inner shelf and seems to be a local focus of littoral sand supply. It is suggested that these characteristics would have encouraged development of a transgressive dune belt in front of a transgressing shoreline. Additional sediment was supplied by tephras during this period from the Central Volcanic Region. Several tephras (Table 2.1) mantled the Coromandel Peninsula, including the Pleistocene barrier deposits and transgressive dunes, and now form a mixed 2m thick sequence of tephras and associated paleosols (Hogg and McCraw 1983).

Near the termination of this period barriers would have probably stabilised within the coastal embayments. However, the age pattern of the Holocene barriers found on the east Coromandel coast suggests that equilibrium was achieved at different times for various embayments (Section 6.2).

Holocene Stillstand (6.5 ky - present)

Australian studies suggest that at the cessation of the marine transgression, coastal embayments reacted rapidly to the disequilibrium slope of the transgressed surface in different ways, depending on the energy regime, the shelf configuration and the sediment supply. Landward sand migration ceases, and continued additions of marine sediment can be attributed to the nearshore system attempting to restore the equilibrium profile in which transfer of sediment from marine to subaerial environments is minimised (Roy and Thom 1981).

In east Coromandel the accumulation of onshore sediment produced rapid shoreline progradation, as beach ridges and large foredune development, in some embayments. In Opoutere embayment, there was early barrier development (*c.* 6200 y), while the earliest date for the prograded Pauanui barrier is 5060 ky (Gibb and Aburn 1986). At localities on the east Coromandel coast where progradation rates can be estimated, as at Whitianga and Pauanui, the accretion rates per year vary from 0.4m for Whitianga, and a decrease from 0.4m (5 ky - 4 ky BP) to 0.12m (4 ky - 2 ky BP) to 0.06m (last 2 ky) for Pauanui (Gibb and Aburn 1986). These data indicate that states of equilibrium were reached at different times in the embayments, and the decrease of accretion rates with time for Pauanui suggests a shoreline steadily approaching a state of long-term dynamic equilibrium (Gibb and Aburn 1986).

Enclosed bodies of water behind accreting Holocene barriers rapidly become estuaries as marine connection became restricted by sand deposits. Sand infilling by washover was probably high in these estuaries during the early stages of barrier formation, but as sea level stabilised and barriers developed, tidal processes probably dominated sand transport. Fluvial deltas and floodplain deposits have progressively superceded estuarine basins during the stillstand

The later stages of the Holocene stillstand were characterised by periods of foredune development and dune transgression. The Holocene barriers in the eastern Coromandel embayments are typified by large foredunes at their seawardmost edge or covering a large area of the barrier. Three main phases of foredune instability have been inferred from soil development and some dated horizons (Section 2.1) suggesting episodic sedimentation during the last 2 ky. The oldest phase is a stabilised ridge which in many cases is the innermost surficial deposit of the Holocene barrier and onlaps the backbarrier flat. Incorporated in the dune unit are discontinuous lenses of Taupo Pumice (*c.* 1.8 ky), suggesting the unit has an age from 2.0-1.5 ky. The next phase is common at Opoutere, Otama, Waikawau, Tairua, and Wharekaho embayments and is documented by a stabilised ridge covered in *Pinus radiata* forest and scrub vegetation. Soil development (type 5: Table 7.1) and the occurrence of a grey pumice, possibly Loisels Pumice, is consistent with a late Holocene age and a phase of dune movement 900 to 600 y BP. In all embayments open to the ocean, a set of high discontinuous dunes are evident and represent the initiation of a phase of dune instability less than 500 y BP, based on radiocarbon dates. This phase includes contemporary dune activity. Typical aspects of this event include cycles of foredune retreat (e.g. Waihi Beach), and dune building, wind erosion and landward sand migration (e.g. Tairua and Hotwater Beaches). In the last few decades, high intensity east coast storms have largely been responsible for frontal dune erosion in most coastal embayments. Stabilising vegetation, mainly sand-binding plants (e.g. spinifex) have had to compete with man's influence (e.g. walking tracks and vehicular access), that has tended to favour sand mobility.

7.5 The Eastern Coromandel Story within the Australian Setting

The late Quaternary record from large portions of the New Zealand and Australia coasts suggests a similar sea level history. It is well known that the last interglacial represents the maximum high sea-level stand. During this event the Pleistocene barriers (termed Inner barriers) on the Australian coast formed (Thom 1965, Bird 1978), as they did on the east Coromandel coast. Relative to the Holocene barriers, the morphostratigraphy and depositional histories of the Pleistocene deposits in the two areas is not as clear. However, it is probable that the accretion of these barriers was broadly similar to that of the Holocene barriers.

New Zealand studies, in conjunction with monitored sites from Australia, suggest that sea level was close (within 1-2m) to its present position 6500 y BP (Thom and Roy 1985, Carter et al. 1986, Gibb 1986, Gibb and Aburn 1986). Locally, Marks and Nelson (1979) suggest sea level was 2-3m above present mean high water level 4000-5000 years, at Omaro (Matarangi) Spit, Coromandel Peninsula. Other regions with sea level histories at variance with this sea level record can be attributed to localised tectonic influences experienced by different continental margins (Pullar and Warren 1968, Schofield 1975, Semeniuk 1985).

Commonly, barriers on both continents commenced progradation during the period 6000-5000 y BP (Thom et al. 1981, Pye and Rhodes 1985, Thom and Roy 1985, Gibb and Aburn 1986). Major sediment influxes resulting from the postglacial marine transgression or volcanic eruptions enabled rapid progradation several thousand years earlier in some locations (e.g. LeFevre Peninsula, south Australia - Bowman and Harvey (1986); Rangitaiki Plains, New Zealand - Pullar and Selby (1971); and episodic dune barriers in New South Wales, Australia - Thom et al. (1981)).

Radiocarbon dates and stratigraphic data show that the rate of accretion of many Holocene sand barriers has diminished over the last 6000 y. Few barriers are sufficiently well documented to enable determination of accurate accretion rates, and those rates that have been obtained are only very approximate. On the east Coromandel coast, Whitianga evidence suggests that over half the barrier width accreted in the last 2000 y, while the Pauanui barrier had obtained half its width by 4000 y BP. From tephra chronology it is estimated that during the last 5000 y coastal progradation of Rangitaiki Plains has been 6.5 km, with an average progradation rate of 0.5-0.7 m/y for the last 2000 y (Pullar and Selby 1971). Evidence from New South Wales barriers shows that at some sites between 80 and 100% of barrier width had been obtained by 4000 y BP, while at others progradation continued after that date (Thom et al. 1981, McLean 1984). These cases highlight local variability in embayment evolution.

7.6 Regional Differences in Embayment Evolution

In the foregoing discussion, involving the presentation of a conceptual model of sedimentation and comparison of late Quaternary coastal sequences of east Coromandel and Australia, which is consistent with the primary objectives of this thesis, it is apparent that regional differences in embayment evolution exist. These include:

1. The development of certain types of barriers in particular embayments;
2. The ubiquitous occurrence of Holocene barriers in each embayment compared to an absence of Pleistocene barriers in some areas.
3. Coastal accretion has not been a continuous process in all embayments, but rather the growth of barriers over the last 6500y has been episodic.

First, why different barrier types occur along a coast which has experienced the same sea level history, arises largely because of the varying valley and shelf geometry inherited from pre-transgression times and the wave regime operating at the coast. The ultimate criteria for sedimentation in coastal embayments is an excess of sediment supply and the ability of the embayment to trap and retain the sediment. In the coastal system, the main sediment supplies arise from fluvial erosion, littoral transport and onshore sediment movement. As mentioned in Chapter 6, valley geometry or embayment form played an important role regarding fluvial sediment supply. Embayments associated with large hinterland areas also tended to be sites of the largest prograded barriers. Shelf geometry may also be responsible for evolutionary differences within coastal embayments. At present sea level conditions, the compartmentalised nature of the east Coromandel coast limits littoral sediment transport and supply, meaning that coastal sand is derived largely from onshore transport and fluvial erosion. But during lower sea levels, a greater amount of sediment is probably available because compartmentalisation of the shelf is minimised and sand is being added to the shelf by both littoral and fluvial processes.

Australian studies suggest that under a rising sea level the sediment transport response is controlled by the nature of the transgressed surface (Roy and Thom 1981). The equilibrium profile is maintained throughout a sea level rise by shoreface erosion, first described by Bruun in 1962, where during storms sediment is lost offshore (Swift et al. 1985, Neidoroda et al. 1985). During fairweather, sand is contained within a closed nearshore system, and transported in a shore-normal landward direction by the complex interaction of wave motions and currents (Niedoroda et al. 1985). Roy and Thom (1981) suggested that on a shallow and low gradient shelf, sediment transported seaward under storm conditions aggrades at relatively shallow depths and remains within wave base and the nearshore system. Conversely, with offshore profiles that are steep and deep, sediment is lost seaward into relatively deep water to become a relict sand blanket; reworking of this sediment will only occur during subsequent glacial stages or lower sea levels.

Therefore, at the culmination of a transgression, a large sediment supply is likely to be available within shallow embayments for onshore transport by shoaling waves and beach ridge progradation. However, embayments with steeper shelf gradients will probably have a more limited supply of sand feeding only a narrow zone of coastal deposition.

Hence, not only is coastal configuration (e.g. large embayments or past valleys with large hinterland areas) important for sediment supply but also the shelf geometry. These interactions which are responsible for different barriers along the east Coromandel are summarised in Table 7.2.

It is apparent then that barrier formation in the eastern Coromandel embayments has involved a combination of interacting controls:

1. The geometry of each incised valley controlled the embayment form and supply of fluvial sediment. Generally the largest valleys and hinterland produced the most fluvial sediment and largest prograded barriers.
2. The shallower the transgressed shelf under a rising sea level, the greater the volume of sediment moved onshore and the more likely the development of a prograded barrier from abundant sediment.
3. Stationary barriers generally occur in smaller embayments, with reduced catchment areas and fronted by intermediate shelf slopes. Consequently they have a limited sediment supply relative to prograded barriers. However, morphological differences across the barriers (e.g. low dunes, high dunes, transgressive dunes) are more likely attributed to the energy regime, as discussed in Chapter 6.

Second, the presence of dual barrier systems comprising a Pleistocene and Holocene barrier in many of the eastern Coromandel embayments, suggests that there has been significant sediment trapping during both the last interglacial and postglacial transgressions. Tentative reasons for the absence of Pleistocene barriers in several currently shallow embayments with appreciable Holocene progradation (e.g. Whitianga) include: (a) erosion of the Pleistocene deposits since deposition; (b) the deposits were not recognised in the field; and (c) the availability of sediment during the last interglacial within these embayments was low. This third point seems unlikely, unless during the last interglacial transgression shelf gradients were steeper, meaning the equilibrium profile was maintained by shoreface erosion and sediment was lost seaward onto the shelf. Additional sediment eroded during the glacial may have then infilled and produced

Table 7.2 Geomorphologic factors that determine aspects of coastal sedimentation.

Relative Shelf Geometry	shallowest slopes		moderate slopes		steeper slopes	
Coastal Configuration	large valley and catchment	small valley	large valley	small valley	large valley	small valley
Relative Sediment Supply	high	low	high	low	high	
Morphology[1]	PBRP	SB/RB	PBS	SB	SB (hd)	
Examples	Whitianga	Wharekaho Hahei	Matarangi	Otama	Hotwater Beach	

1. PBRP - prograded beach ridge plain, SB - stationary barrier, RB - receded barrier, PBS - prograded barrier spit, hd - high dunes

a much shallower bay allowing sediment to be reworked shoreward during the postglacial sea level rise, and the formation of Holocene barriers.

Third, studies of morphology, soil development and radiometric dating of dune formations in eastern Queensland and New South Wales have clearly supported an episodic history of eolian sedimentation during the late Quaternary, with periods of active sand blowing and intervening periods of dune stabilisation and weathering (Thom 1978, Thom et al. 1981, Pye 1983, Thompson 1983). There is little evidence to suggest that these depositional and erosional events on the Australian coasts are synchronous from one region to another, although to a degree there is some overlap.

Oscillations of sea level were used to explain periodic phases of progradation of the South Kaipara Barrier, New Zealand (Schofield 1975). Schofield argued that a sea level fall promotes progradation, the larger the fall the greater the scale of progradation. More recent views suggest other factors such as sediment supply and wave climate variation as causes of progradation, and that dune activation reflects local rather than regional causes. Australian studies have shown that most embayments experienced sudden and relatively rapid growth in subaerial sand accumulation soon after the termination of the postglacial marine transgression (Thom et al. 1981), and that during the stillstand interval, periods of onshore transfer of sand were punctuated by erosional episodes (Pye and Rhodes 1986). In general, major environmental changes such as transgressions, regressions, glacials and interglacials are likely to affect dune and barrier accumulation in all embayments along a coast, but smaller fluctuations in sea level, wave climate and wind energy which have probably occurred during the Holocene stillstand will only influence local dune accumulation.

Three main factors can be used to explain periodic shoreline changes along east Coromandel and Australian coasts during the Holocene stillstand of the last 6500y, namely fluctuations in the volume of available sand, sea level oscillations and storm activity. Other phenomena which have contributed to recent coastal change include the influence of humans through coastal subdivisions, beach access, settlements, etc. For instance, Maori settlement and agricultural practices reactivated sand mobility, approximately 800 y BP, at some locations on the west coast of the North Island (Pain 1975, Stokes 1987). Sediment supply, ultimately the chief control of coastal sedimentation, is in part dependent on the other two variables sea level and storm climate. Sea level along east Coromandel has probably varied no more than 2m during the Holocene stillstand, effectively discounting sea level oscillations as a cause of episodic Holocene progradation. However, evidence from separate locations in Australia indicate that between 10 and 6 ky ago, when sea level was rising, transgressive dunes were active in exposed coastal embayments (Pye and Bowman 1984). Some were later submerged by the rising sea, but others climbed bedrock hills. At Opoutere, transgressive dunes overlie bedrock hills and may indicate a similar event.

Changing storm wave climates and their influence on sediment supply are perhaps the most important factor capable of explaining local differences in embayment evolution. Storm events are characterised by erosive periods, where incipient foredunes are removed, established dunes are cut back, and vegetation destroyed, so encouraging sand blowouts and mobility. Intervening calm weather periods restore the beach form and vegetation colonises incipient dunes and stabilises dune surfaces. Unfortunately, historical and climatic records of storm events cover only a very short period of time.

