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Reconstruction of sea level history during the middle Holocene at the Leschenault Peninsula, Western Australia

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Abstract

At the Leschenault Peninsula, a reconstructed sea level curve showed a maximum sea level of 3 to 4 m above the present mean sea level during the middle Holocene. This did not agree with other sea level curves along the Western Australian coast, which were lower at that period. It was assumed that local tectonic uplift could be a reason for this difference.

In this report, a sea level curve for the Leschenault Peninsula is reconstructed. Shells are dated using ^{14}C-analysis. The results show that the maximum found sea level was approximately 2.8 m above mean present sea level. Other factors than tectonic uplift could also contribute to this reconstructed sea level high stand, like reworking of shells and periods of higher storminess.

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Previous research

Introduction

The Holocene epoch, 10,000 years before present to present, is characterised by a climate much milder than in the preceding glacial period. When the last glaciation was at a maximum, some 21,000 yrs ago, sea level was -120 ± 20 m lower than at present. With the melting of the ice caps, water masses flowed into the ocean, causing global (eustatic) sea level changes. Global sea level changes may be driven by several factors: variations in the volume of ocean basins, the mass of ocean water, the ocean water density and geoidal changes (Pirazzoli, 1991, Rona, 1987) (Table 1). In addition to the global sea level changes, local or regional variations in relative sea level may be caused by additional factors (Table 1).

The main factors causing local sea level changes are hydro- and glacio-isostasy and tectonic movements. Isostasy is the regional variation in the Earth's response to the loading of the crust by eg. water (hydro-isostasy) or ice (glacio-isostasy) which can cause local displacements of the sea level record (Lambeck and Nakada, 1990; Searle and Woods, 1985).

Tectonic phenomena can result in relative displacements of the land relative to the mean sea level. Tectonic movements in Western Australia have been demonstrated for the Pleistocene and earthquakes occur episodically (Pirazzoli, 1991). Hence Holocene tectonism has been debated for various coastal areas.

Dynamic sea level changes may be insignificant on the time-scale of interest, however all of them need to be acknowledged. In particular, ephemeral variations in sea level (eg phases of storm activity) may leave marks or deposits on the shore, which may subsequently be misinterpreted as being due to a more permanent sea level high-stand (Pirazzoli, 1991). Incorrect interpretation of sea level evidence also results in variations in sea level records around the world. This affects the precision of the data base by which isostatic, eustatic and tectonic movements are judged. Without detailed information about the nature or stratigraphic position of the evidence cited the problem is further complicated (Searle and Woods, 1985).

Sea level history in Western Australia

The pioneering work on Late Holocene sea levels in Australia dates back to the 1950's. Fairbridge established a sea level curve showing rapid rise from 10,000 to 6,000 yrs B.P. for Western Australia, ending in a series of decreasing oscillating high-stands (Figure 1). In his sea level curve, sea level first reached its present level at about 6,000 yrs B.P. This corresponds to the final stage of the post-glacial marine transgression which was the result of the melting of the ice-sheets in the late Pleistocene and early Holocene. After 6,000 yrs B.P., sea level has remained relatively constant due to the cessation of melting of the ice (Lambeck and Nakada, 1990).

The sea level curve for Western Australia is distinctly different from northern hemisphere data. Fairbridge's highstands of several metres between 6,000 yrs B.P. and the present were not recognised in the European and North America data. Northern European sea level curves reached their modern levels much more recently (Lambeck and Nakada, 1990).

More recent research has been undertaken at a range of locations along the Western Australian coastline (Figure 2), to reconstruct the sea level history during the Holocene (Table 2, Figure 3). The resulting curves show marked discrepancies when compared to the Fairbridge curve concerning:

- the exact time that modern sea level was first achieved, this time varying from prior to 6,000 yrs B.P. to present
- whether or not sea level had been higher than its present position in the Holocene
- whether or not the sea level changes of the Holocene included short period (ca 1,000 yrs) oscillations (Hopley and Thom, 1983).

Sea level curves are reconstructed for several places along the southwestern coast of Australia (Table 2, Figure 3). Results point out that there is no spatial trend along the coast, but considerable differences are found within relative short distance.

Sea level history at the Leschenault Peninsula

The sea level history at the Leschenault Peninsula was reconstructed by Semeniuk (1985). The curve showed a maximum sea level of 3-4 m above present level during the period 4,800-3,000 yr B.P. (Figure 3). This maximum sea level was higher comparing to previous interpretations of sea level history in Southwestern Australia (Table 2). It was assumed that localised tectonic uplift caused the discrepancies between the sea level curve at the Leschenault Peninsula and other sites in Southwestern Australia. The validity of this theory was examined in an honours thesis (Matthews, 1993). In this thesis the morphostratigraphy of the Leschenault Peninsula is described. The stratigraphic units were correlated to conditions at the time of deposition. In the region, no plausible evidence for Holocene tectonism was found, like faults. The findings of that research represented that the influence of tectonism on the sea level record at the Leschenault Peninsula was not certain.

Hence, there is little agreement on the sea level history of the Leschenault Peninsula. The main question remains whether the sea level was 3-4 m above present sea level during the period 4,800-3,000 yr B.P. or not. And if there was such a sea level highstand, the reasons have to be examined. One of the reasons can be tectonic activity (Playford, 1988; Semeniuk and Searle, 1986; Semeniuk and Semeniuk, 1991).

Objectives of this study

The aim of this study is to reconstruct the sea level history at the Leschenault Peninsula. The specific objectives of this research are to:

(1) Describe the stratigraphic units and identify indicators of former sea levels (eg. shoreline facies, swash facies or shells)

(2) Identify the factors that could influence the sea level history at the Leschenault Peninsula

(3) Compare the reconstructed sea level history with previous research.

(4) Reconstruct the sea level history through ^{14}C-analysis of material extracted from these former sea level facies

Description of the study area

Regional setting

The Leschenault Inlet is an elongate sand barrier tending approximately north-south along the southwestern Australian coast, 180 km south of Perth (33°15'S 115°4' W AGD 1966) (Figure 4A). The Peninsula separates the shallow estuarine waters of the Leschenault Inlet from the Indian Ocean (Figure 4C).

The barrier system is approximately 12 km long and between 800 and 1500 m wide. The maximum height of the barrier is 37 m above mean sea level (Bunbury, sheet 2031, series R 611).

Stratigraphic setting

The Leschenault Inlet is a coastal dune system which has been developed along the western edge of the Swan Coastal Plain (Figure 4B). Other similar systems north of the Leschenault Inlet are Preston Lake, Clifton Lake and the Peel-Harvey Inlet. The Swan Coastal Plain is a Quaternary depositional system of the Phanerozoic Perth Basin (Figure 4D) (Semeniuk, 1985). The Holocene coastal beach/dune sequences of this system have been termed Safety Bay Sands. This formation extends discontinuously along the coast (Figure 4B).

The bulk of the Leschenault Peninsula is formed from Safety Bay Sands. The modern estuarine lagoonal sediments (the Leschenault Formation) interfingers this deposit. In depositional phases of the Safety Bay Sand and Leschenault Formation, the Holocene history is preserved.

Depositional history

Three distinct units have been identified within the Safety Bay Sand at the Leschenault Peninsula (Figure 5) (Semeniuk, 1985).

Each of these units was formed during a discrete stage of sea level history (Figure 6). The first stage (circa 7,100-5,500 ^{14}C yrs B.P.) involved deposition of estuarine sediments behind a coastal dune barrier (stage 1, Figure 6). At that time, sea level was 2-3 m lower than present. With still-stand conditions, the barrier dunes (Unit 1) migrated shoreward until the eastern edge of the barrier reached approximately the present eastern margin of the Peninsula. The bulk of the barrier is composed of sediments of Unit 1 (Semeniuk, 1986). Unit 1 thus comprises dune sand overlying estuarine sediment. It underlies all other units of the Safety Bay Sand. The maximum thickness is approximately 35 m, thinning to the south.

The second stage occurred from circa 4,800 to 3,600 ^{14}C yrs B.P. when sea level was 3-4 m above present (stage 2, Figure 6). During the first period of this stage, erosion narrowed the barrier. This was followed by net coastal progradation on the west side of the barrier which forms Unit 2. This Unit is formed from the accumulation of a shoaling sequence of subtidal sand, beach sand, beach ridges and a capping of aeolian sand. Its maximum thickness is ca. 15 m (Matthews, 1993). The sediments occur 3-4 m above their modern counterparts and have an erosional contact with Unit 1.

During the final stage (2,800 ^{14}C yrs B.P. to present), sea level has remained close to present levels (stage 3, Figure 6). At the landward side lagoonal/estuarine sediments accumulated. Erosion occured at the seaward side of the barrier. At present, erosion and net northward sediment transport are the major processes operating along the seaward edge of the barrier dune system. As the barrier transgresses eastward, estuarine-lagoonal sediments of the Leschenault formation are exposed and cliffed. Unit 3 is thus composed of aeolian sands and soils which are presently accumulating. The eastern margin of the beach has an erosional contact with Units 1 and 2.