McFadgen (1985) proposed three depositional episodes for late Holocene (<1800 y BP) coastal deposits between Auckland and Dunedin, New Zealand, each consisting of two phases. An unstable phase was characterised by a high rate of deposition and was followed by a stable phase or low rate of deposition and soil formation. The possible correlation of these episodes with the phases of dune activity along the east Coromandel is shown in Figure 7.6. McFadgen

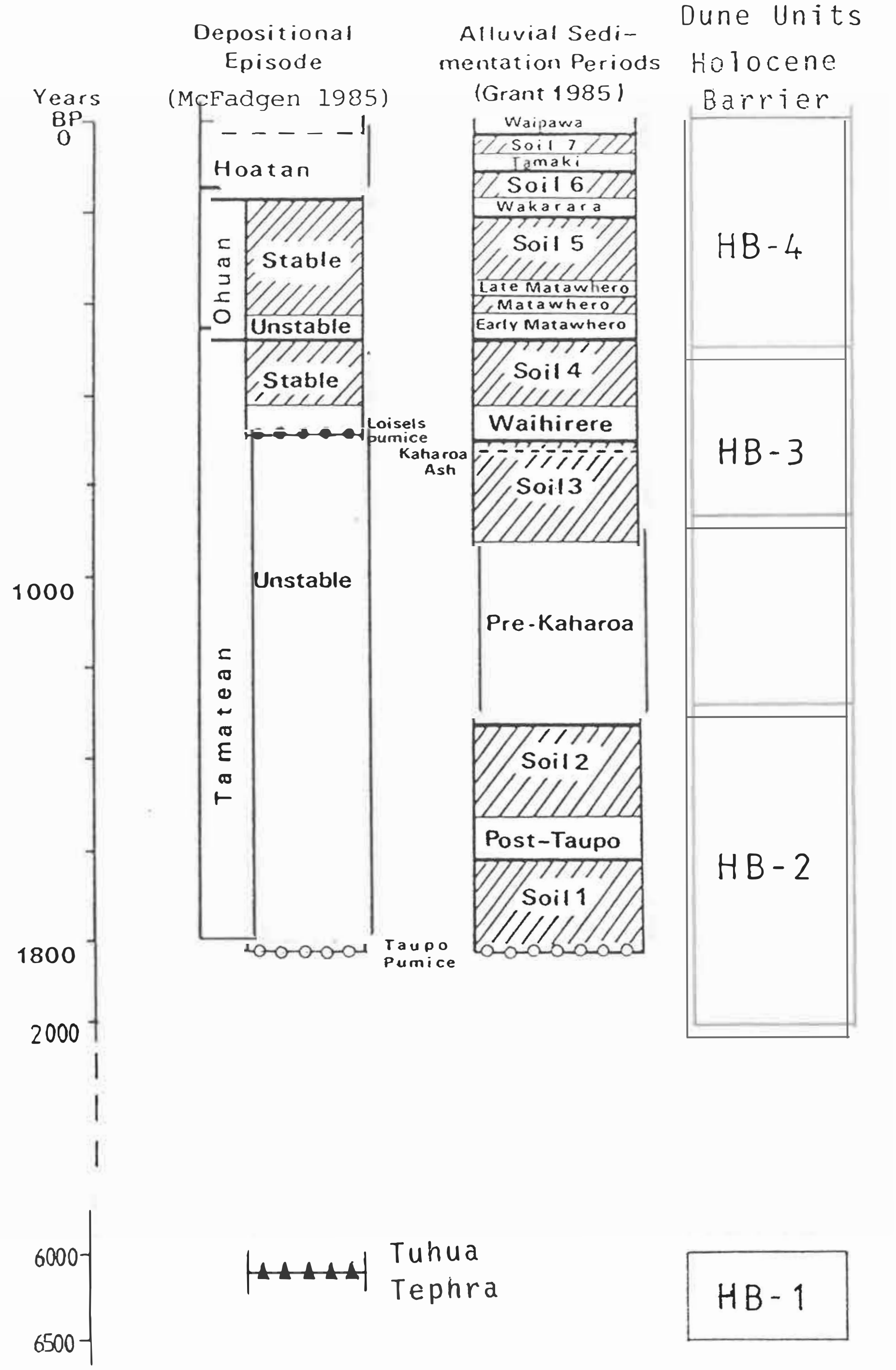


Figure 7.6 Correlation of east Coromandel dune phases with Depositional Episodes of McFadgen (1985) and Alluvial Sedimentation Periods of Grant (1985).

suggested that the first episode began about 1800 y BP. The unstable phase of sand accumulation, which may have been interrupted by periods of soil formation, continued until after the first polynesian settlement. The second episode began about 450 y BP, with only about 50 y of sediment accumulation. About 150 y ago, shortly after European influence, the third episode began and its unstable phase continues today. McFadgen suggested that these phases appear to be related to climate, rather than man's influence, earthquakes, volcanic eruptions and/or sea level changes, where unstable phases appear to correlate with periods of high temperatures; and stable phases with times of low temperatures. He attributes the depositional episodes to changes in erosion rates in river systems; unstable phases occurring when rates were high and stable phases during low rates. Slips and hill erosion are generally caused during storms and greatly increase the transport of sediment in river systems. Grant (1981) has shown there has been a significant increase in the frequency of tropical cyclones and storminess periods in the southwest Pacific since 1950, and is able to correlate these storm frequency increases with warmer temperatures, thereby inferring possible links between cyclone activity and depositional episodes (McFadgen 1985).

Grant (1985) describes eight periods of erosion and alluvial sedimentation in New Zealand, each followed by a tranquil interval when erosion rates were low and soils formed on the fresh alluvium. McFadgen is able to correlate his depositional episodes with Grant's periods based on the Taupo Pumice, Loisels Pumice and the adopted dates for the periods.

There is some agreement and overlap between the dune phases described in this study and the depositional intervals presented by McFadgen and Grant (Figure 7.6). Evidence from this study suggests that McFadgens' Tamatean Stage could be divided into two separate phases according to soil development, radiocarbon dates and pumice appearance. Field evidence indicates that the series of dunes grouped into set 4 of this study and including those actively accreting at present, have accumulated via a sequence of episodic events during the last 500 y. This set compares with McFadgens Ohuan and Hoatan Stages, and whether this phase is further divisable into these two stages along the east Coromandel is unclear. However, as previously stated, embayment evolution and coastal sedimentation is an interaction of coastal configuration, coastline orientation, sea level changes, sediment supply and wave climate. While regional controls (e.g. marine transgressions) probably initiate similar responses in each embayment, smaller controls reflecting localised storm events and changed sediment supply are superimposed upon regional sedimentation within local embayments, so that embayment histories can differ considerably along a coastline. It is therefore considered that to strictly apply a regional sequence of depositional events across the coastal system (as attempted by McFadgen 1985) is improper.

In summary, the late Quaternary record of east Coromandel and southeast Australia suggests a similar sea level record. Late Quaternary sea level movements have to a large extent determined the nature of deposition along these coastlines, where two main barrier depositional phases are associated with the current Holocene sea level and the last interglacial high sea level stand. Variations between the coastal morphologies of separate embayments have arisen largely because of varying valley and shelf geometry inherited from pre-transgression times and the wave regime operating at the coast. Additional local evolution differences superimposed upon the basic barrier development in each embayment include phases of dune and coastal activity, possibly induced by changes in the storm wave climate and related cyclone activity.

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APPENDICES

APPENDIX 1

LABORATORY PROCEDURE

1. Organic matter percents were determined by loss on ignition following standard soil methods, for approximately 100 representative samples .

2. 156 samples were wet sieved. The gravel (<1ϕ), sand (<4ϕ) and mud (>4ϕ) proportions were collected separately. Sands and gravels were dried and stored, while the mud was stored under water.

3. Some 57 representative samples were selected for sand-sized mineral petrographic analysis. Thin-section block preparation required agitation of clean unconsolidated sand grains with Araldite K411 epoxy resin, producing an artificial rock slab. The slabs were then thin-sectioned following standard thin section preparation procedures (after Carver 1971). Petrographic examination was carried out primarily using a petrographic microscope. Quantification of mineral constituents was achieved by identification and point-counting of 400 grains per slide.

4. 69 heavy mineral sub samples were seperated using a Frantz isodynamic seperator (side tilt 15°, forward tilt 25°). 95% pure (by observation under a binocular microscope) separates were obtained by repeating the procedure several times.

5. An approximate 20-50g sand split of 130 representative samples were analysed in the University of Waikato's Rapid Sediment Analyser. The Rapid Sediment Analyser determines the grain size distribution of a sediment sample by settling it through a column of water and measuring the rate of accumulation of the sediment on a balance pan at the bottom of the column. Computer analysis of the textural data included settling velocity analysis, size distribution curves, the arithmetic cumulative and cumulative probability curves and Folk and Ward (1957) parameters of mean, median, sorting, skewness and kurtosis. Sand samples from the Pleistocene Barrier unit were commonly coated with iron oxides. To remove any possible error during the settling tube method (i.e. from additional iron oxide weight) the coatings were removed with oxalic acid according to Carver (1971) for each sand split.

6. A 40-50g sand split of 44 representative samples were digested in HCl acid after Reid (1978), allowing the determination of $CaCO_3$ content.

7. Pipette analysis of 130 representative samples followed that of Folk (1968), producing clay and silt contents.

8. X-ray diffaction (XRD) analysis of the clay mineralogy of the finer than 4ϕ material from 44 representative samples, was undertaken on the University of Waikato Phillips 1050 geiger-counter x-ray diffraction spectrometer, using nickel-filtered copper radiation. Machine settings are the same as those in Hume and Nelson (1982) and samples were scanned from 3° to 15°2θ. Clay (>8ϕ) XRD samples were extracted from deflocculated suspensions of bulk samples. The samples were mounted onto 25x35mm glass slides using the dropper-on-glass slide (DOGS) technique (Hume and Nelson 1982). Samples were analysed and treated according to the schedule outlined in Hume and Nelson (1982), Lowe and Nelson (1983).

APPENDIX 2

PUMICE DESCRIPTIONS

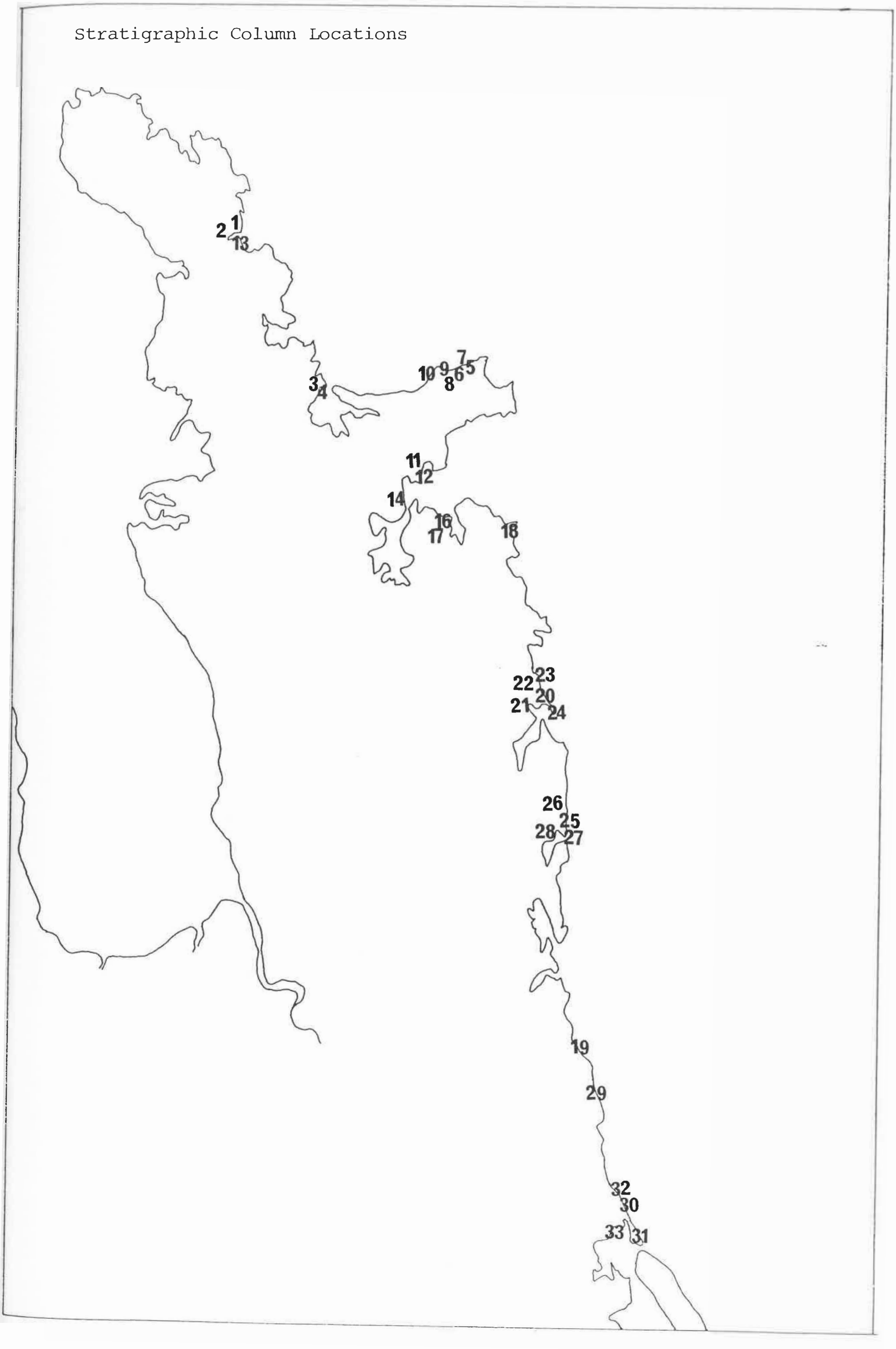
Pumice No.	Grid Ref.	Description
Pumice 1	T10/647635	Dark grey pumice and light grey bands up to 3.5cm. Very hard, cannot be broken between fingers except along weathered planes of weakness, shown by a brown appearance. Rare ferromagnesian minerals.
Pumice 2	T10/573590	Dark and light grey banded pumice up to 2 cm. Very hard, not crushable by fingers. Floats well. Common small angular white crystals, rare ferromagnesian minerals. Highly vesicular, fine small circular vesicles.
Pumice 3	T11/503825	Light grey pumice, large pieces up to 0.5m, commonly 6cm. Highly vesicular, large and elongated vesicles. Crushable between fingers. Large tabular ferromagnesian minerals upto 2mm long.
Pumice 4	T12/663523	Yellow brown weathered surface over a light grey pumice. Very easily crushed between fingers. Highly vesicular, large elongate vesicles, common large angular crystals, rare ferromagnesian minerals.
Pumice 5	T11/540864	Dark grey pumice with light grey bands up to 10 cm. Angular crystals of quartz and rare magnetite and ferromagnesian

		minerals. Very hard cannot be broken. Abundant tiny circular vesicles.
Pumice 6	T13/691284	Dark to medium grey pumice with a rusty weathered appearance on some surfaces. Highly vesicular, fine round cavities. Some angular white minerals and uncommon angular ferromagnesian crystals. Very hard cannot be broken.
Pumice 7	T11/562808	Light yellow pumice, very hard. Small rounded pieces upto 1.5cm. Very vesicular, ranging from large elongate to small circular cavities. Abundant ferromagnesian crystals a variety of sizes up to 3mm.
Pumice 8	U13/735123	Tiny lapilli yellow brown to rusty red, upto 6mm. Easily crushed, very vesicular, elongate cavities and rare ferromagnesian minerals.
Pumice 9	T12/663512	Reddish yellow brown pumice, weathered on surface, pale yellow light grey centres. Easily crushed between fingers. Highly vesicular, common angular quartz, rare ferromagnesian minrals and blue grey rock fragment inclusions.
Pumice 10	T10/569952	Dark grey pumice with a weathered brown appearance. Angular quartz crystals and rare ferromagnesian crystals. Abundant circular vesicles.

APPENDIX 3

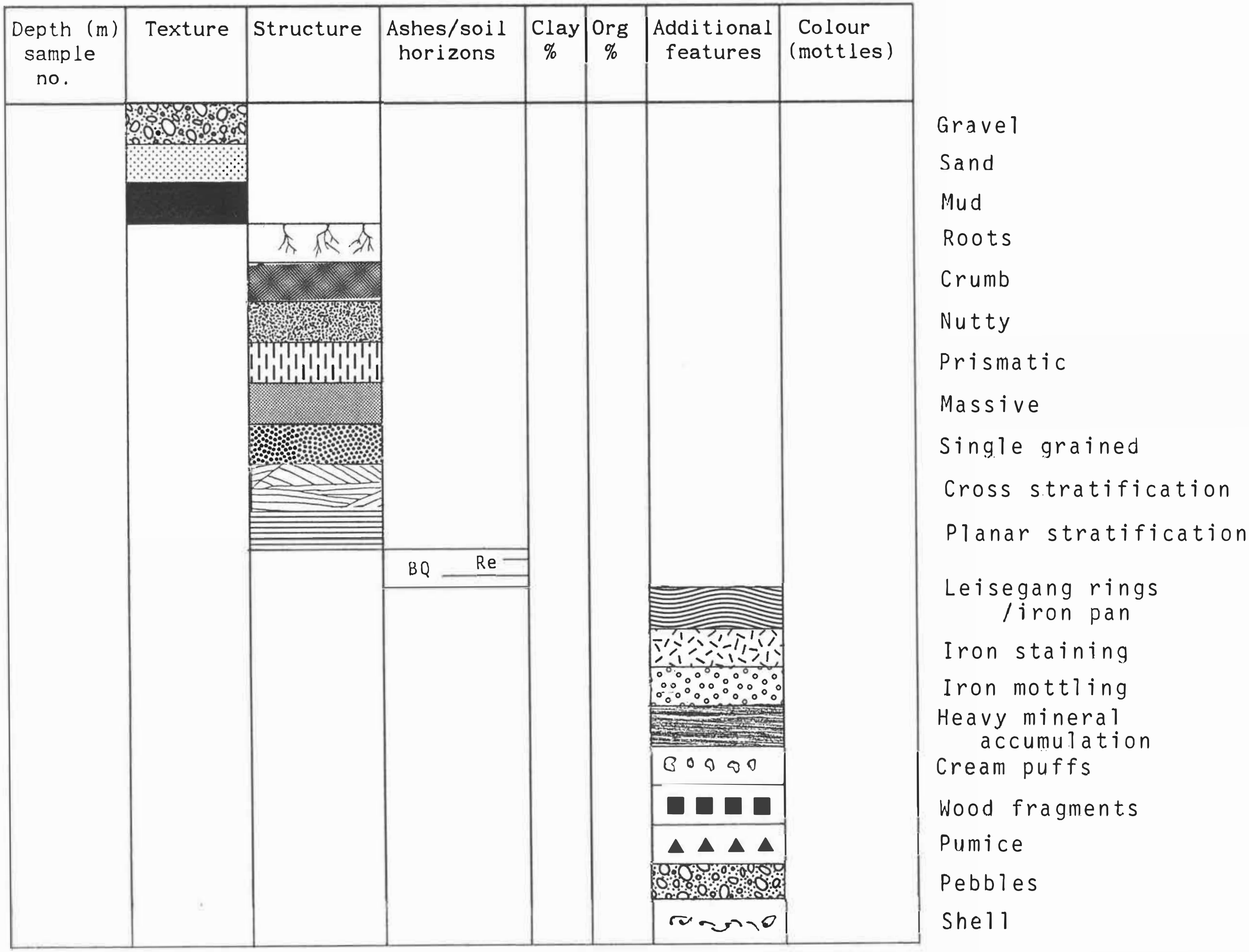
STRATIGRAPHIC COLUMNS

Stratigraphic Column Locations



STRATIGRAPHIC COLUMN NO.:
GRID REFERENCE:
LOCATION:

BOREHOLE NO.:
FROM DEPTH(M):



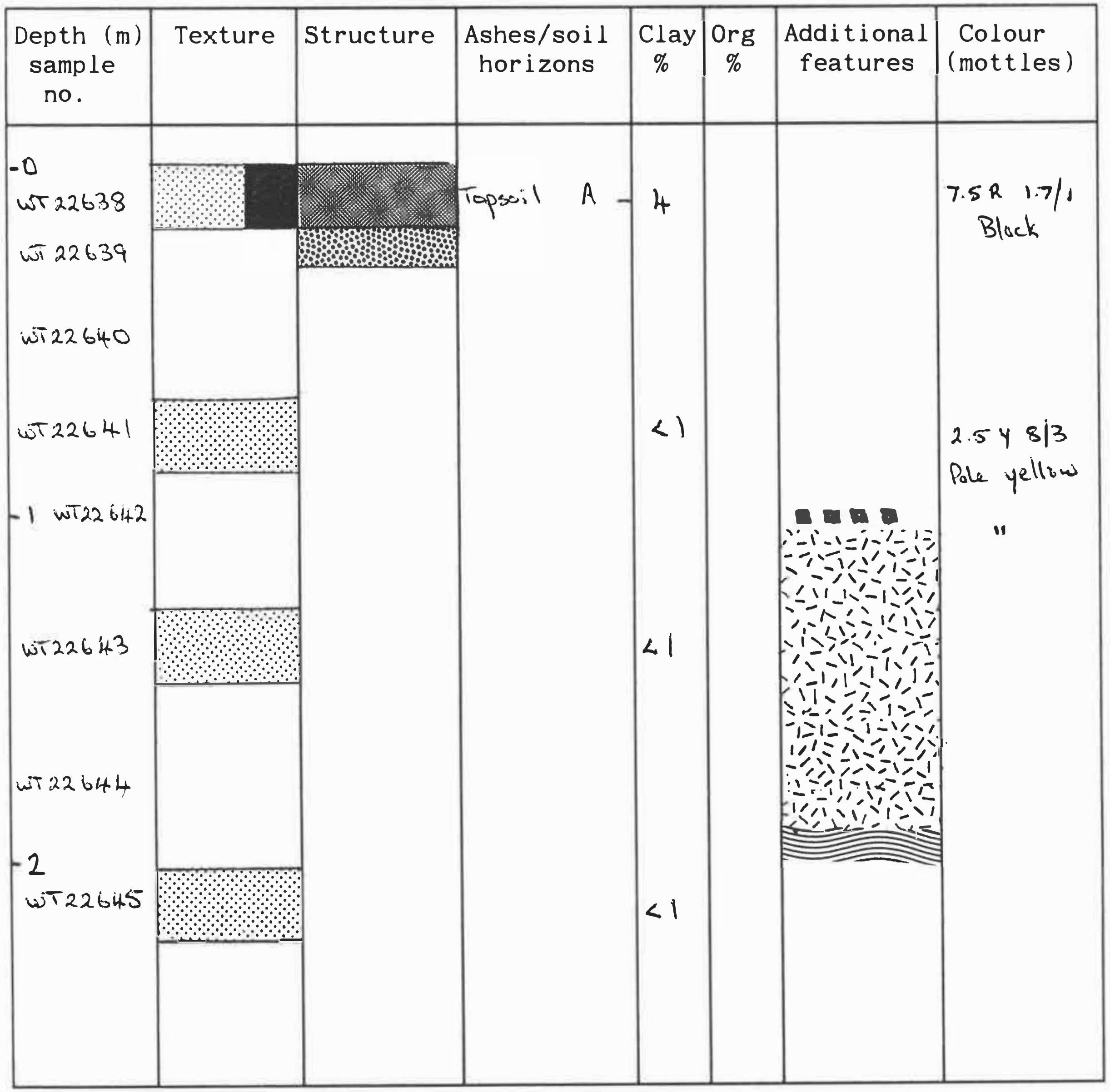
STRATIGRAPHIC COLUMN NO.: 1
GRID REFERENCE: T10/364080
LOCATION: Waikawau

BOREHOLE NO.: 1
FROM DEPTH(M): 1.3

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
-0							
WT 22664			Topsoil A	7.8			Brownish black 5YR 2/2
WT 22665			Bq	8.6			Reddish brown 5YR 4/8
WT 22666			Re	9.7			Orange 7.5 YR 6/8
-1							
WT 22667				3.0			
-2							
WT 22669				4.2			Bright yellowish brown 10 YR 6/8
-3							
WT 22671				4.5			
-4							
WT 22673				6.3			
-5 WT 22675				7.4			
WT 22676							

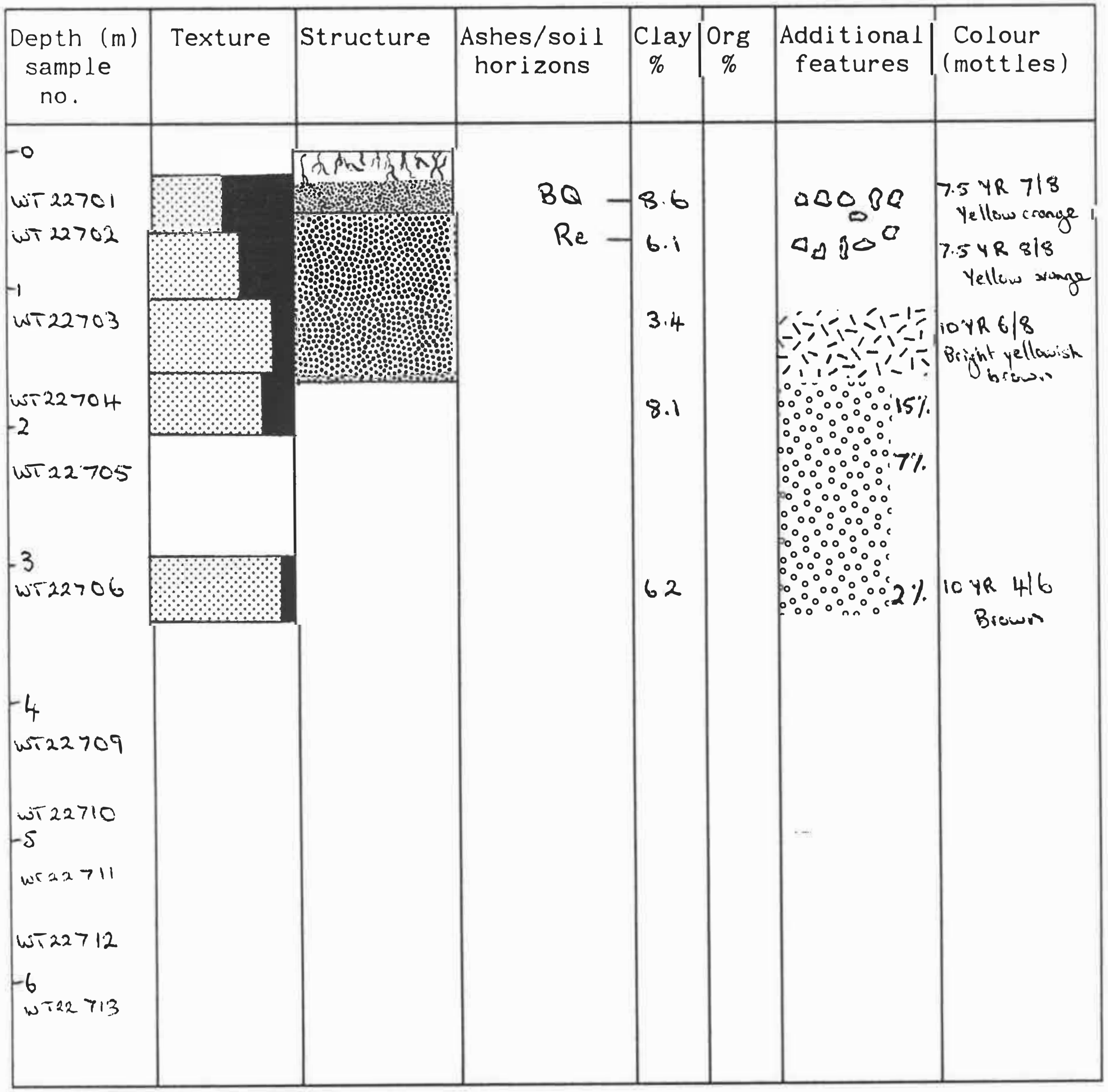
STRATIGRAPHIC COLUMN NO.: 2
GRID REFERENCE: T10/389077
LOCATION: Waikawau

BOREHOLE NO.: 2
FROM DEPTH(M): 0.3



STRATIGRAPHIC COLUMN NO.: 3
GRID REFERENCE: T10 /438951
LOCATION: Whangapoua

BOREHOLE NO.: 3
FROM DEPTH(M): 1.7



STRATIGRAPHIC COLUMN NO.: 4
GRID REFERENCE: T10/439951
LOCATION: Whangapoua

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0			Topsoil A				10 YR 2/3 Brownish black
0.2							
WT 22781				<1			10 YR 5/4 Dull yellowish brown
WT 22782				<1			"
1							

STRATIGRAPHIC COLUMN NO.: 5
GRID REFERENCE: T10/572957
LOCATION: Otama

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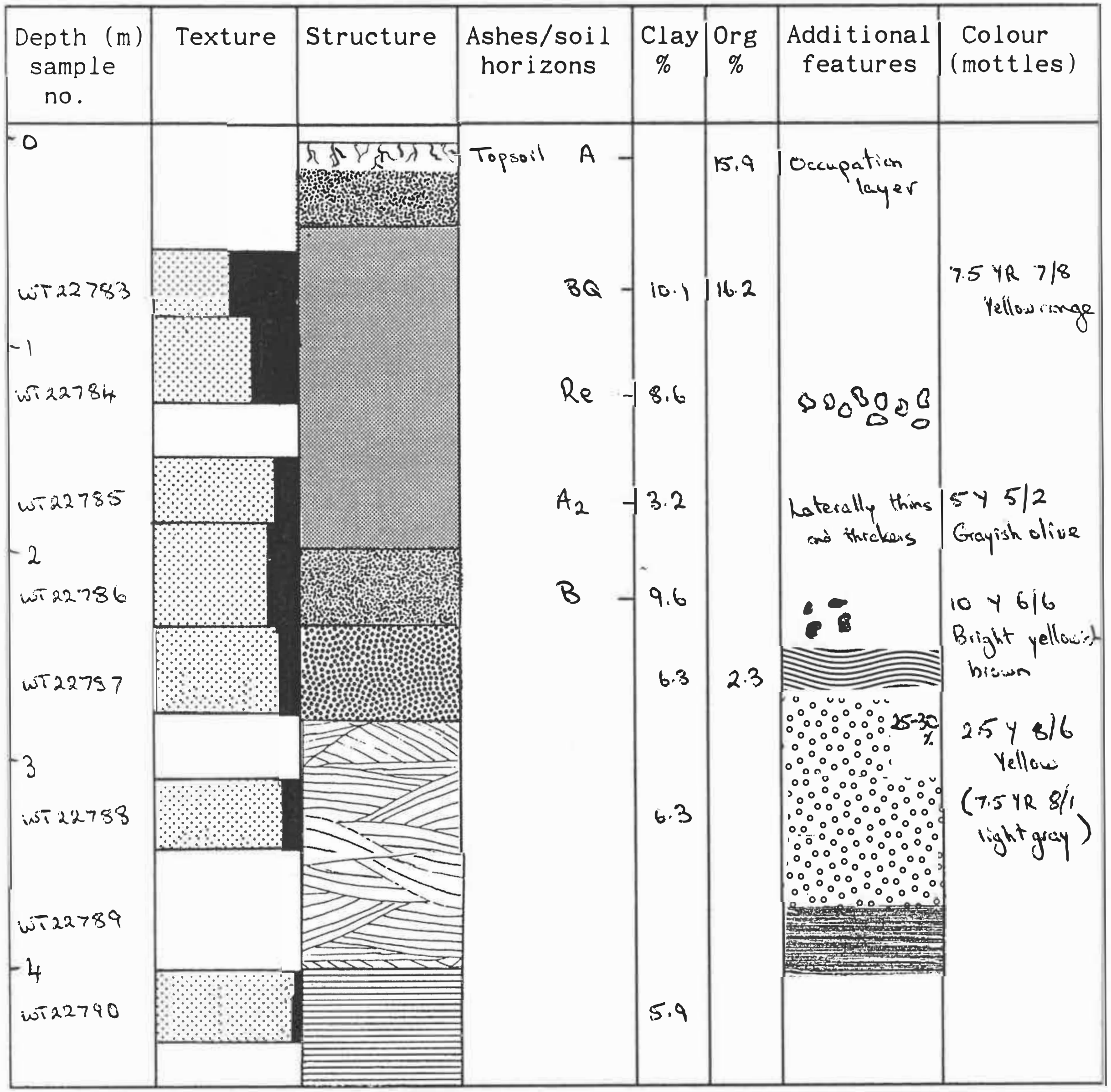
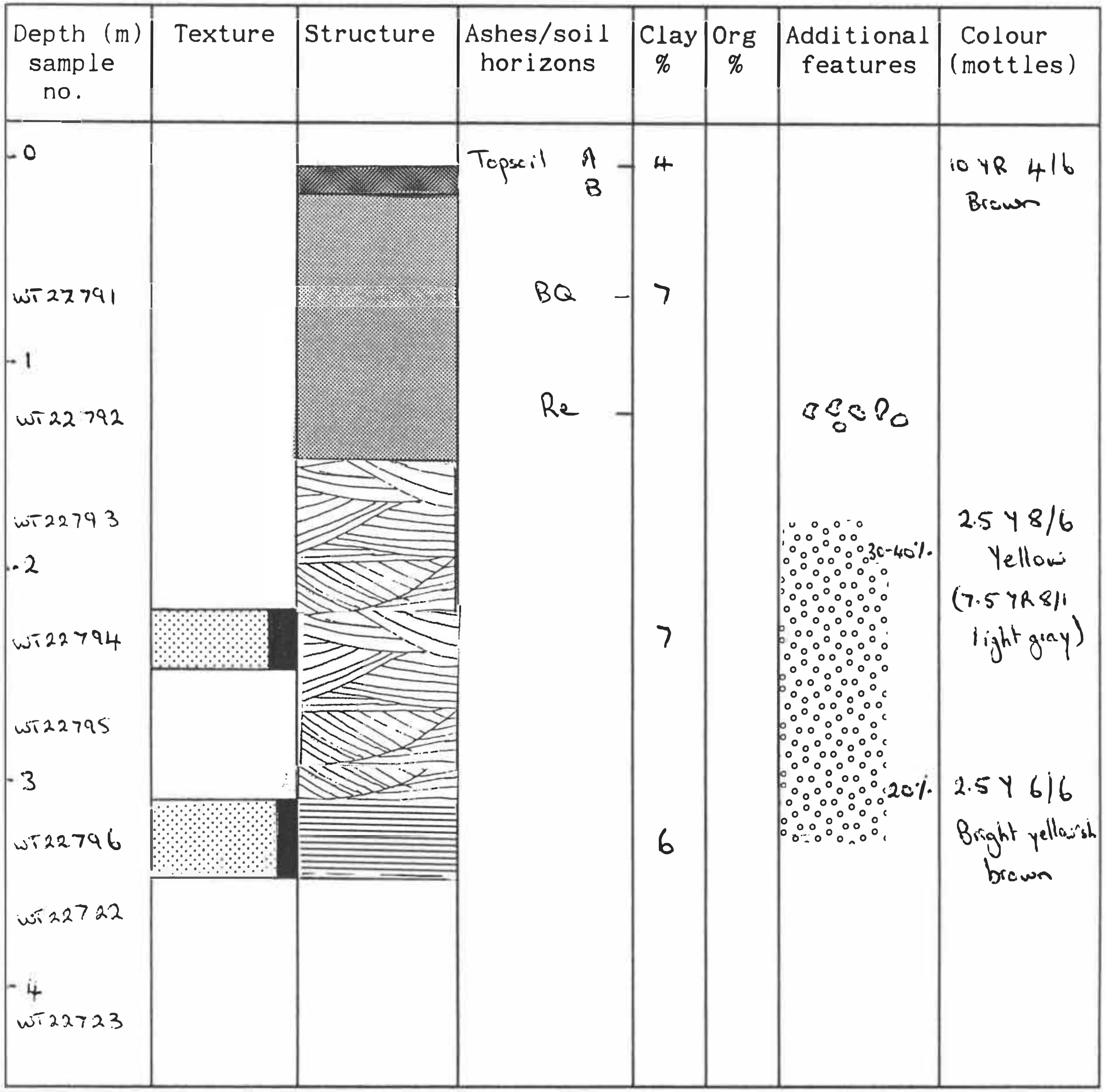