Sedimentary facies

Coastal processes are effective agents in sorting sediments, shaping sedimentary bodies and generating sedimentary structures. Hence the sedimentation can result in a prograding sequence of beach/dune units. In an idealised sequence four facies can be recognised. Many of the features within this sequence are diagnostic of a certain location within the beach/dune environment. Recognition of a facies within a sedimentary sequence therefore enables reconstruction of height of mean sea level and shoreline conditions like energy level (Semeniuk and Johnson, 1982).

The idealised sedimentary sequence contains the following zones (Figure 7):

Shoreface

The shoreface is the environment of the trough-bedded sand and gravel, situated below mean low-water level (Figure 7). Intense winnowing removes fine sediment and leaves lags of gravel. The shoreface consists of medium and coarse sand, with small pockets and layers of gravel or coarse sandy gravel. Small-scale trough cross-strata are the dominant bedding type and cross-strata may oriented landward or seaward. Biogenic structures are not found because intense physical reworking would destroy burrows which do form (Semeniuk and Johnson, 1982).

Swash zone (foreshore)

The swash zone is situated between mean low-water and mean high-water levels (Figure 7). The deposits are bedded and laminated sand with gravel and shells in layers oriented parallel to layering. Large-scale structures consist of wedge-shaped sets of subhorizontal continuous parallel lamination. Each set has low dip, generally seaward, and it truncates the underlying set. The laminae are defined by variation in composition (quarts, skeletal grains, shell gravel and dark minerals) and grain-size (medium, coarse and rarely fine sand). Shell and lithoclast gravel layers form as lags after winnowing or accumulate during storms, these deposits are subject to reworking and remobilisation and hence are rarely incorporated into the sediment. Gravel bodies, up to 0.5 m thick and several metres across, trailing into thin layers, are developed periodically, generally located on cusp horns. Biogenic structures are rare except near low-tide level. In the upper part of the swash zone bubble sand can develop. Air bubbles trapped in the sediment form rounded holes 1-4 mm across (Semeniuk and Johnson, 1982).

Berm zone (backshore)

The berm zone is situated between mean high-water and storm high-water levels (Figure 7). The deposits generally consist of fine to coarse sand with irregular gravel deposits derived from storms. Parallel bedding and lamination and small-scale cross-strata are common but disrupted and homogeneous structures also occur. Bedding is generally horizontal in contrast to stratigraphic units above and below. The backshore is subject to extended periods of wind action which transports fine grained sediment, forms aeolian bedding structures and pile sand drifts around obstacles such as storm debris. Erosion during storms or by winds truncate earlier strata, and subsequent deposition forms minor erosional interfaces. Storm debris like wood, seagrasses and sepia is incorporated into the berm zone deposits. Similar deposits occur also at lower beach levels but are subject to reworking and remobilisation and hence are rarely incorporated into the sediment (Semeniuk and Johnson, 1982).

Beach ridge or dune

The beach ridge or dune unit is situated landward of the beach (Figure 7). Dune deposits consist of fine and medium sand, generally finer than that of the beach ridge. These form thick wedges of large-scale cross-strata, dipping landward. Bounding surfaces observed immediately above beach deposits are planer. Trenches show curved bounding surfaces and intercalated incipient soil sheets. Rootlets and soils occur when the beach ridge has been stabilised for sufficient time (Semeniuk and Johnson, 1982).

Methods

Field and laboratory techniques were used to reconstruct the sea level history of the Leschenault Peninsula.

Field methods

The large-scale development of the Leschenault Inlet was determined from the following evidence: available literature, aerial photographs and field observations. Field observations consisted of description of the geomorphology and the stratigraphy.

Three sites were selected and examined on a smaller scale. Trenching was conducted along the beachface and foredune scarp. When the surface profile was steep the trench was stepped at regular intervals. The sedimentary sequence of these sites was examined to determine the stratigraphic zones. Shell layers at the boundary between the swash and berm zone were assumed to represent a mean high-water level, and from these layers samples were taken. The exact elevation of these shell layers relative to present Mean Sea Level was surveyed.

At the three sites, bulk samples were taken from the stratigraphic units which were considered to be indicative sea level markers. A 2 mm sieve was used to recover the shells and shell fragments from the bulk samples. Shells were washed and sorted into taxa. Aragonitic shell species representing an open sandy coast were used for ^{14}C-analyses. Shells reworked from older Holocene or Pleistocene deposits could create errors if they were mistaken for shells which extenuated during sedimentation. To minimise the time between death and deposition only shells common to the near beach environment and without visible signs of erosion were used for dating.

Analysis methods

At the University of Western Australia, radiocarbon analyses were carried out on the samples collected in the trenches. The radiocarbon dates were used to determine the age of stratigraphic units which indicate former Mean Sea Levels. The dates were correlated at the three different localities after which the elevation of the stratigraphic Mean Sea Level indicators was plotted against age.

Results

First it was tried to locate the trench site described by Matthews (1993) to compare the field stratigraphy with the described stratigraphy. Because the field stratigraphy did not correlate with the described stratigraphy, the results of Matthews (1993) were not used in this research. Three trenches were dug at the seaward side of the Leschenault Inlet. The co-ordinates of the trench sites were determined using a G.P.S. (Figure 8, Table 3). The distance between trench sites I and II was 562 m, and 310 m between trench sites II and III. The different stratigraphic structures in each trench site were described, after which the sedimentary units of the profile were identified.

Trench site I

Trench site I consisted of seven steps (Figure 9, Figure 10). The stratigraphy in the seven steps was combined in one profile, in which five sedimentary units could be recognised (Figure 11). The base of the trench site I was situated at Step A, -3.3 m below the temporary benchmark (T.B.M.). Step A displayed three different stratigraphic units.

The first unit was situated from the base of the trench to -2.9 m below the T.B.M. It consisted of light grey quartz sand, no bedding structures were evident and the sand was cemented. The second unit was observed to have a sharp contact with the first unit at -2.9 m below T.B.M. The thickness of the second unit was 0.2 to 0.3 m and consisted of brown quartz sand with layers of organic material and without bedding structures. The third unit had a sharp contact at -2.6 m below T.B.M. with the second unit, this was observed at Step A and Step B. The first two units were homogeneous and differed in compaction from the above laying beach or dune deposits. The situation of the first two units in the profile was compared with the previous described model of Semeniuk (1985) (see section Description of the study area, Depositional history). It was concluded that these first units represent deposits of an estuarine environment.

The third unit was 0.6 m thick and consisted of subhorizontal continuous parallel laminae, characterised by thin beds of heavy minerals. Truncations in the laminae were evident, due to minor erosive events. Three distinct shell layers were found, these were formed either as lags after winnowing or were accumulated during storms.

The first two shell layers were found in step B situated -2.5 m and -2.4 m below T.B.M. The shells were bedded convex-side upwards and cemented. The identified shells are listed respectively in Appendices I and II. Also a bulk sample of both layers was taken (Appendix III). It was assumed that the shells were representative of inshore and intertidal zones of a sandy open coast with medium to high energy levels. The most common shells were *Mactra (Mactra) australis* (Deshayes) and *Donax (Deltachion) electilis* (Iredale). Some shells had probably been reworked from an older lagoonal deposit, these are specimens of *Katelysia rhytiphora* (Lamy) which lives in the littoral or intertidal zone of sheltered sandy beaches. They are likely to be of Middle Holocene age (Kendrick, pers. comm.). The third layer containing shells was found 0.5 m above the second layer (-2.0 m below T.B.M.) in step B. The shell species are listed in Appendix IV. It was assumed that the layer at -2.2 m below T.B.M. in step C was the same shell layer. Though the third layer contained a wider range of species, these shells were essentially like the species in the lower two shell-layers. The most common species were *Glycymeris striatularis* (Lamarck), *Donax (Deltachion) electilis* (Iredale) and *Mactra (Mactra) australis* (Deshayes). It was assumed that the shells represented a range from shallow sublittoral to beach derived species from an open sandy coast with moderate to high energy. A sample of this layer was taken and the aragonitic shells representing an open sandy coast were used for ^{14}C-analysis. Like the other layers this layer contained material suspected to be reworked from a pre-existing lagoonal deposit. These fragments were attributable to a species of *Katalysia*, which is probably of Middle Holocene age (4000–6000 years B.P.) (Kendrick, pers. comm.). Because of the parallel lamination in the third unit and the shell layers it is assumed that this is a sedimentary unit characteristic of a swash zone. The swash zone is situated between mean low-water and mean high-water levels.

The forth unit extended from -2.0 m to -1.6 m below the T.B.M., and was found in step C and the bottom of step D. The unit consisted of landward dipping laminated sand with heavy mineral layers and some shells. The landward dip of the laminations was used as an indication to support the assumption that the fourth unit consists of berm deposits. The berm may slope landward as a wash over into a small depression in front of the beach ridge, and is situated between mean high-water and storm high-water levels. There is only inundation during storms where water level reaches higher than the normal high tide level. The shells are part of the storm debris which is left behind as storm water rapidly retreats.

The fifth unit formed the topmost stratigraphic unit which was 2.4 m thick. It was characterised by thick wedges of large-scale cross-bedding, dipping in many different angles. Layers comprised of heavy minerals and some concentrations of organic material were found. The cross-stratification is typical for beach ridge and dune deposits. Plants could grow on the ridge when it was stabilised for sufficient time. The organic material found is a part of the remains of the rootlets.

In short the stratigraphic profile found at trench site I could be divided in four different sedimentary units. From bottom to the top these units represented estuarine, swash zone, berm zone, and beach ridge or dune sedimentary environments. The shell layer representing the swash zone and situated at -2.0 m below the temporary benchmark (+2.5 m above present mean sea level), was used for ^{14}C-analyses.

Trench site II

Trench site II consisted of nine steps (Figure 12, Figure 13) The stratigraphic profile shows four distinct sedimentary units (Figure 14). The base of the lowest step, step A, was situated at -2.3 m below the T.B.M. The top of the trench was situated at +3.3 m relative to the T.B.M.

The first unit of the stratigraphic profile extended from the base of step A to -1.6 m below the T.B.M. This unit consisted of grey to brown sand with a subhorizontal parallel lamination, and layers of heavy minerals. A distinct shell layer was recognised in step A and the bottom of step B, at -1.6 m below the T.B.M. (Appendix V). The shells were bedded convex-side upwards. The most common species of shells were *Mactra (Mactra) australis* (Deshayes) and *Donax (Deltachion) electilis*

(Iredale). These species were assumed to be representative for inshore and intertidal zones of a sandy open coast with medium to high energy levels. Also found were shell fragments of the species *Lima gemina* (Iredale), *Mimachlamys asperrima* (Lamarck) and *Mesopeplum anguineum* (Finlay). These species were possibly reworked from a pre-existing deposit (Kendrick, pers. comm.) The calcite shells and the reworked shells were excluded from ^{14}C-analysis. The aragonitic shells representing an open coast were used for ^{14}C-analysis. The parallel lamination and the shell layer are indicators of a swash zone. This zone is situated between mean low water and mean high water levels.

From -1.6 m to +1.3 m, the second unit was recognised. This unit was characterised by homogeneous brown sand that had an even distribution of shells. At -1.3 m, a moderate distinct shell layer was found. Shells were less abundant than in the previously described shell layer. Although no distinct landward dip was seen, it is assumed that this unit was a berm deposit. The homogene distribution of shell fragments indicates storm debris, deposited only during storms above high tide level. As water rapidly retreats after a storm, shell fragments are left behind.

The third unit extended from -1.3 m to +1.0 m relative to the T.B.M., and was found from the top of step B to step F. Fine to medium sands formed thick wedges with a large scale land- and seaward dipping. No small scale lamination or shells were found. The third unit was characterised by an alternation of dark and light coloured sand. The top of unit three consisted of 0.4 m of dark brown homogenous sand. The colour was a result of a high content of organic material. Below the dark sands, a layer of 0.6 m sand was found. The colour gradually passed from dark brown at the top to lighter brown at the bottom. This was the result of leaching out of the dark brown layer above. Dark brown mottles were present, also as a result of the process of leaching out. Under this layer, 0.6 m of grey sand was found with brown mottles of organic material. This was underlain by 0.05 m dark brown, organic material rich sand. This layer showed dark mottles above and below. The base of unit 3 consisted of 0.6 m brown homogenous sands. The third unit represents phases of stabilisation of the deposits, during which plants could grow and a organic rich horizon developed. The growth and decay of the organic material homogenised the soil. During a more active period the plants were buried and dark organic rich incipient soil sheets remained. The location of this unit above the berm deposits and the organic material indicate that this is a beach ridge or dune unit.

The uppermost unit, unit four, extended from +1.0 m to +3.3 m above the T.B.M. This unit was found in the top of step F and step G, H and I. The brown to grey sands showed a low angle seaward dipping and a few layers comprised of heavy minerals were found. There was an alternation in grain sizes differing between 210-300, 300-420 and 420-600 μm. Throughout the profile, shell fragments were found. A layer of shells was found at +1.0 m above T.B.M., situated directly above unit three (Appendix VI). The most abundant species in this layer were *Mactra (Mactra) australis* (Deshayes) and *Donax (Deltachion) electilis* (Iredale). These are the same as in the shell layer at -1.6 m below T.B.M. Also fragments of *Lima gemina* (Iredale) and *Mimachlamys asperrima* (Lamarck) were found, both are possibly reworked from older deposits (Kendrick, pers. comm). The shell fragments and layers with coarse sand indicate that this unit represents deposits of wash overs. During a wash over, sand from the seaward side is transported over the barrier. The coarse sand (420-600 μm) and shell fragments can be deposited during this high energy process. The layers of less coarse sand were deposited during periods in between wash overs.

The stratigraphic profile found at trench site II could be divided in four different sedimentary units. These units are deposits from the swash zone, berm zone, beach ridge or dune zone and wash-over zone, from bottom to the top. One shell layer was used for ^{14}C-analysis. This layer was situated at -1.6 m below the T.B.M, that is +2.9 m above present mean sea level.

Trench site III

Fourteen steps were dug at trench site III (Figure 15, Figure 16). They were situated between -2.5 m below and +4.8 m above the T.B.M. The found stratigraphy was described and combined into one profile (Figure 17). Six units were distinguished.

The first unit was found in step A and the bottom part of step B and extended from -2.5 m to -1.6 m relative to the T.B.M. It consisted of parallel laminated sand with a seaward dipping and contained layers of heavy minerals. Also some calcareous concretions were found. At the top of this unit, -1.6 m below T.B.M., a shell layer was found (Appendix VII). As with the sample taken in the trench sites I and II, the species *Mactra (Mactra) australis* (Deshayes) and *Donax (Delatachion) electilis* (Iredale) were abundant. The sample also included material possibly reworked from an older, pre-existing deposit. This, and the calcite shells were excluded from the ^{14}C-analysis. The parallel lamination, heavy mineral layers and the shell layer are all characteristics of the swash-zone, situated between mean low-water and mean high-water levels.

The second unit was found between -1.6 m and -1.2 m relative to the T.B.M. and was present in steps B and C. The unit consisted of homogeneous sand with an even distribution of shells. Although no landward dipping was seen, it was assumed that these were deposits of the berm. The berm is situated between mean high water and storm high water levels. Storm debris, like shell fragments is deposited during water levels higher than the normal high tide level.

The third unit was found in the steps C, D E and F and extended from -1.2 m to +0.5 m relative to the T.B.M. This unit comprised a 0.1 m thick, dark brown, organic rich horizon which was found in step C, D and E. The horizon was situated between 0.2 and 0.3 m below the surface and was dipping in seaward direction. It was assumed that this horizon was formed during a stable period during which the sedimentation was low and vegetation could develop. The remaining part of the unit consisted of homogeneous grey-brown sand. Grey-white concretions were found. These are rhizoconcretions, representing burrows during a stable period. The organic activity homogenised the soil. The location of this unit above the berm deposits and the organic material indicate that this is a beach ridge or dune unit.

The fourth unit extended from +0.5 m to +2.6 m relative to the T.B.M. and was found in step G, H, I, J and K. It consisted of landward dipping laminated sand with an even distribution of shells and heavy mineral spots and layers. These are characteristics of a period during which wash-overs were present. A period of higher sea level or a higher storm intensity can cause wash-overs. During a wash-over, coarse particles and shells can be transported over the barrier. A few layers of fine grained sand were present, indicating short phases of aeolian activity between the wash-overs.

The fifth unit was found in the steps L and M, extending from 2.6 m to 4.3 m above the T.B.M. The sand was in general fine-grained with an average grainsize of 210-300 μm. The small grainsize and the absence of laminations, shells and heavy minerals indicate that this unit represents aeolian sands of the beach ridge. No soil-layers were found, so it is assumed that possible phases of stabilisation were not long enough to leave distinct marks of vegetation.

The sixth unit extended from 4.3 to 4.8 m above T.B.M. The unit was only found in step N. The unit showed a low-angle landward dip. Layers of heavy minerals and shell fragments were present. The fact that this unit was found on the deposits of the beach ridge, indicates that unit six represents wash over deposits.