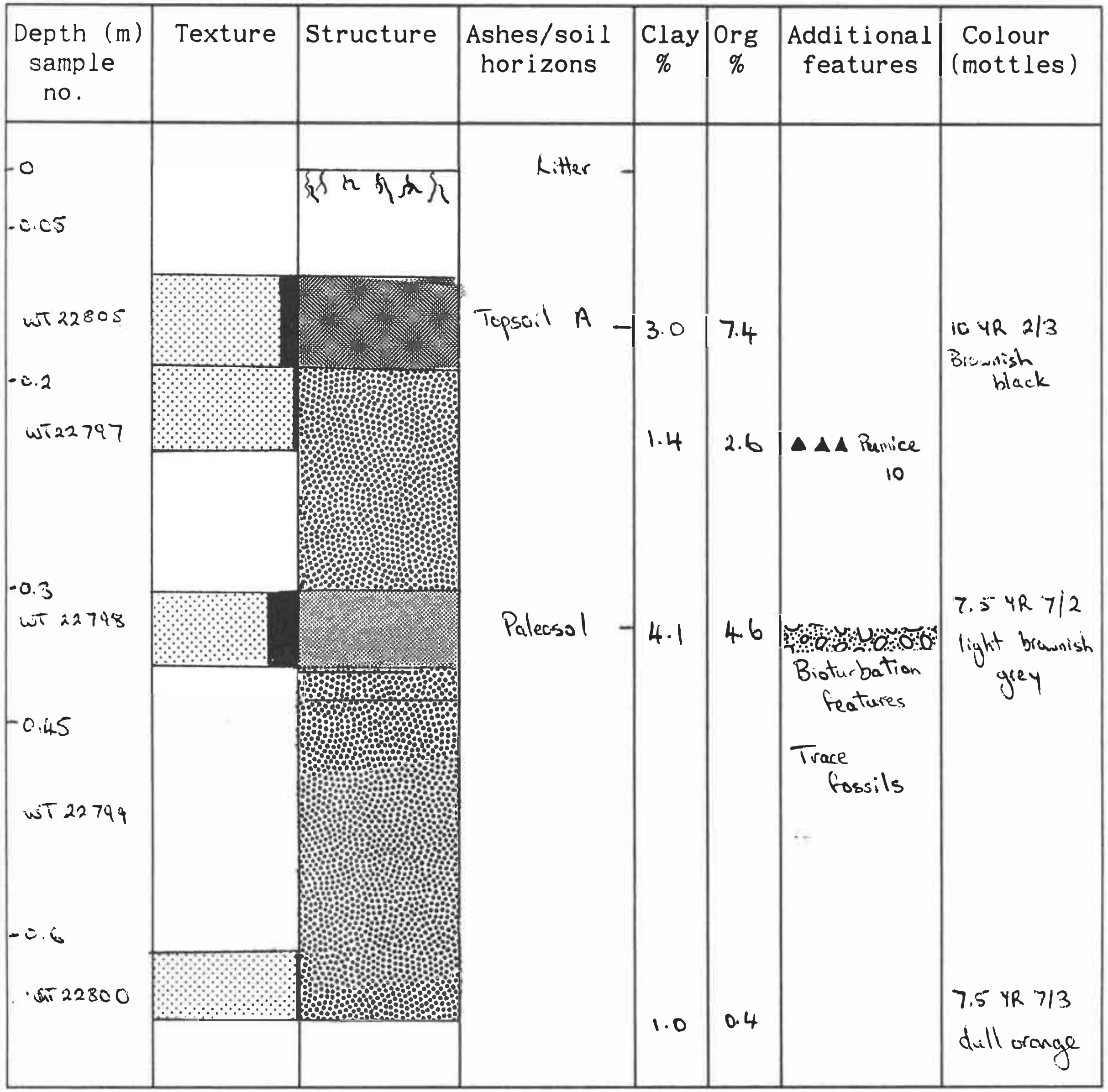
STRATIGRAPHIC COLUMN NO.: 6
GRID REFERENCE: T10/570953
LOCATION: Otama

BOREHOLE NO.: 8
FROM DEPTH(M): 3.6



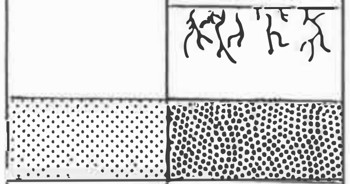
STRATIGRAPHIC COLUMN NO.: 7
GRID REFERENCE: T10|569952
LOCATION: Otama

BOREHOLE NO.:
FROM DEPTH(M):



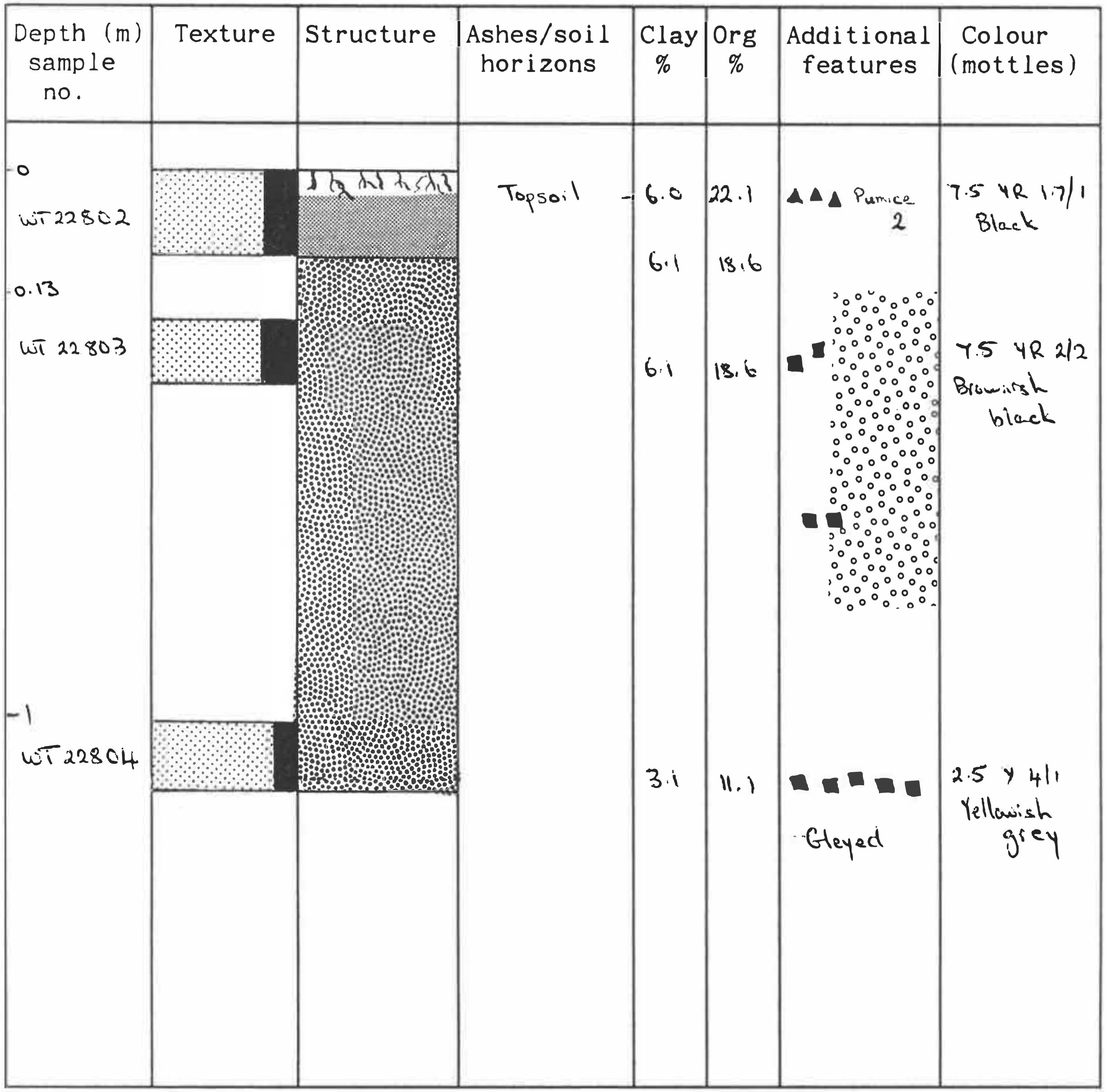
STRATIGRAPHIC COLUMN NO.: 8
GRID REFERENCE: T10|565955
LOCATION: Otama

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
-0			Litter				
-0.01							
WT22801				<1	<1		5 YR 8/1 light grey

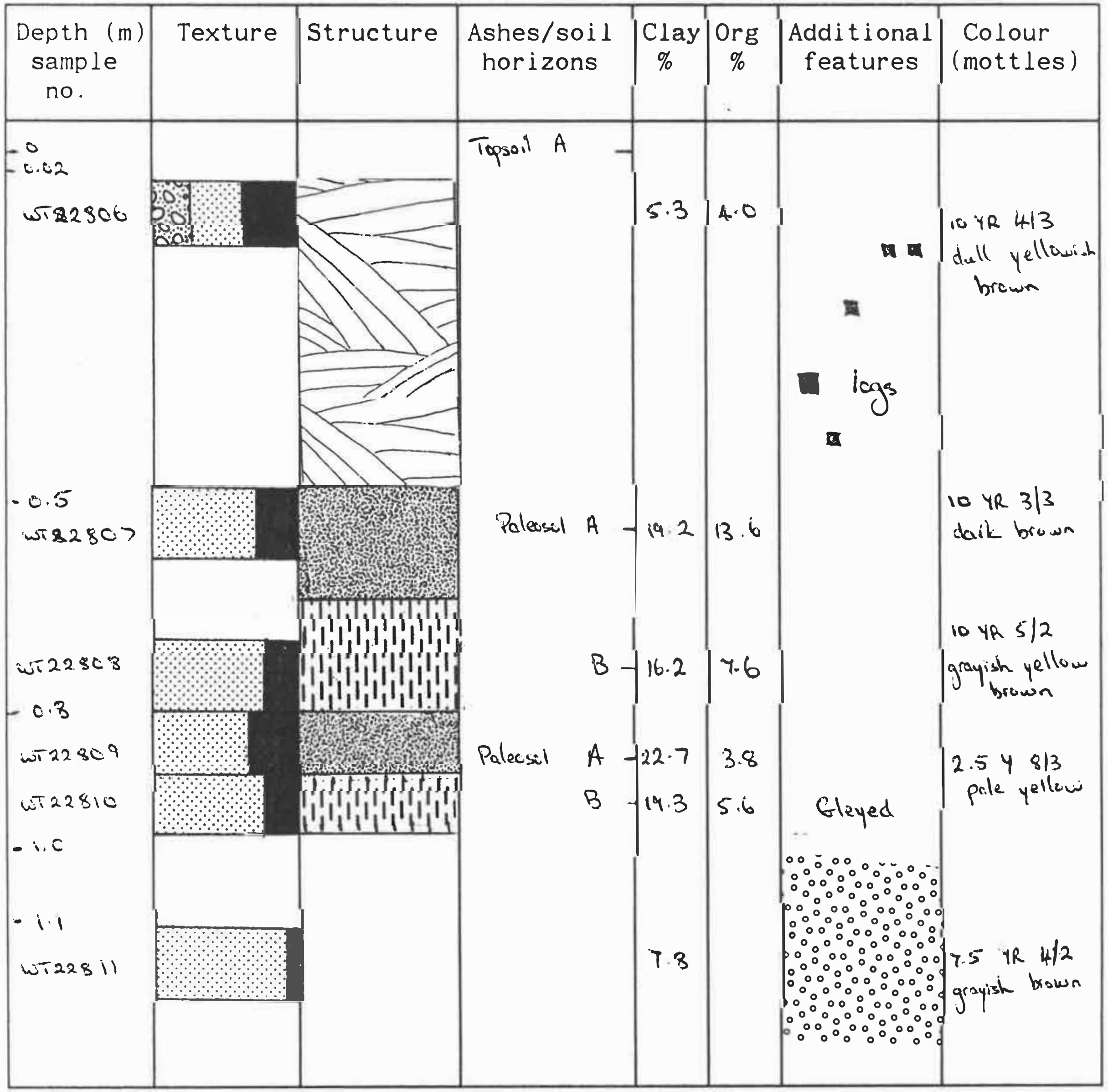
STRATIGRAPHIC COLUMN NO.: 9
GRID REFERENCE: T10 573590
LOCATION: Otama

BOREHOLE NO.:
FROM DEPTH(M):



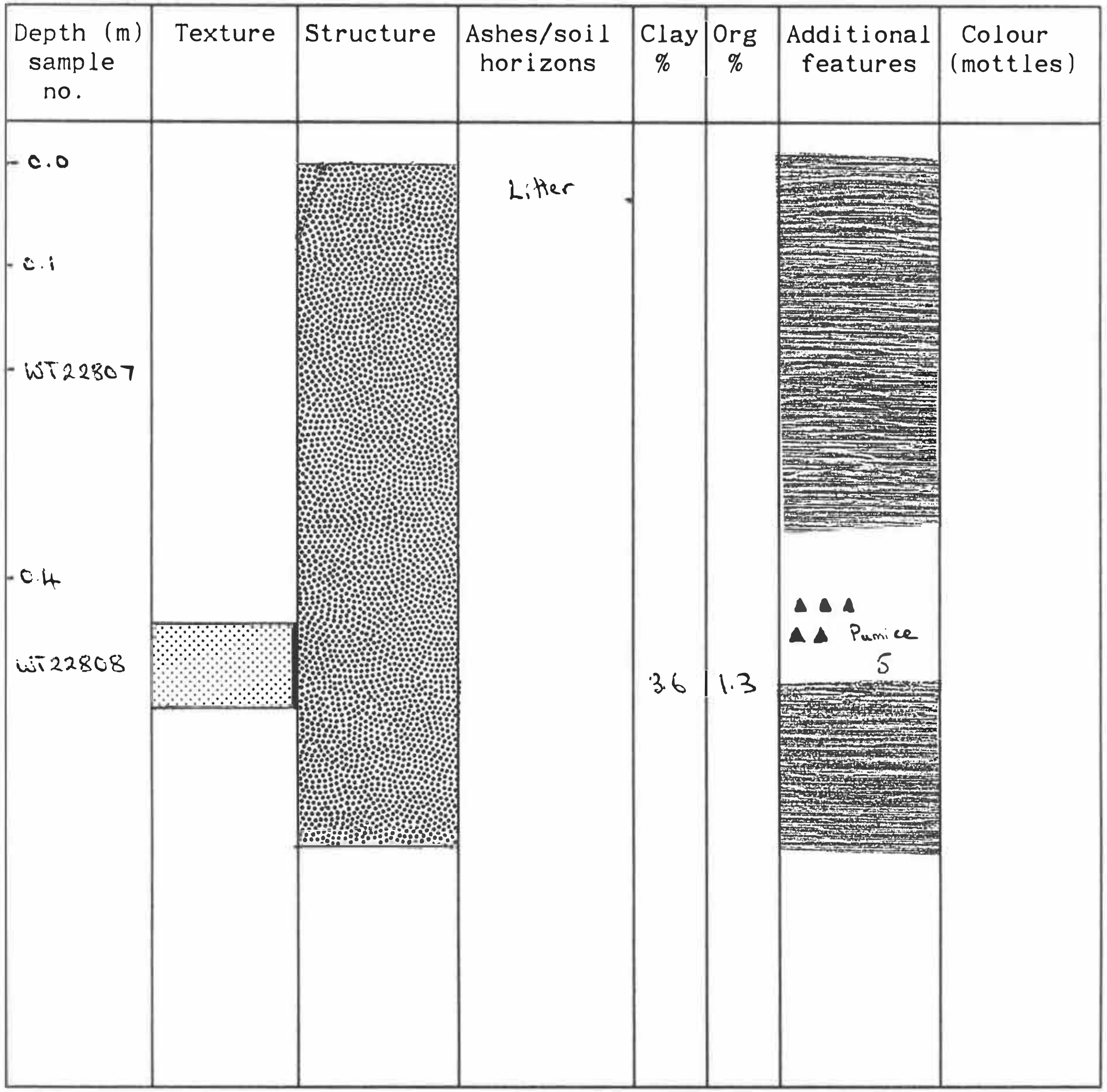
STRATIGRAPHIC COLUMN NO.: 10
GRID REFERENCE: T10/562951
LOCATION: Otama