In the stratigraphic profile of trench III, six sedimentary units were found. The lowest unit represented the swash-zone, on which the berm was found. Above the berm deposits, indicators from a stable period were found. This was followed by sediments of a wash over, aeolian sands and again wash over deposits. The shell layer at -1.6 m below T.B.M. (+2.9 m above present mean sea level) was used for dating with ^{14}C-analysis.

Indicators of sea level history

One of the aims of this research was to reconstruct the sea level history through ^{14}C-analysis of material extracted from sea level indicators. Because indicators of a sea level high stand had to be dated, it was chosen to take samples of the highest found sea level indicator in each trench site. In this case a shell layer at the boundary between the swash zone and the berm zone was used because a shell layer at this location represents mean high water level. The heights of the samples were levelled relative to a Temporary Bench Mark (T.B.M.) situated approximately 4.5 m above present mean sea level. A precise height will be obtained using a differential-GPS. At trench sites I, II and III the heights of the samples were respectively -2.0, -1.6 and -1.6 m below the T.B.M., that is about 2.5, 2.9 and 2.9 m above present mean sea level. No dates of the samples have been obtained by the submission time of this research.

Development of the Leschenault Peninsula

Based on the stratigraphic profiles, described above, a reconstruction of the development of the Leschenault Peninsula can be made. During the first stage the barrier was situated more seaward and estuarine sediments were deposited at the landward side of the barrier. At that time, sea level was probably lower than present. Gradually, sea level started to rise. The rising sea forced the barrier to migrate eastward. The migration of the barrier took place over the estuarine sediments. When sea level was more stable again, accretion at the seaward side of the barrier occurred. This resulted in the accumulation of a shoaling sequence, consisting of swash , berm and beach ridge deposits. The first part of the shoaling sequence is the swash zone which was deposited between mean low water and mean high water levels. On top of the swash zone, the berm zone was deposited. These are characteristic sediments of the zone between mean high water and storm high water levels. The fact that the berm zone is not exactly at the same height in the three trench sites is due to the fact that slight differences in height occurred along the coast. Beach ridge or dune sediments were deposited above the berm zone. In trench site II and III, paleosols were found in these sediments. Paleosols are indicative of an alternation of dune development and stabilisation during which vegetation started to develop. They can not be used as an indicator of mean water level. The active sedimentation during dune development caused the burial of the vegetation. This resulted in dark organic layers that are included in the beach ridge unit. Finally, during periods of higher storminess wash-over sediments were deposited.

Discussion

Depositional history

In this research a former sea level high-stand was reconstructed at approximately 2.8 m above present mean sea level. This high-stand is lower than the high-stand found by Semeniuk at 3-4 m above present mean sea level. The shells in this layer were dated 4,800-3,600 ^{14}C yrs B.P. Because these results were not consistent with previous research in Western Australia, it was assumed that localised tectonics are of influence (Semeniuk, 1985, Semeniuk and Searle, 1986). However, the decreasing oscillations in Fairbridge's sea level curve (Figure 1) do not support the suggested theory of tectonic influence. Several other points have to be considered.

At first, shells can be reworked. There are two possible sources for reworking at the Leschenault Peninsula. These are shell beds in estuarine deposits and shell beds in drowned barriers. Reworking of estuarine deposits can occur when shells are eroded from the lagoonal side of the barrier, transported, and deposited at the seaward side of the barrier. A drowned barrier can form as a response to sea level rise (Figure 18A). Overstepping of the barrier during transgression leaves it drowned on the seabed as a relict feature. According to Rampino and Sanders (1983), factors that favour overstepping are:

- increase of rate of sea level rise
- low sediment influx
- stranding on a topographic high

Research to sediments and stratigraphy on the shelf along the east coast of the USA supports this theory (Leatherman, 1983a).

A second point that has to be considered is that water levels at both sides of the Leschenault Peninsula can differ from eachother. Two factors can cause this difference, these are periods of higher storminess and peak levels in the runoff from the Collie river. Elongated periods of storminess cause a setup in the water level at both sides of the barrier. The setup at the ocean side will be lower than at the lagoonal side because at the ocean side the water can flow along the coast, whether the water that is forced into the lagoon can not flow out. Besides, during peak levels in run off of the Collie river the water level at the lagoonal side of the barrier will be higher than at the ocean side of the barrier. Hence, shells deposited at lagoonal side during periods of higher storminess or peak discharge of the river, are situated higher than shells deposited during the same period at the ocean side.

A third point is that sea level is unstable over a range of time spans. Wave action or tidal variation with relative small periodicities can influence oscillations produced by tectonic or eustatic influences which lasted thousands of years. Most types of evidence have a range of heights over which they occur, the greater the range the less the degree of refinement which is possible using that evidence. Moreover, height relationships are not finite even in areas of similar tidal range because of variations related to wave exposure.

Formation of Leschenault

At the Leschenault Inlet, Semeniuk applied a model in which a rising sea level is resulting in 'rollover' or 'translation' (Figure 18B). In this theory, barriers are thought to be continuously migrating landward without loss of material. The driving mechanism is barrier overwash, which transports material landward from the shoreface into the backbarrier. This enables its continual reworking as transgression proceeds (Leatherman, 1983B). The rate of retreat is controlled by the balance between sand supply and sea level change.

There are however several points against this model.

A first point is that data from coring of present barriers indicate that many barriers formed very near their present location (Davis, 1994). Some have experienced initial drowning followed by subsequent upward shoaling due to transgression. Semeniuk (1985) however states that the barrier at Leschenault originally stood 2-3 km further offshore.

A second point is that, according to Semeniuk's model, the first depositional stage in the development of the Leschenault Peninsula involved deposition of lagoonal sediments behind the barrier. Sea level stood 2-3 m lower than present during this time. The next stage involves barrier migration over a distance of 2-3 km with sea level still at 2-3 below present. A migration of a barrier over a long distance requires however (Davis, 1994):

-changes in sea level

-wave regime

-tidal regime

Because sea level is said to remain equal, a distinct change in wave or tidal regime must have taken place. For a barrier migration of 2-3 km, these changes must be extensive. Reasons for such a change are not mentioned.

A third point concerns the distribution of backbarrier sediments. Research in southeastern Australia showed the existence of relict estuarine sediments in present-day shelf environments. This was thought to provide evidence for the 'in place drowning' theory. When barriers migrate continuously landward, wave activity results in complete or nearly complete destruction of backbarrier sediments. Conversely, if a barrier drowns, extensive erosion will not take place (Leatherman, 1983a). Finding evidence for this development was not one of the objectives of this research. More research to estuarine sediments on the present-day shelf at Leschenault, will provide more clearness.

Radiocarbon ages of shells

Using shells as material for ^{14}C-dating has the principal advantage that the calibration curve is smoother than for terrestrial samples. It is therefore possible to obtain more precise calendar ages (http://c14.sci.waikato.ac.nz/webinfo/shell.html).

There are also a number of uncertainties for dating shells. Potential sources of error are: contamination, reservoir effect and recrystallisation (Woods and Searle, 1983). Firstly, to avoid contamination, all the shells were identified. Reworked shells or shells that were deposited in a lagoonal environment were excluded from dating. The second problem is the reservoir effect. Comparison of shell dates and terrestrial dates from the same stratigraphic layers of the same site has shown that shell dates were approximately 300-500 yrs older. This is due to the reservoir effect and is caused both by the delay in exchange rates between atmospheric CO_2 and oceanic bicarbonate, and the dilution effect caused by the mixing of surface waters with deep ocean waters (Mangerud 1972, cited in http://c14.sci.waikato.ac.nz/webinfo/shell.html). When dating Australian marine shells from the south-west coast, Gillespie and Polach (1979) have determined a mean correction factor for reservoir effects of 450 ± 35 yrs (to be subtracted from the uncorrected date).

Conclusions

The combined stratigraphies from the three trench sites at Leschenault Peninsula showed the following sequence: estuarine unit, swash unit, berm unit, dune unit, wash over unit, dune unit and wash over unit. This was in line with the expectations based on literature. Shells at the transition between the swash unit and the berm unit were assumed to represent a former sea level high stand. At trench site I an indicator of a former sea level high-stand was found at 2.5 m above present mean sea level. Trench site II was situated 562 m north of trench site I, and showed a mean sea level high-stand of 2.9 m. The same mean sea level high-stand was found at trench site III, 310 m north of trench site II. The mean sea level high-stand was approximately 2.8 m above present mean sea level.

The sea level history at Leschenault Peninsula was reconstructed using shell layers as indicators of a former mean sea level. The location of the dated shell layers could have been influenced by local factors as tectonics, periods of higher storminess and reworking of shell material. However, no evidence was found for tectonic influence. Besides, the decreasing oscillations in Fairbridge's sea level curve (Figure 1) do not support the suggested theory of tectonic influence. It appears that regional differences in reconstructed sea level history are not necessarily due to tectonics as stated by Semeniuk (1985) and Semeniuk and Searle (1986).

^{14}C-datings were not completed in the time this occupational traineeship was completed.

Figures

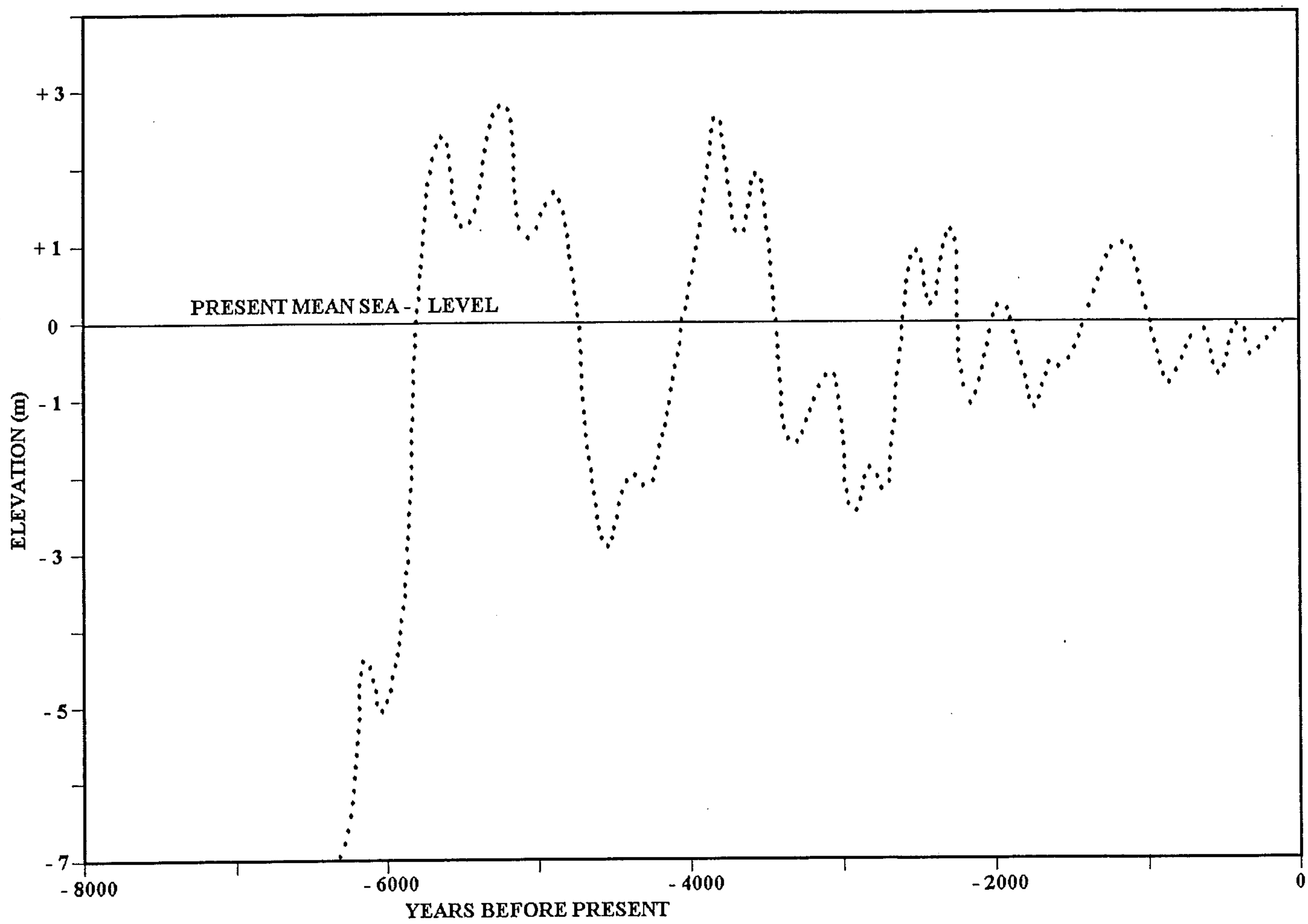


Figure 1: Fairbridge's sea level curve for Western Australia (after Playford, 1988).

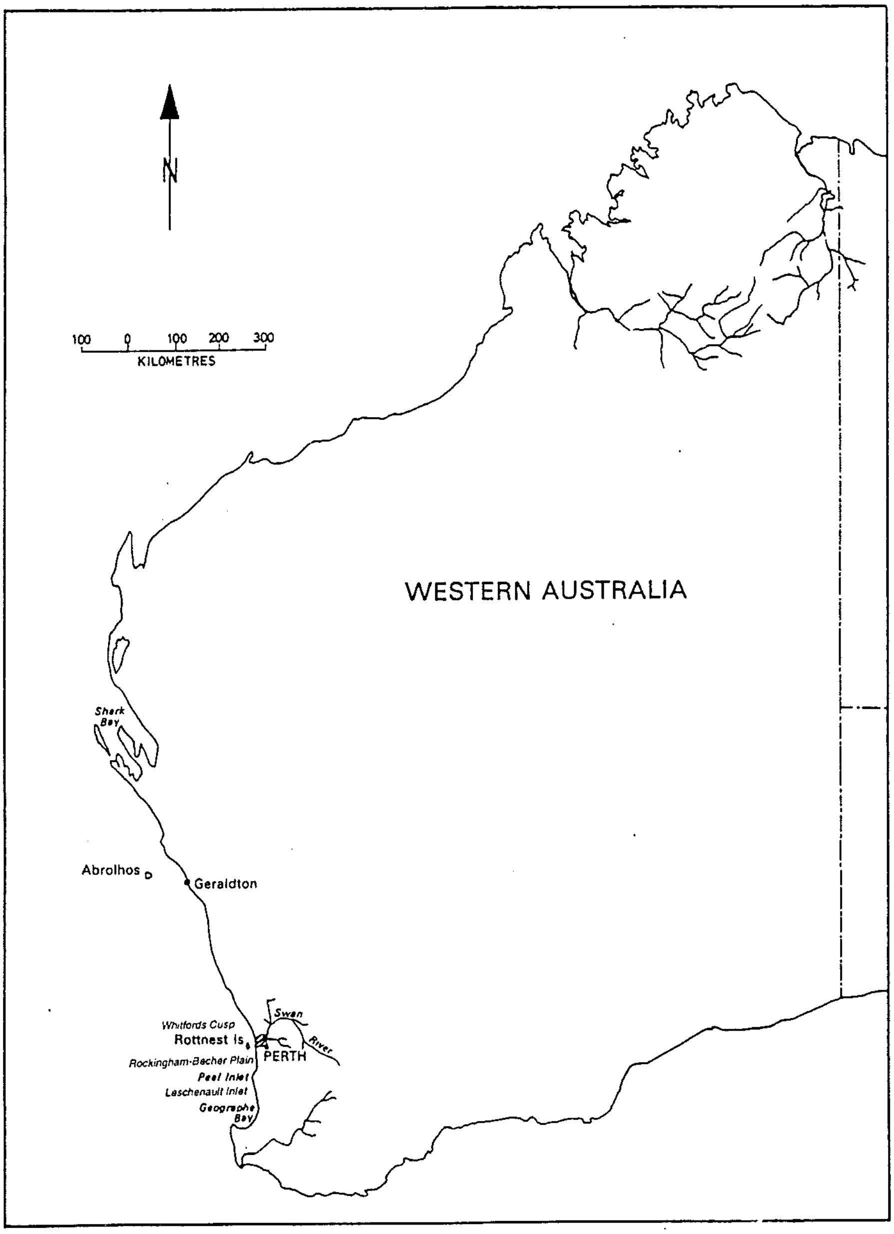


Figure 2: Location map of study sites (Brown, 1983).

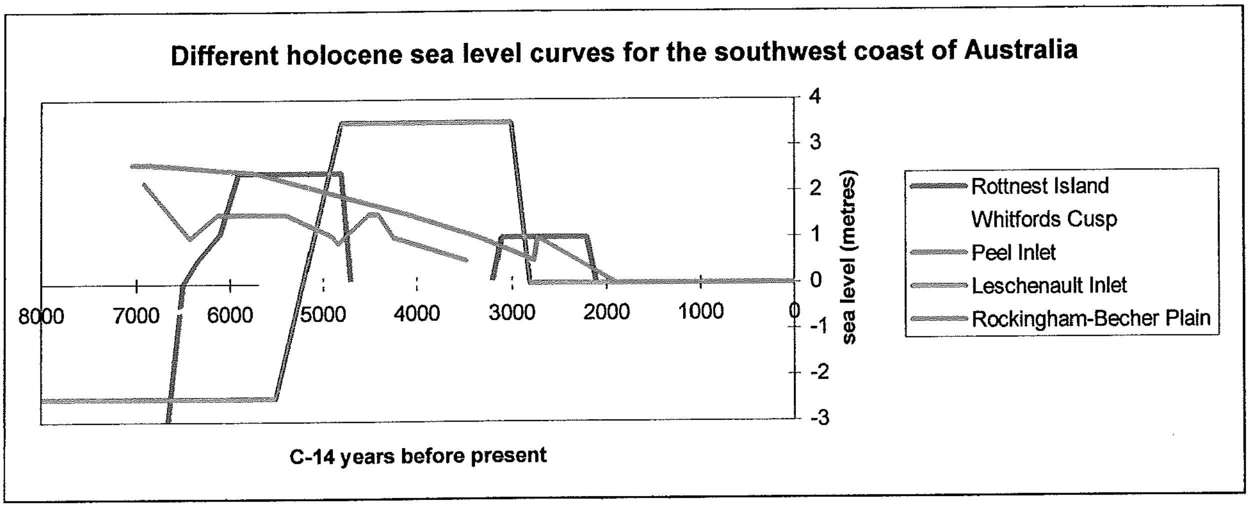


Figure 3: Research in sea level high-stands in southwestern Australia.