BOREHOLE NO.:
FROM DEPTH(M):



STRATIGRAPHIC COLUMN NO.: 11
GRID REFERENCE: T11/540864
LOCATION: Wharekaho

BOREHOLE NO.:
FROM DEPTH(M):



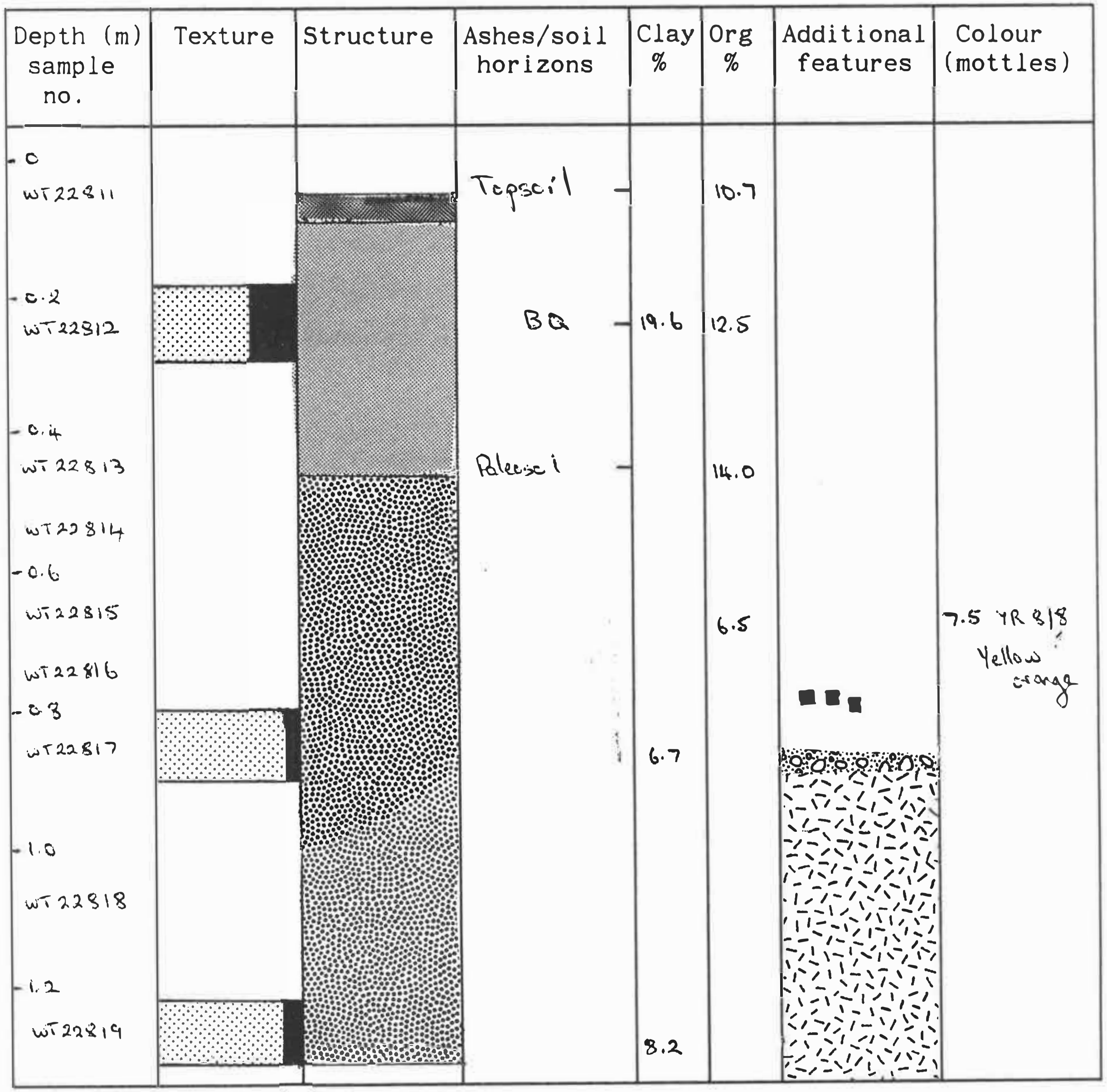
STRATIGRAPHIC COLUMN NO.: 12
GRID REFERENCE: T11/534866
LOCATION: Wharekaho

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0			Topsoil A –		6.3		10 YR 4/6 Brown
0.1							
WT22809				9.8	3.2		7.5 YR 8/8 Yellow orange
0.2							
WT22810				6.2	1.1		2.5 Y 8/3 pale yellow

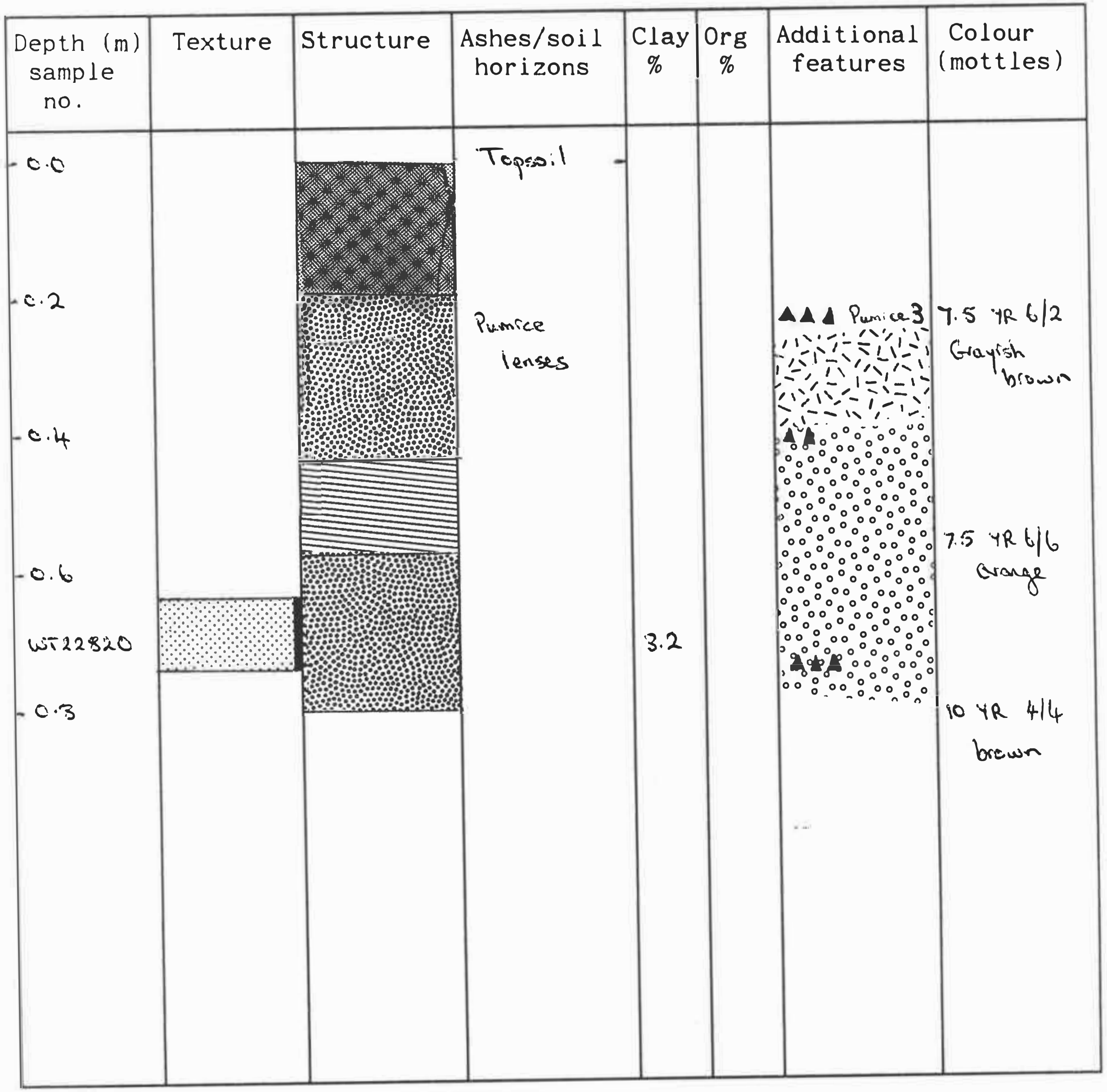
STRATIGRAPHIC COLUMN NO.: 13
GRID REFERENCE: T10/386077
LOCATION: Waikawau

BOREHOLE NO.: 4
FROM DEPTH(M): 0.45



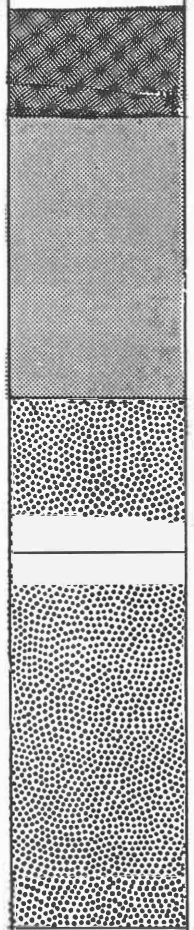
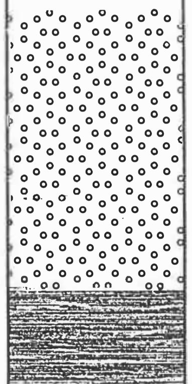
STRATIGRAPHIC COLUMN NO.: 14
GRID REFERENCE: T11/503825
LOCATION: Whitianga

BOREHOLE NO.:
FROM DEPTH(M):



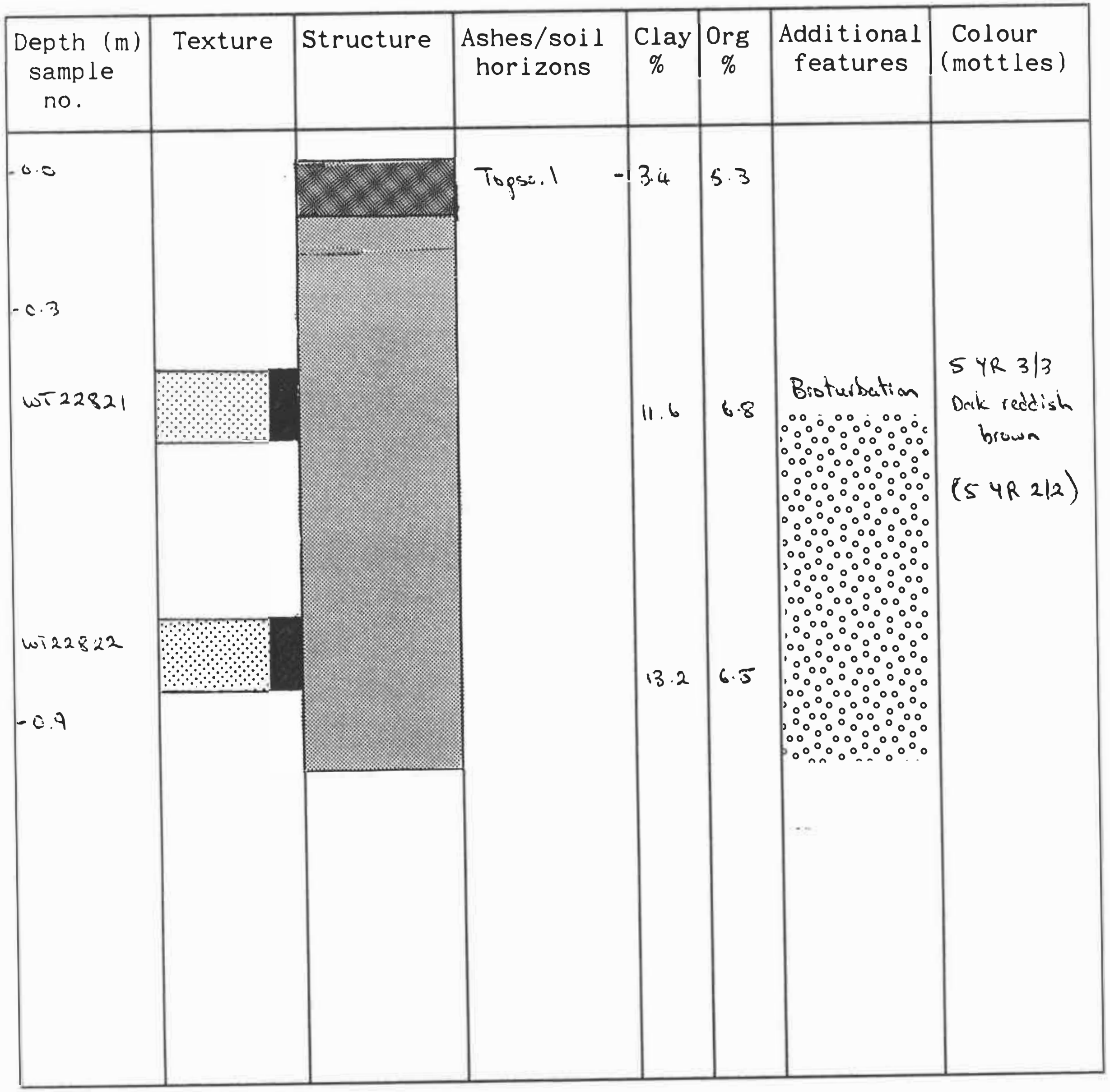
STRATIGRAPHIC COLUMN NO.: 15
GRID REFERENCE: T11/503 828
LOCATION: Whitianga

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0			Topsoil				
0.1			Tephra?			Lumpy	10 YR 5/6 Yellowish brown
0.2							
0.3			Paleosol			Charcoal	10 YR 4/6 Brown
0.4							10 YR 4/3 dull yellowish brown

STRATIGRAPHIC COLUMN NO.: 16
GRID REFERENCE: TN/561806
LOCATION: Cocks Beach

BOREHOLE NO.:
FROM DEPTH(M):



STRATIGRAPHIC COLUMN NO.: 17
GRID REFERENCE: T 11/562808
LOCATION: Cooks Beach

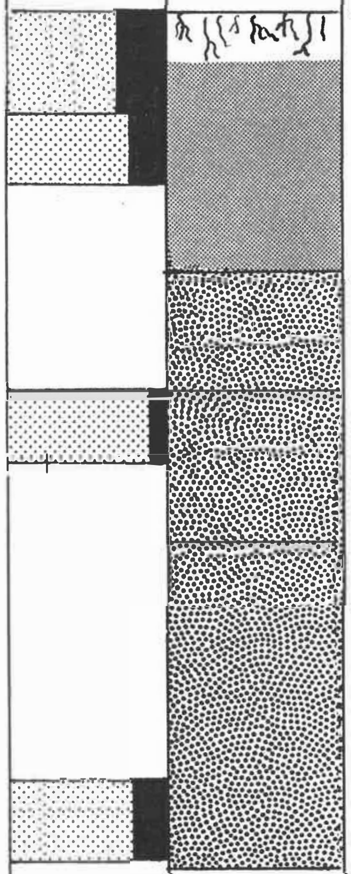
BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0			Topsoil A –			Maori midden	
0.3							10 YR 5/4 Dull yellowish brown
1.1						Pumice ?	(10 YR 5/6 Yellowish brown)
							7.5 YR 5/4 dull brown