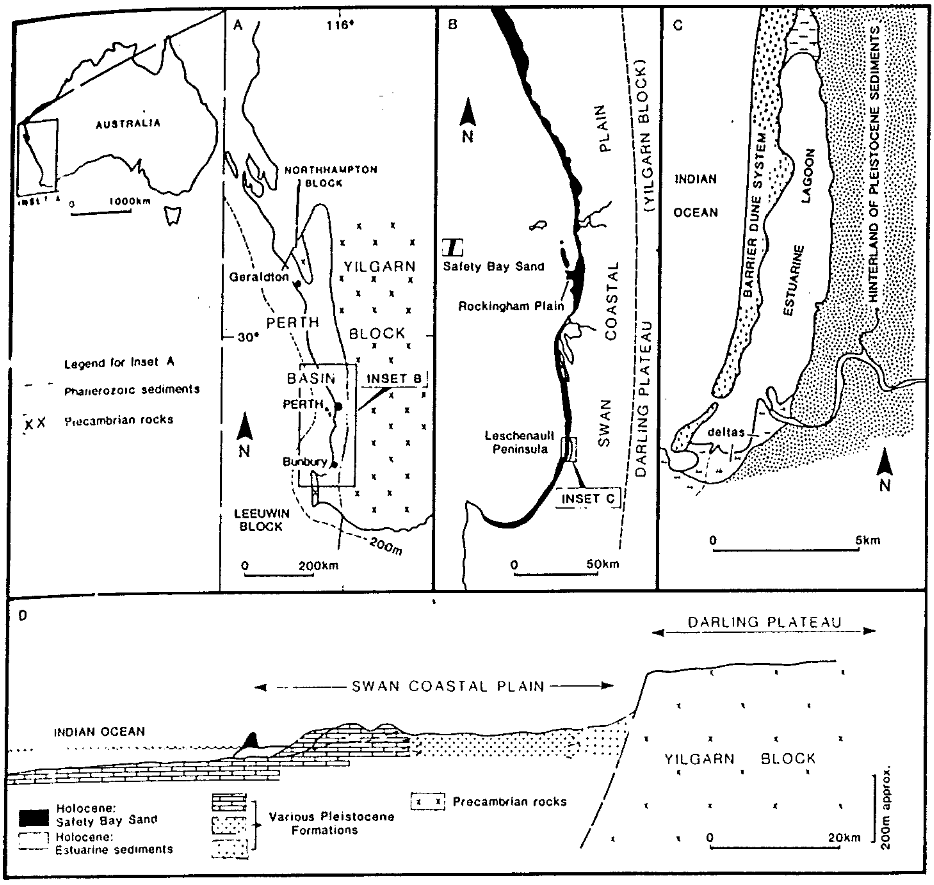


Figure 4: Regional setting of Leschenault Peninsula.

(A) Location of Perth Basin, Western Australia. (B) Distribution of Holocene sands along Swan Coastal Plain. (C) The coastal barrier of Leschenault Peninsula. (D) Schematic diagram showing the regional Quaternary stratigraphic framework at Leschenault Peninsula (Semeniuk, 1985).

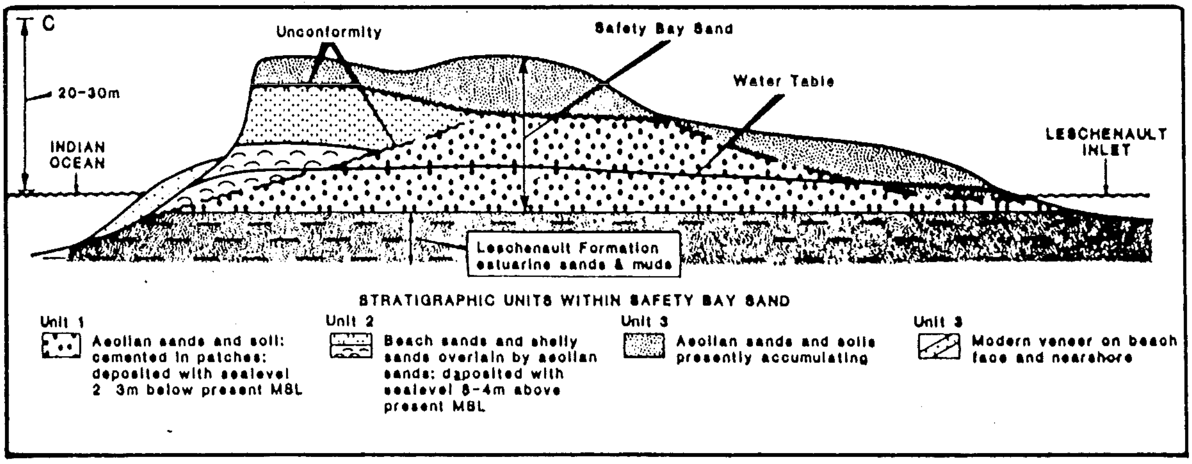


Figure 5: Summary of stratigraphic framework.

Stratigraphic framework of Holocene units, Leschenault Peninsula (Semeniuk, 1985).

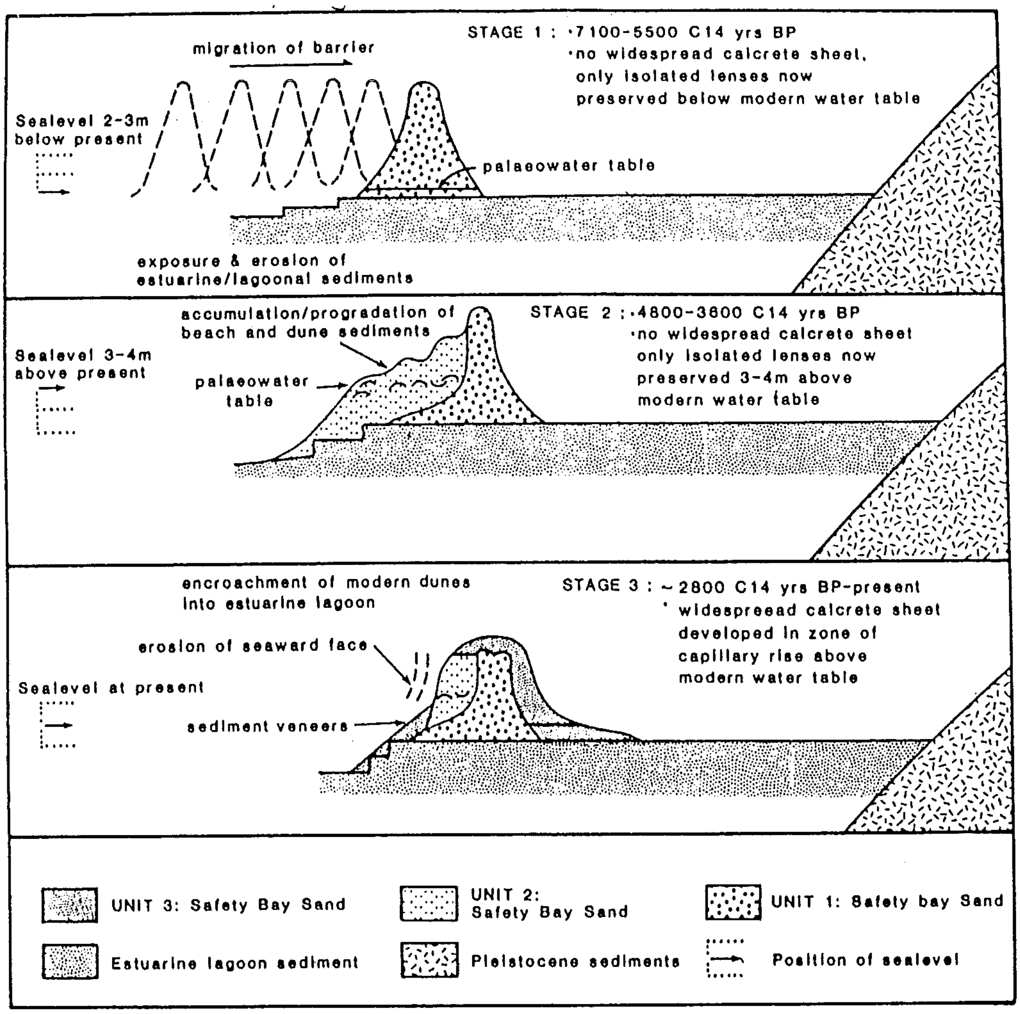
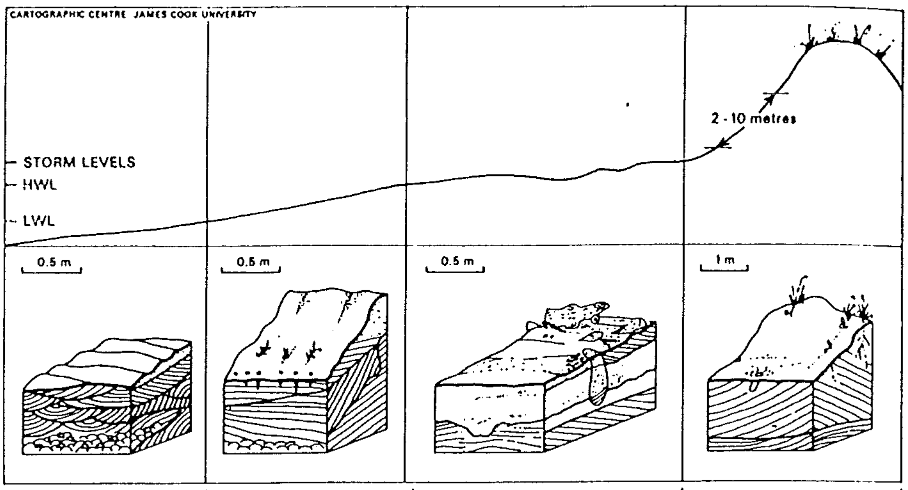