STRATIGRAPHIC COLUMN NO.: 18
GRID REFERENCE: T11/619751
LOCATION: Hotwater Beach

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0			Topsoil A	10.3	7.5		10 YR 2/2 Brownish black
0.2			BG	7.9	11.9		
			Re		4.0		7.5 YR 6/8 Orange
0.5 WT22677				6.8	3.2		7.5 YR 5/4 Brown
0.9 WT22678					5.9		
							7.5 YR 4/4 Brown
WT22679				9.1	2.8		



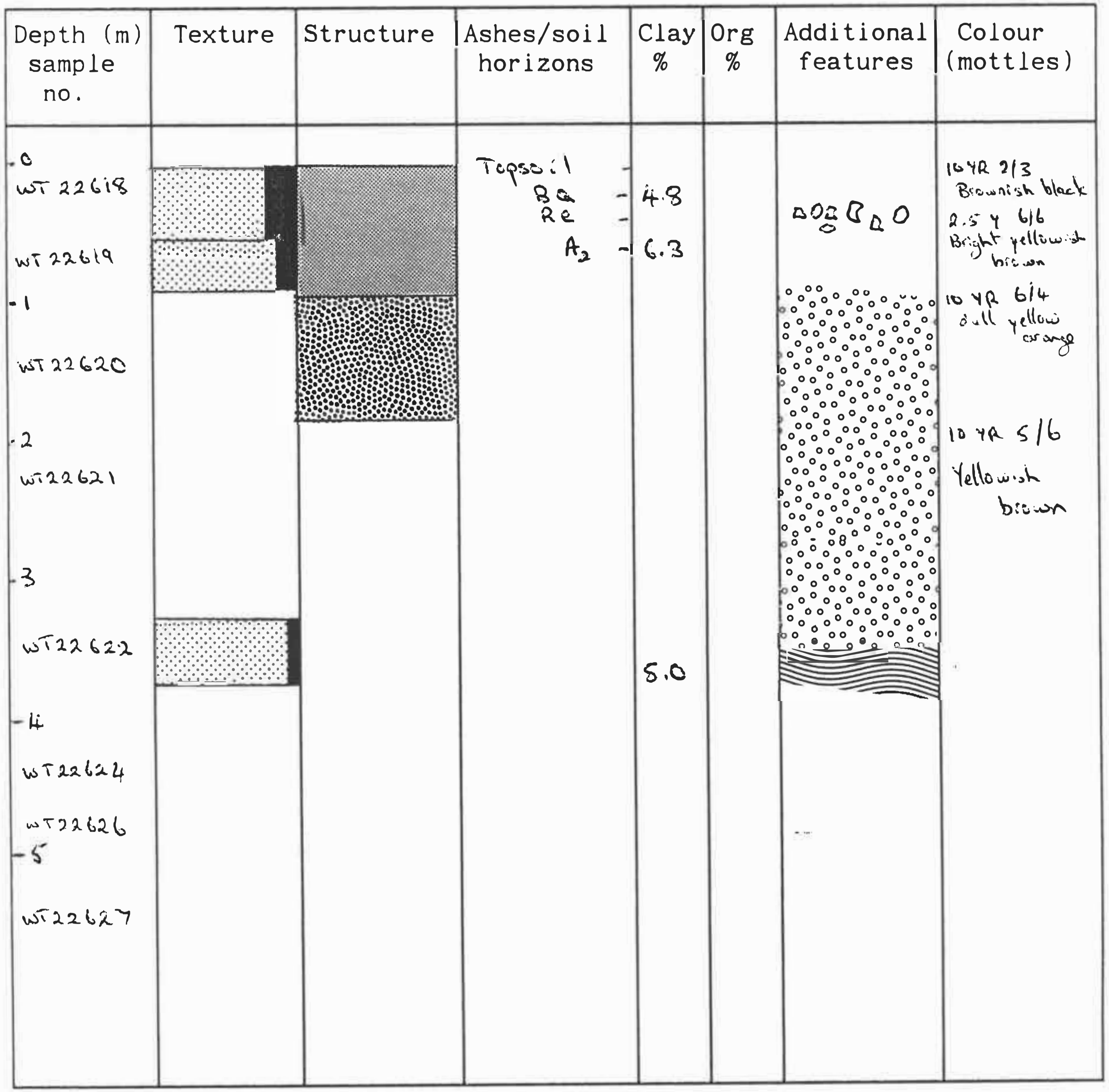
STRATIGRAPHIC COLUMN NO.: 19
GRID REFERENCE: T12/675316
LOCATION: Whiritea

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.1			Topsoil				
WT22748				2.0	0.5		
WT22749				4.1	3.5		
1.0							
WT22750				6.0	6.2		
WT22751			Kaharoa Ash	24.2			
2.0							
WT22752				3.0			

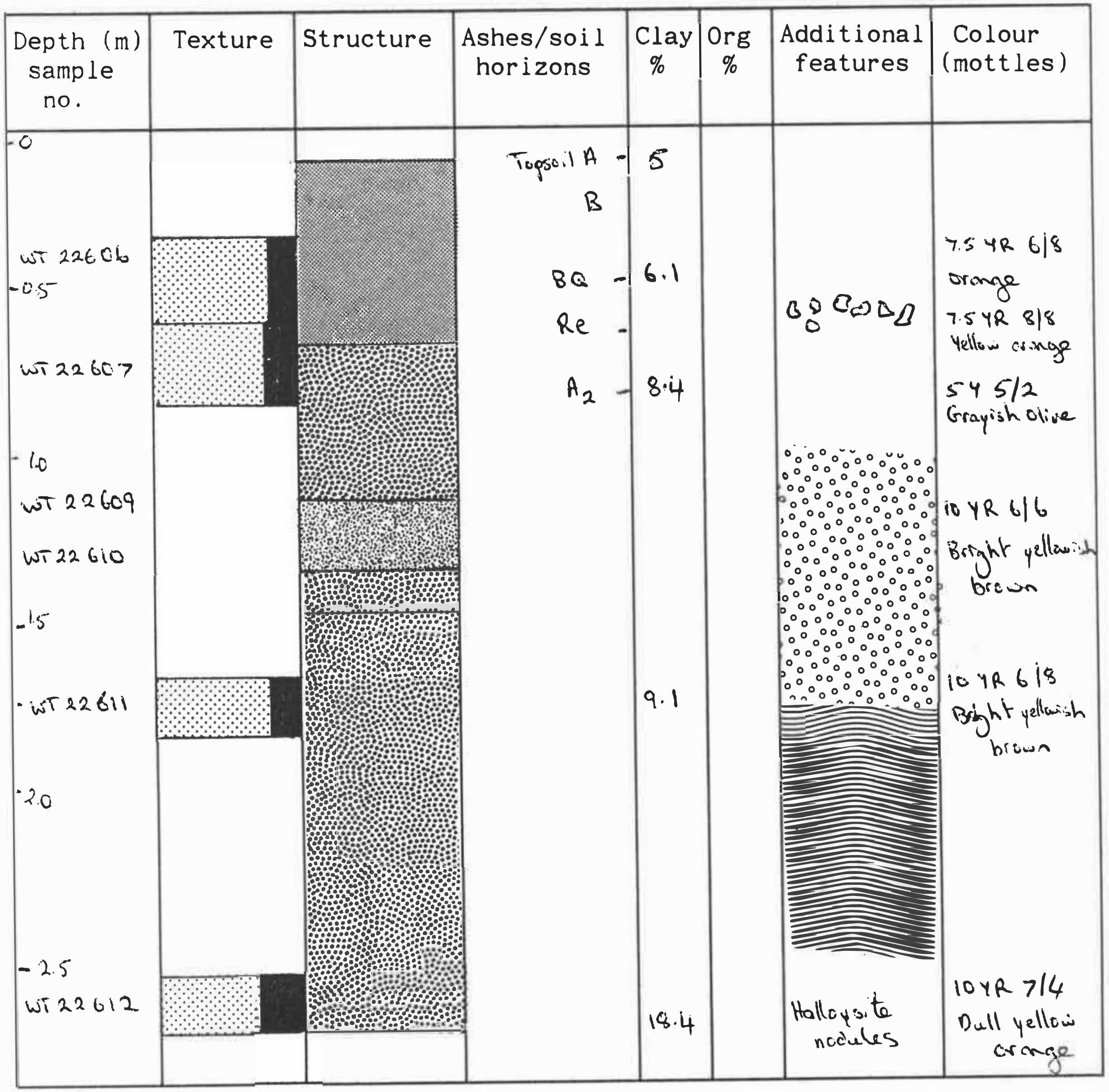
STRATIGRAPHIC COLUMN NO.: 20
GRID REFERENCE: T11/641630
LOCATION: Tairua

BOREHOLE NO.: 5
FROM DEPTH(M): 1.9



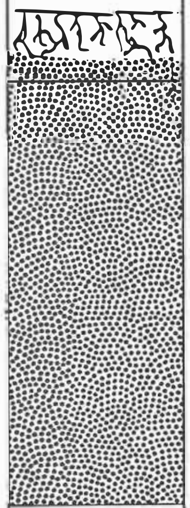
STRATIGRAPHIC COLUMN NO.: 21
GRID REFERENCE: T12/628599
LOCATION: Tairua

BOREHOLE NO.:
FROM DEPTH(M):



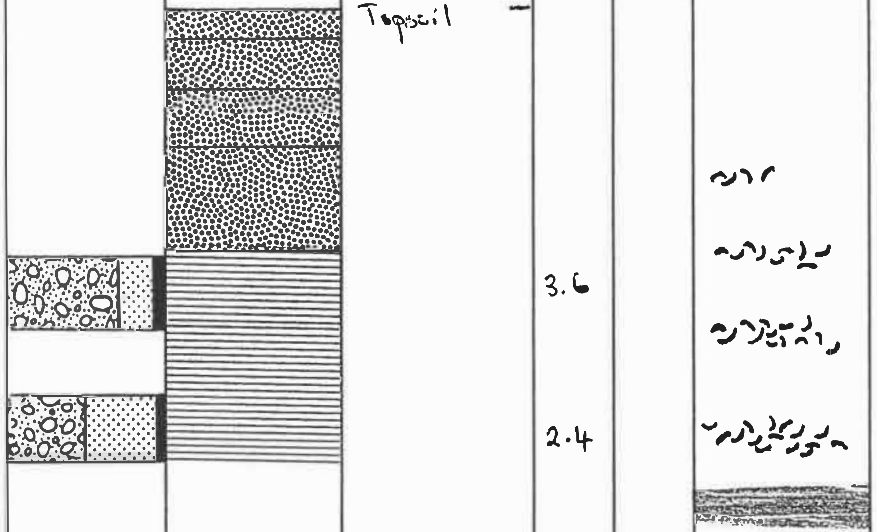
STRATIGRAPHIC COLUMN NO.: 22
GRID REFERENCE: T11/647635
LOCATION: Tairua

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
-0.0			Topsoil			▲▲ Pumice	5 YR 2/1 Brownish Black
-0.15							
WT 22628					2.1	Trace fossils	10 R 3/3 Dark reddish brown
-0.25							
WT22629					1.7	Lithified	10 R 2/2 Very dark reddish brown

STRATIGRAPHIC COLUMN NO.: 23
GRID REFERENCE: T11/649629
LOCATION: Tairua

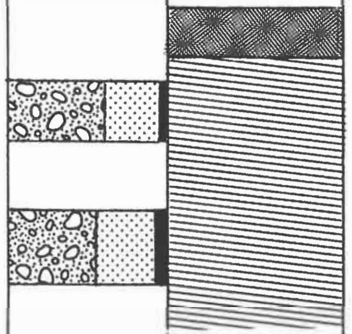
BOREHOLE NO.:
FROM DEPTH(M):



Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0			Topsoil				5YR 2/1 Brownish black
0.4							
WT22630				3.6			2.5YR 7/1 light reddish grey
WT22631				2.4			5YR 4/2 Grayish brown

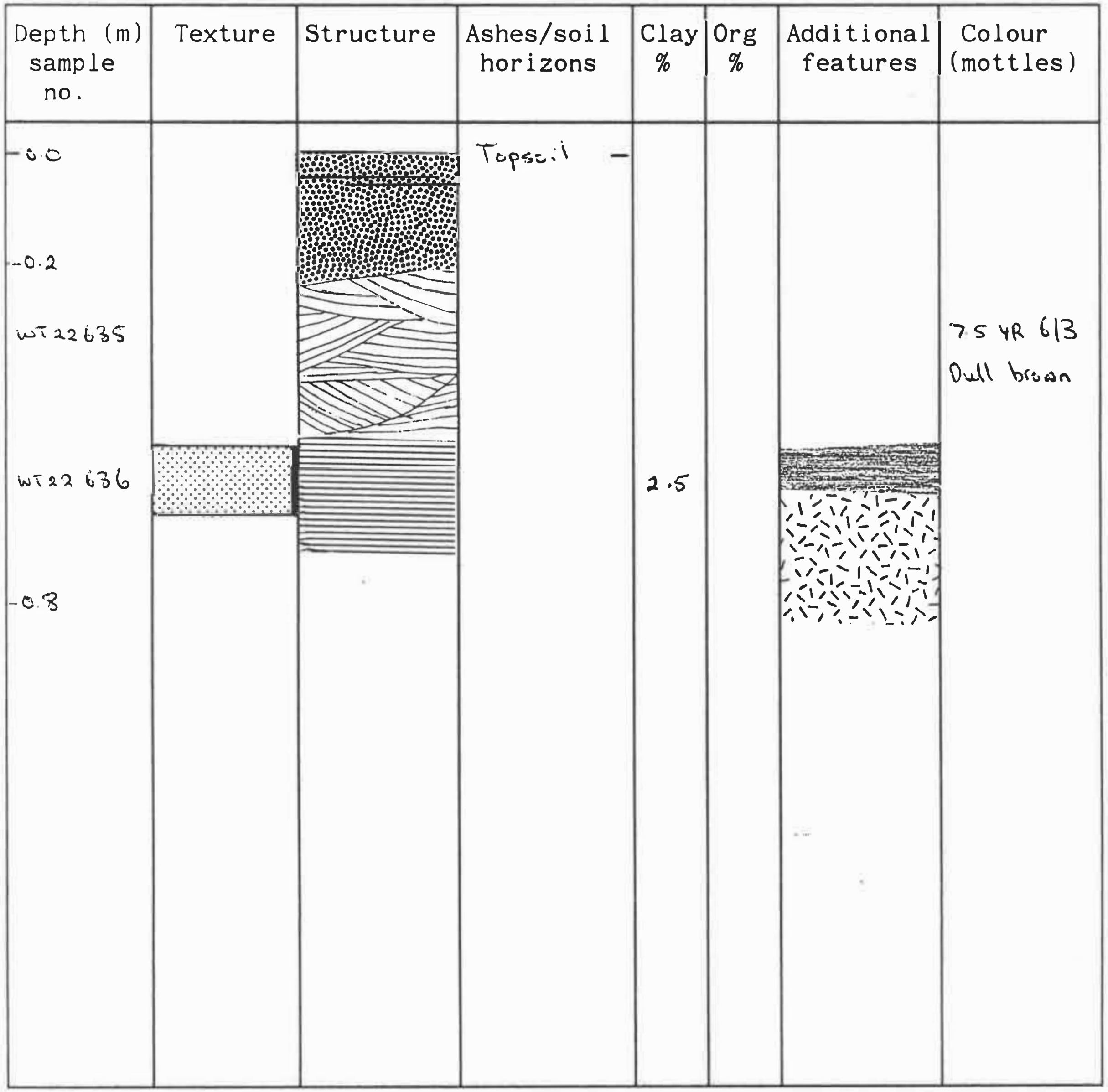
STRATIGRAPHIC COLUMN NO.: 24
GRID REFERENCE: T11/643639
LOCATION: Tairua

BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0							
0.05			Topsoil				5YR 2/1 Brownish black
WT22633				4			2.5YR 5/6 Bright brown
WT22634				6			5YR 6/6 Orange
1.6							

STRATIGRAPHIC COLUMN NO.: 25
GRID REFERENCE: T12/663526
LOCATION: Opoutere

BOREHOLE NO.:
FROM DEPTH(M):



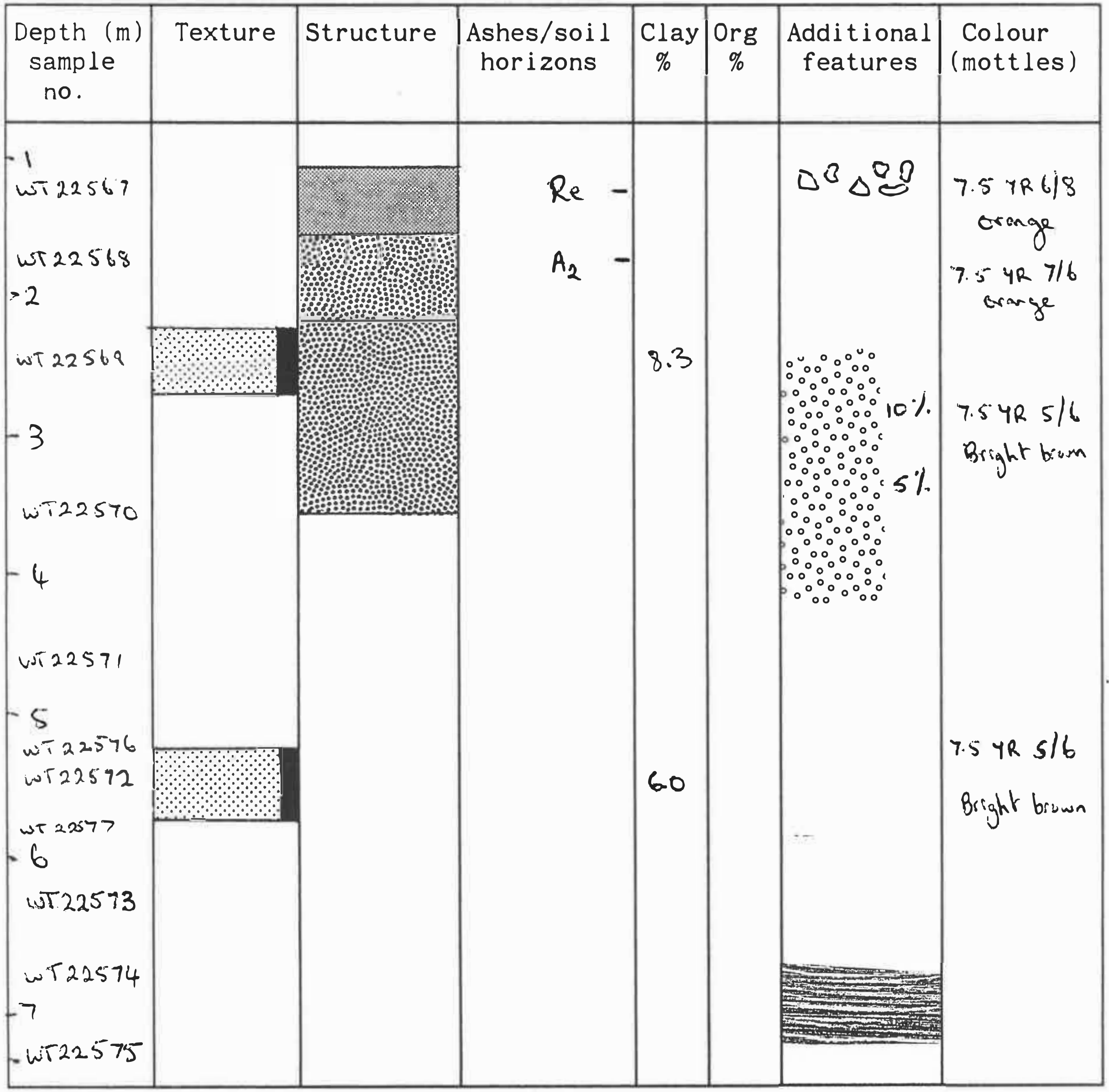
STRATIGRAPHIC COLUMN NO.: 26
GRID REFERENCE: T12/663512
LOCATION: Opoutere

BOREHOLE NO.: 6
FROM DEPTH(M): 1.2

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0							
WT22553			Topsoil A	2.2	8.8	Midden	7.5 R 1.7/1 Reddish black
0.2 WT22554			A2	3.1	1.5		10 YR 5/1 Reddish grey
0.4							
WT22555				6.4	5.9		10 R 2/2 Dark reddish brown
0.6 WT22556				3.9	6.2		7.5 R 2/2 Very dark reddish brown
0.8 WT22557						5%	5 YR 3/6 Dark reddish brown (5 YR 8/4 Pale brown)
WT22558 1.0						25%	
WT22559				7	1.3		7.5 YR 5/6 Bright brown (7.5 YR 7/4) (Dull orange)
1.5						Pumice 9	

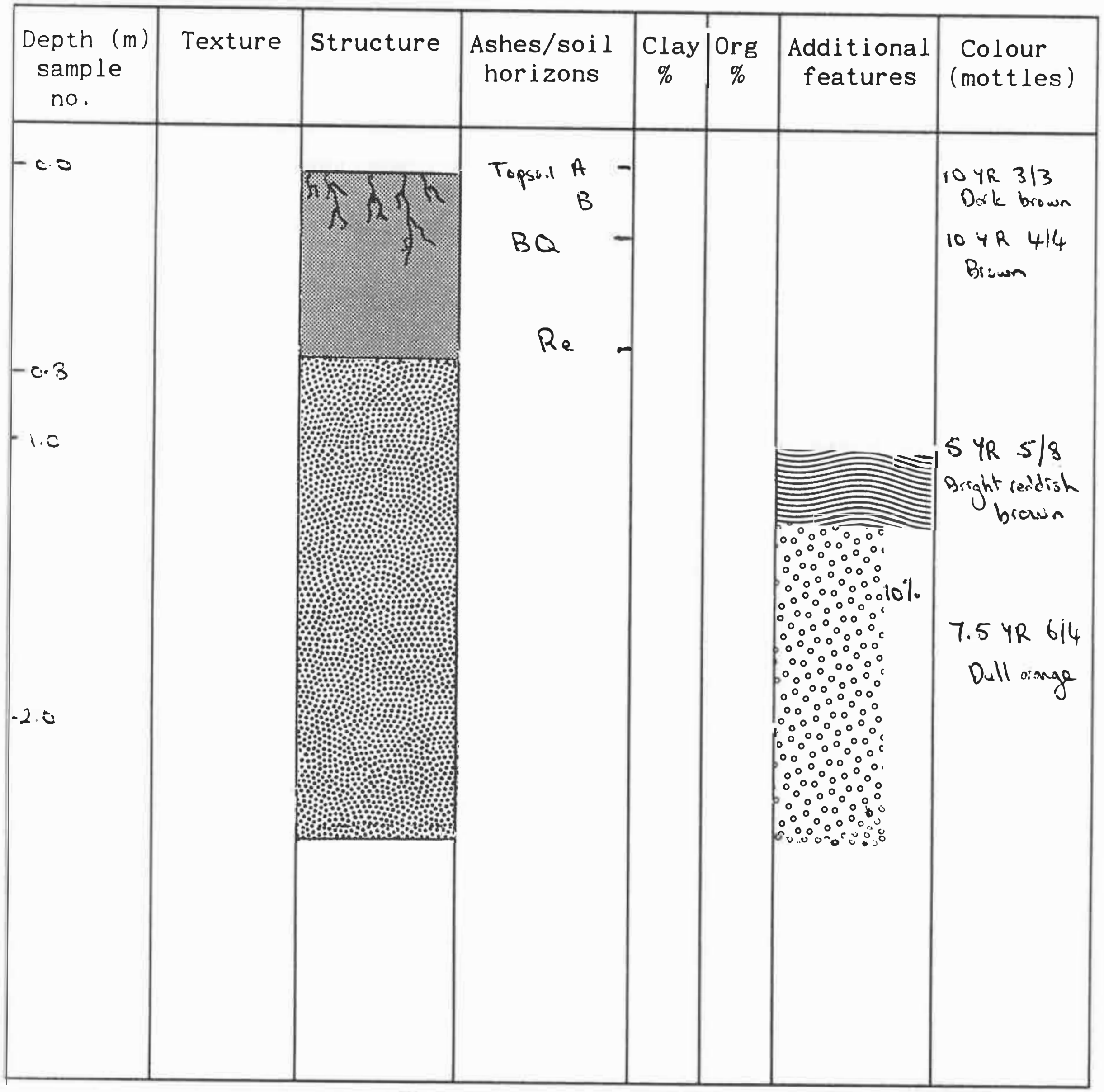
STRATIGRAPHIC COLUMN NO.: 27
GRID REFERENCE: T12/663511
LOCATION: Opoutere

BOREHOLE NO.: 7
FROM DEPTH(M):



STRATIGRAPHIC COLUMN NO.: 28
GRID REFERENCE: T12/663516
LOCATION: Opoutere

BOREHOLE NO.:
FROM DEPTH(M):



STRATIGRAPHIC COLUMN NO.: 29
GRID REFERENCE: T13/691284
LOCATION: Mataora

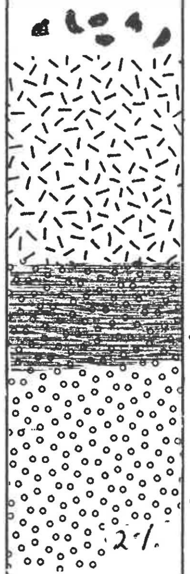
BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0 WT22758			Topsoil	3.1		Obsidian	10YR 2/2 Brownish black
0.2 WT22759				1.5		▲▲▲ Pumice 6	10YR 3/4 Dark brown
0.4 WT22760 0.6				7			7.5YR 2/3 Very dark brown
0.8							
1.0 WT22761 1.2				11			5YR 3/4 Dark reddish brown
1.4							
1.6 WT22762				3			10YR 6/3 Dull yellow orange

STRATIGRAPHIC COLUMN NO.: 30
GRID REFERENCE: U13 735123
LOCATION: Bowentown

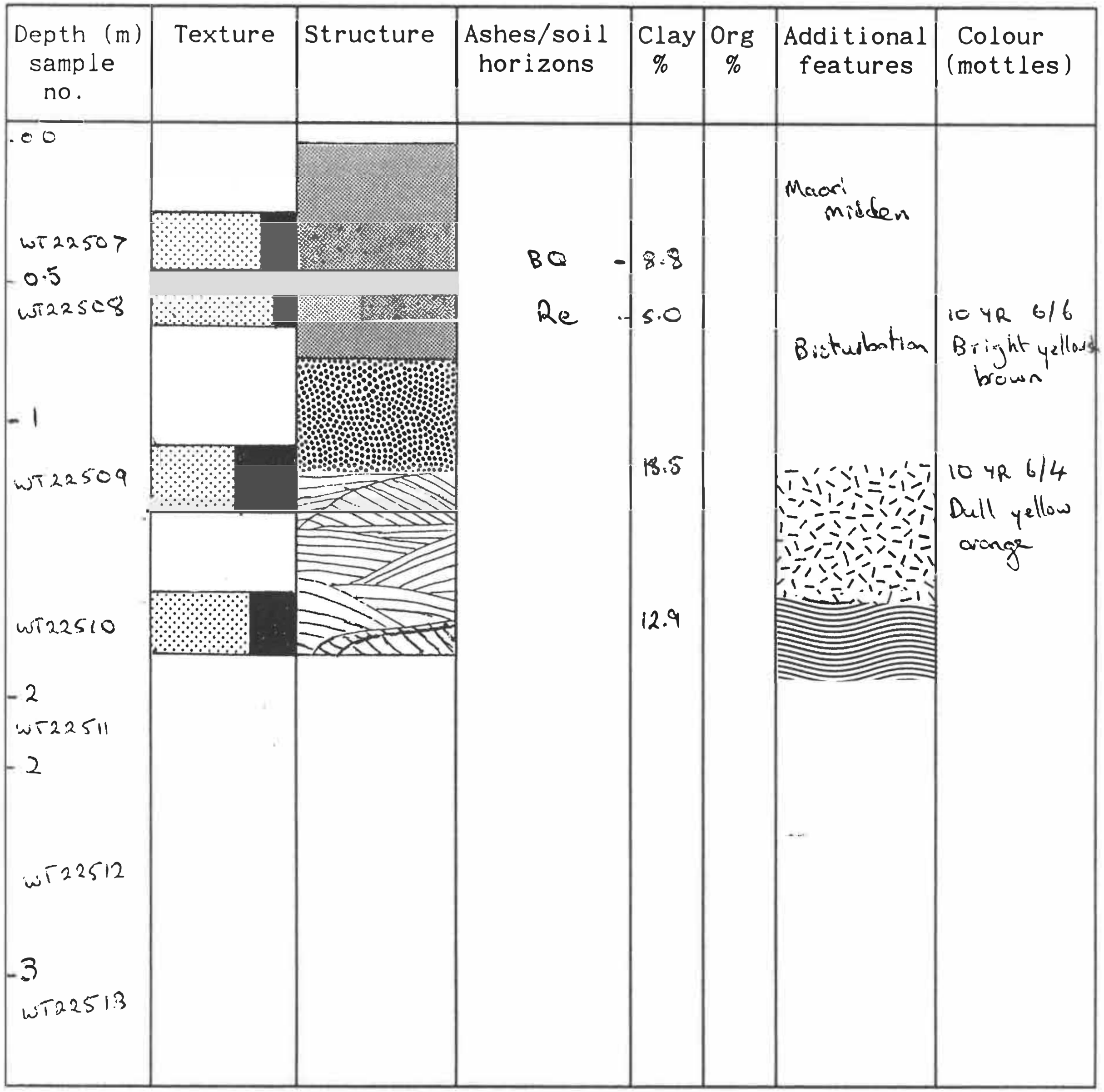
BOREHOLE NO.:
FROM DEPTH(M):

Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0			Topsoil				5YR 1.7/1 Black
WT22734							
0.2						▲▲▲ Pumice 8	7.5YR 2/2
WT22735							
0.4							
0.6							10YR 5/4 Dull yellowish brown
WT22736							
0.8							
1.0							
WT22737						2%	10YR 8/4 Light yellow
1.4							
WT22738							



STRATIGRAPHIC COLUMN NO.: 31
GRID REFERENCE: U13 735 115
LOCATION: Bowentown

BOREHOLE NO.: 9
FROM DEPTH(M): 1.8



STRATIGRAPHIC COLUMN NO.: 32
GRID REFERENCE: U13/711162
LOCATION: Waihi Beach

BOREHOLE NO.:
FROM DEPTH(M):

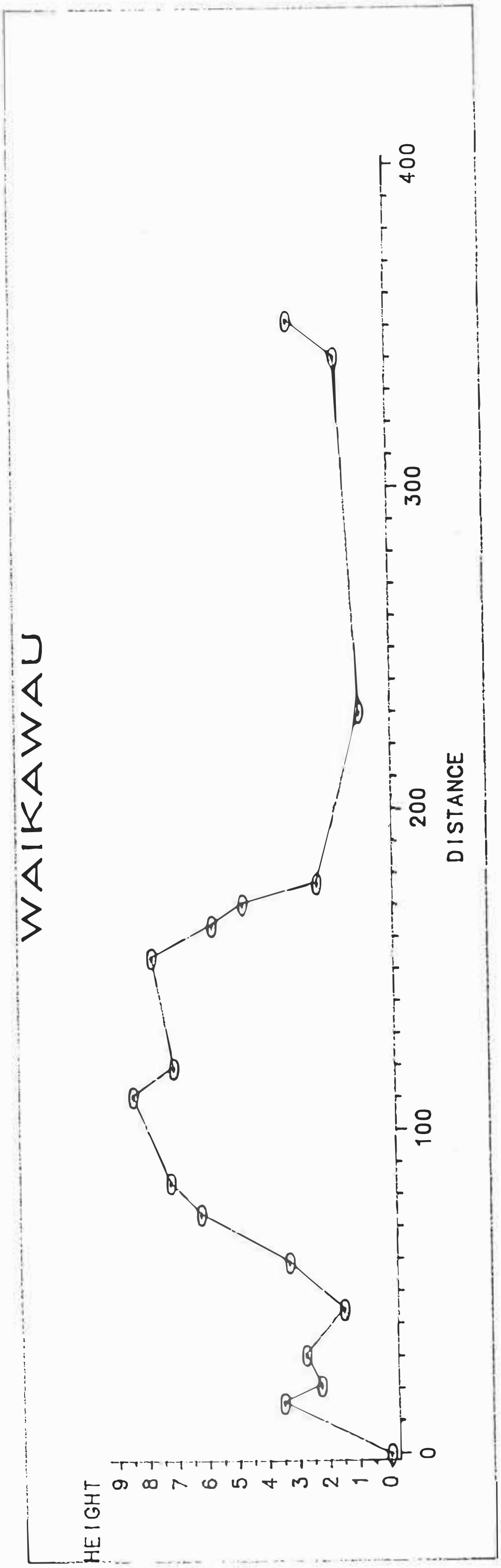
Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0			Topsoil A				2.5 YR 3/1 Brownish Black
0.2			BQ				10YR 4/4 Brown
0.							
0.6			Re			Shower bedded	10 YR 5/8 Yellowish brown
0.8							
1.0							
1.2							
1.4			Hamilton Ashes				10 YR 4/4 Brown
1.6							
1.8							
2.0							
2.2							