Figure 6: The depositional stages.

Depositional stages in the development of the barrier dune system at Leschenault Peninsula (Semeniuk, 1986).



SHOREFACE	FORESHORE	BACKSHORE	BEACH RIDGE/DUNE
TROUGH - BEDDED SAND / GRAVEL LITHOFACIES	LAMINATED SAND AND LAMINATED / BUBBLE SAND LITHOFACIES	LAMINATED / DISRUPTED SAND LITHOFACIES	AEOLIAN CROSS - STRATIFIED SAND LITHOFACIES
Small-scale trough cross-strata	Inclined wedges of parallel lamination	Horizontal bedding, cross-strata and homogeneous bedding	Large-scale foreset bedding
• Lithoclastic and shelly gravels	• Vertical polychaete tubes near LWL • Ridge-and-runnel, rills on surface • Gravel mounds and layers • Bubble sand, especially in berm and near HWL	• Heavy mineral layers, often on minor disconformities • Storm debris, especially floatable skeletons and wood • *Ocypode* burrows	• Soils and rootlets • *Ocypode* burrows • Corroded skeletal debris

Figure 7: Sedimentary structures across a beach to beach ridge transect.

Sedimentary structures across an idealised, modern beach to beach ridge transect (Semeniuk and Johnson, 1982).

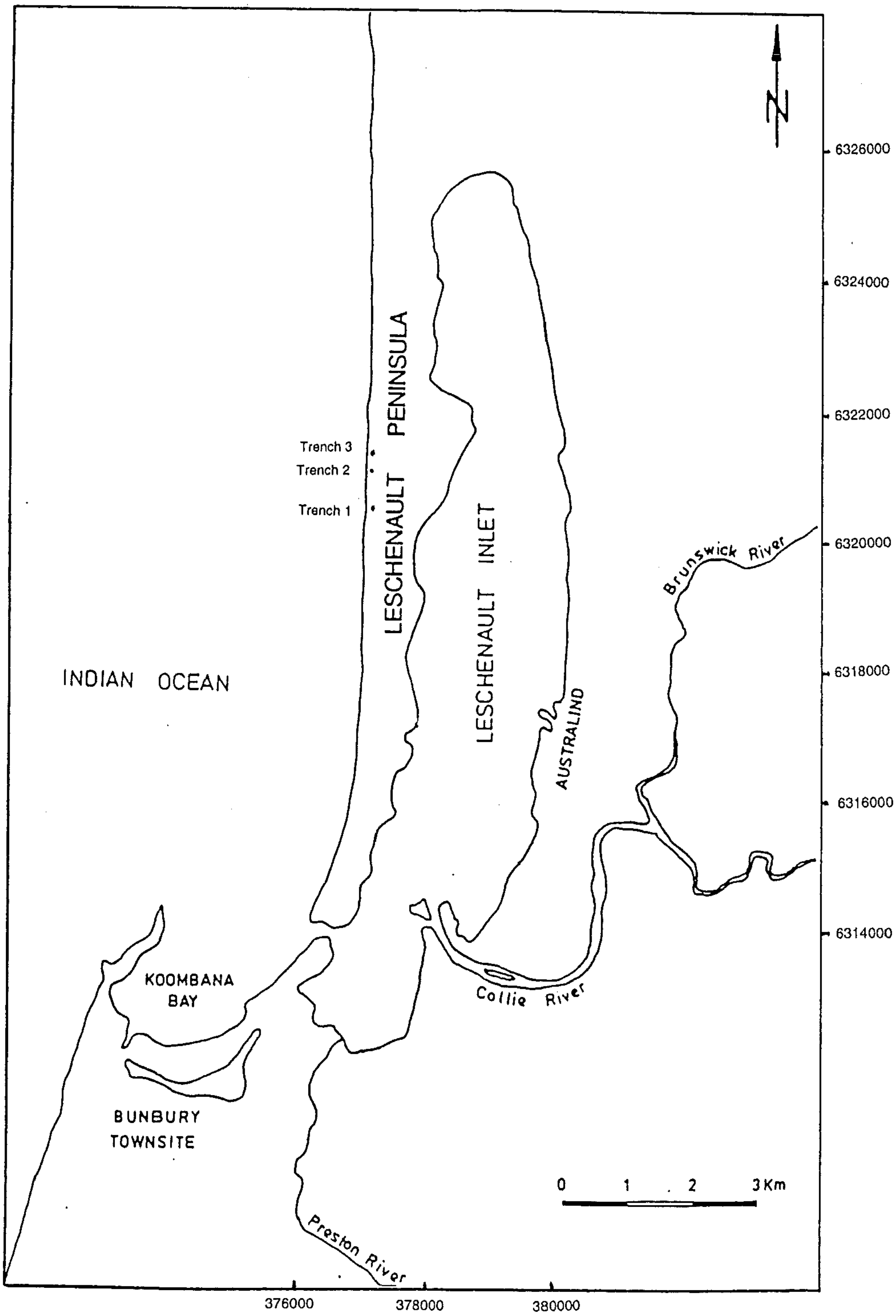


Figure 8: Location of the trench sites.

Figure 9: Photograph of trench site I

This photograph shows six of the seven described steps.
Step A was eroded during a storm