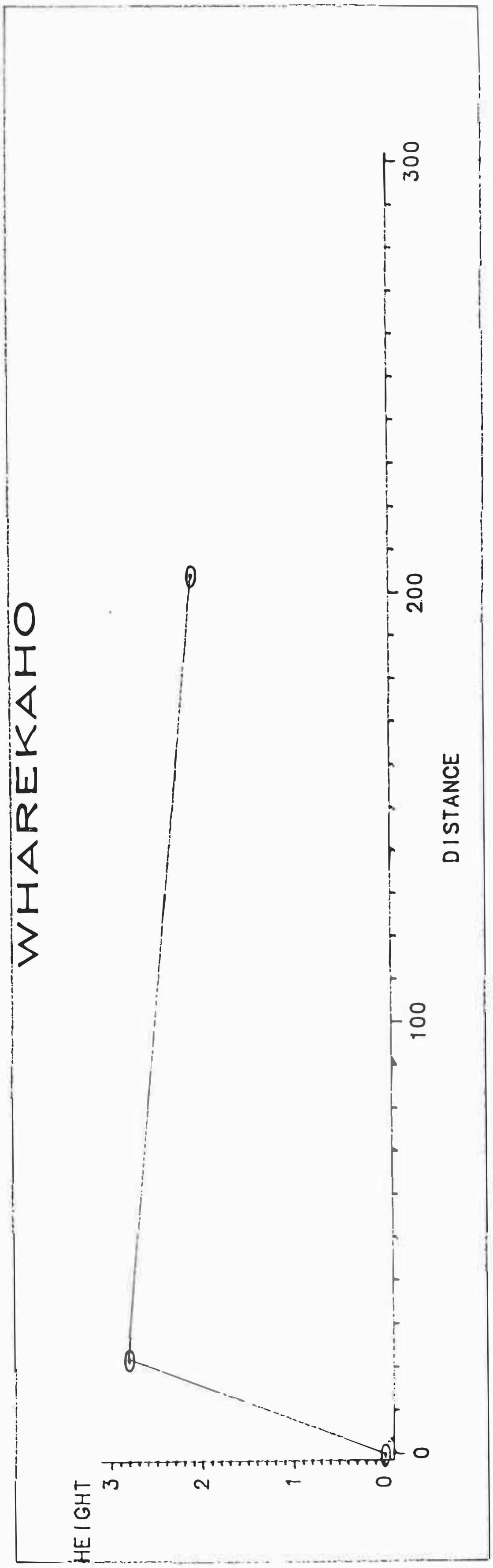
STRATIGRAPHIC COLUMN NO.: 33
GRID REFERENCE: U13/727132
LOCATION: Athenree

BOREHOLE NO.: 10
FROM DEPTH(M): 1.8

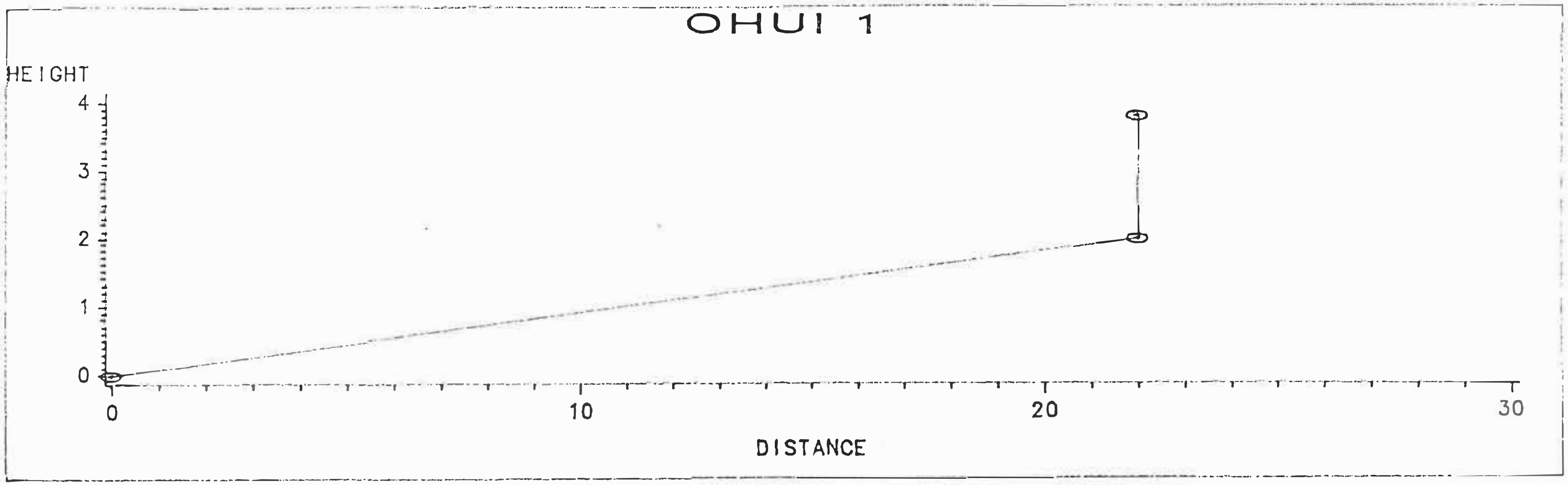
Depth (m) sample no.	Texture	Structure	Ashes/soil horizons	Clay %	Org %	Additional features	Colour (mottles)
0.0			Topsoil			midden	
WT22516			BQ				7.5 YR 5/6
1.0 WT22517			Re	5.0			7.5 YR 2/2 Light grey
WT22518				16.4			7.5 YR 5/8 Bright brown
WT22519 2.0				13.8			
WT22520				11.2			
WT22521				10.9			10 YR 6/4 Dull orange
WT22522 3.0				9.7			
WT22523				10.2			

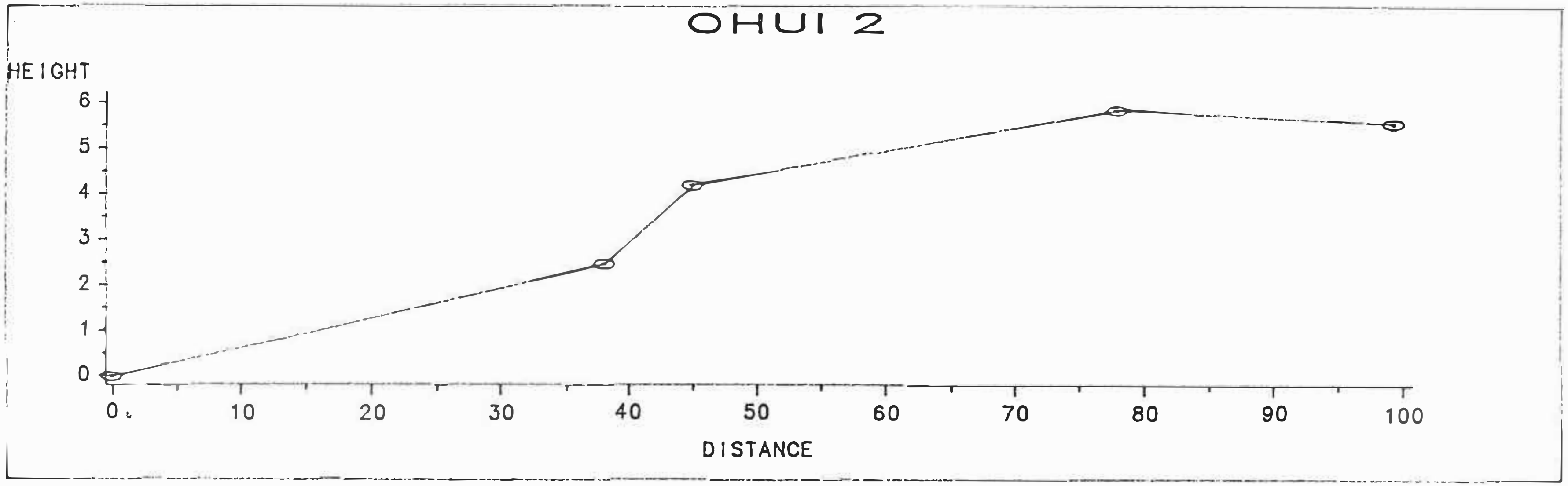
APPENDIX 4
DUNE SURVEYS

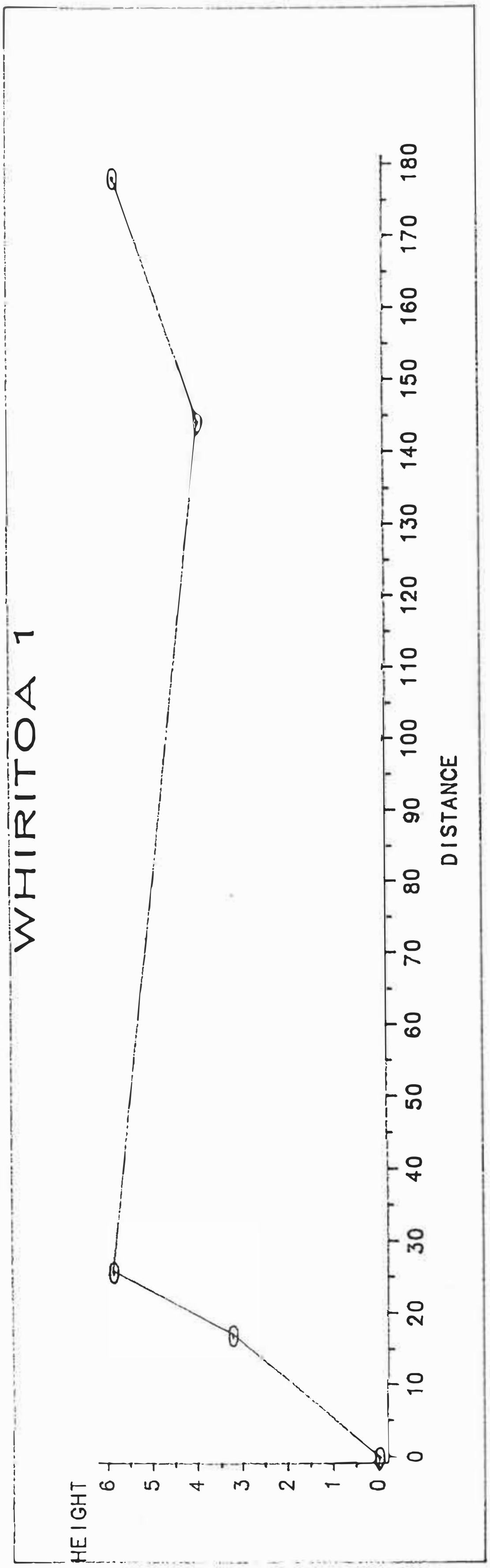


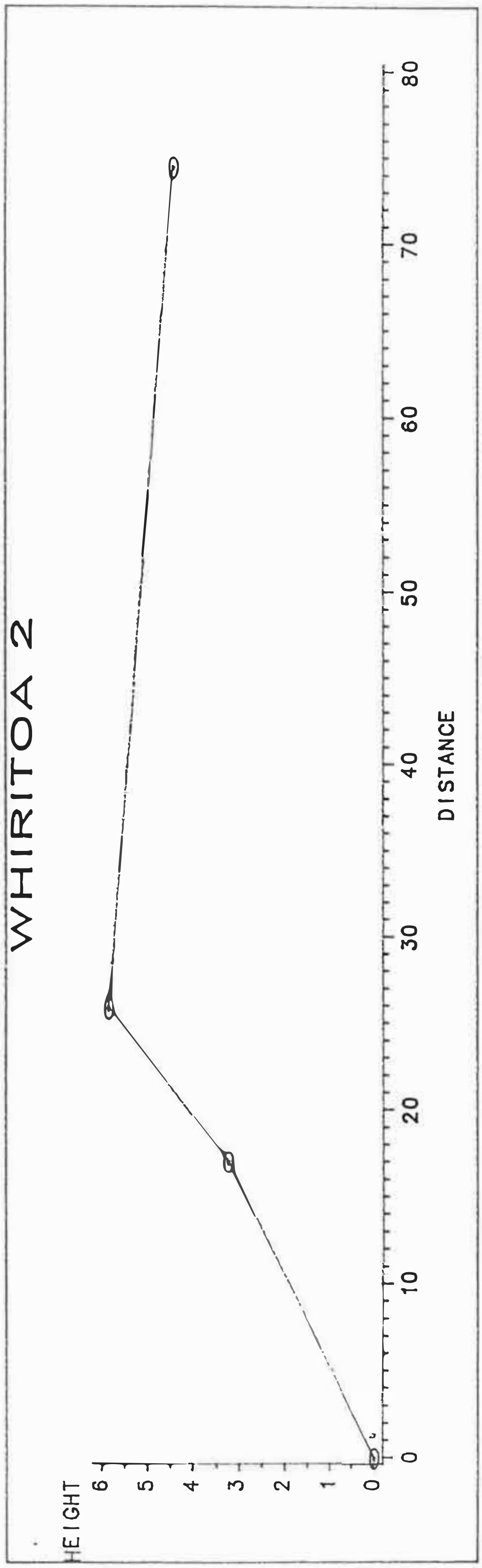


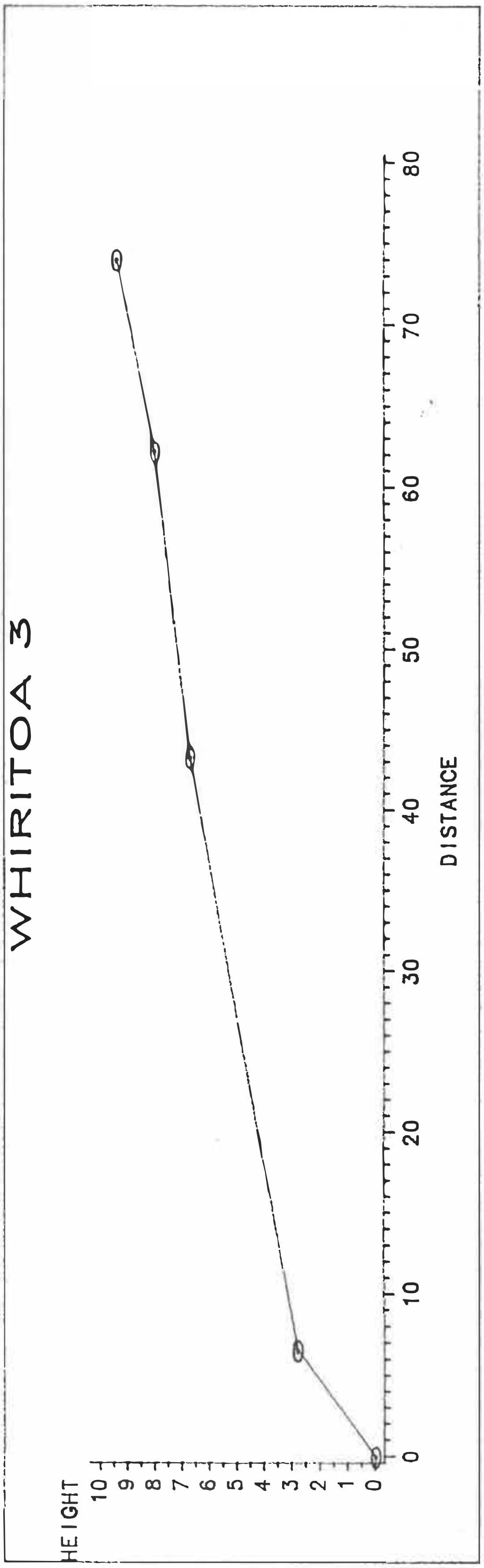
Ohui = Opoutere






WHIRITOA 1
HEIGHT
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
DISTANCE


WHIRITOA 2
HEIGHT
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
DISTANCE


WHIRITOA 3
HEIGHT
10 9 8 7 6 5 4 3 2 1 0
0 10 20 30 40 50 60 70 80
DISTANCE