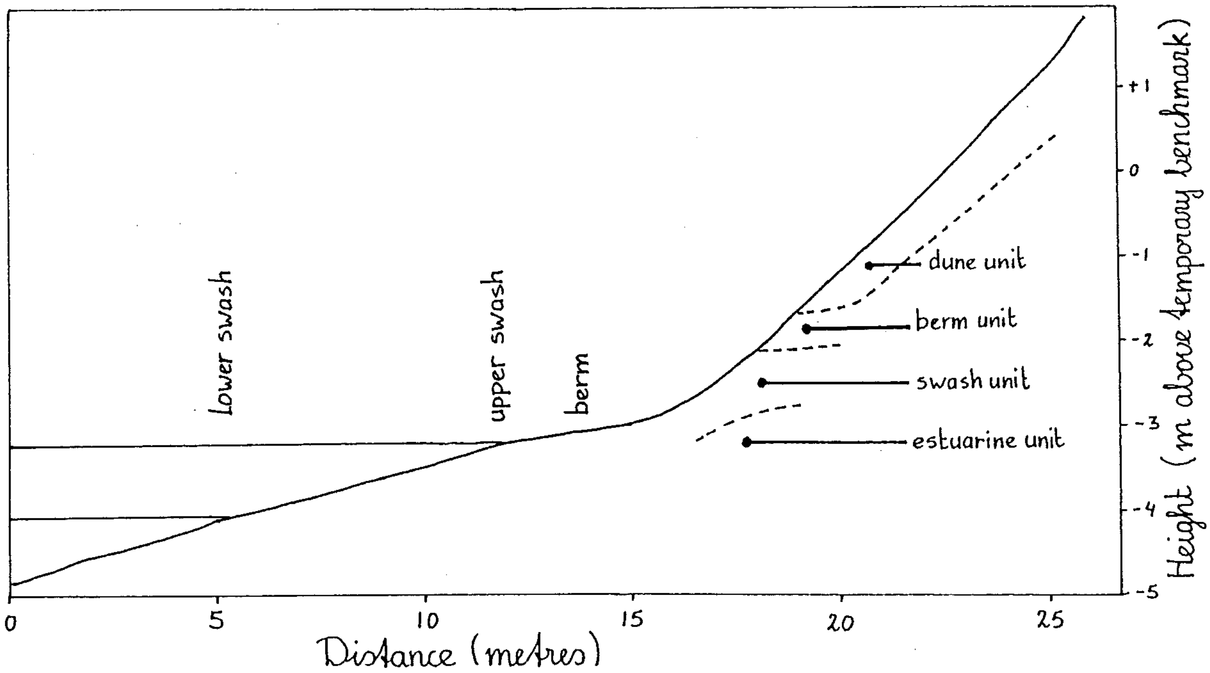
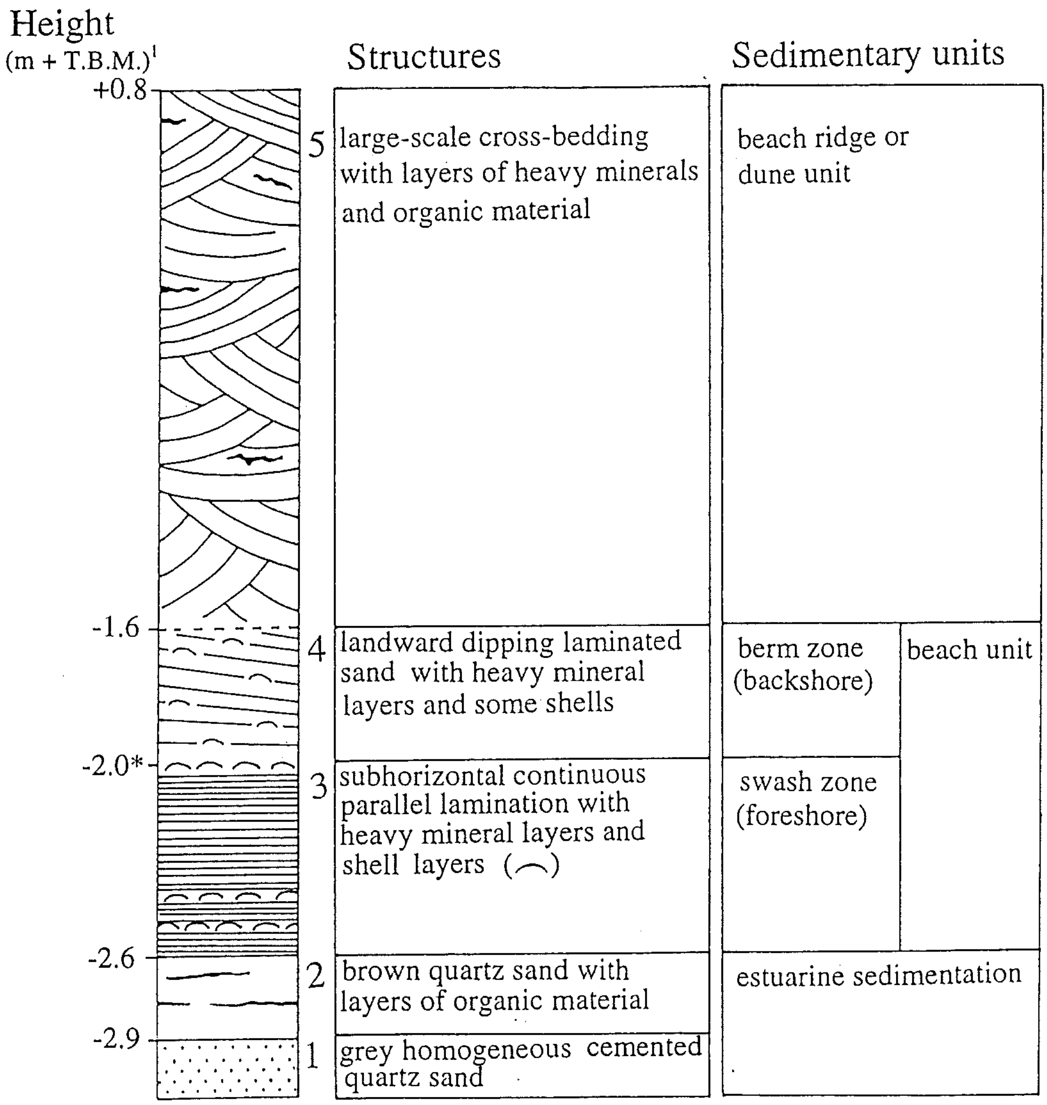


Figure 10: Beach transect at trench site I.

Showing the location of the steps and the basic stratigraphic framework.



[1] T.B.M. = Temporary Benchmark

Figure 11: Stratigraphic profile of trench site I.

Profile illustrating the structures, thickness and sedimentary units of trench site I. The asterisk denotes the location of the sample used for ^{14}C-analyses.

Figure 12: Photograph of trench site II

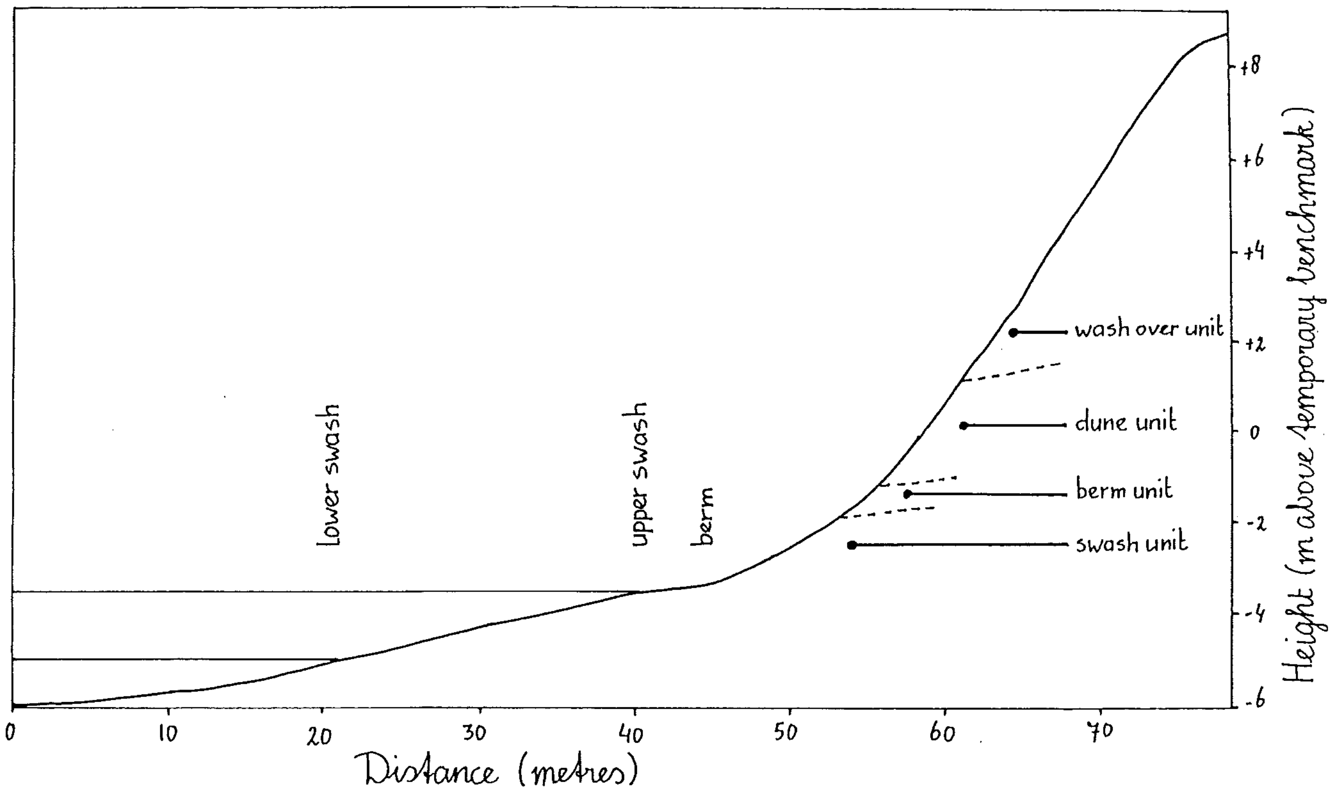
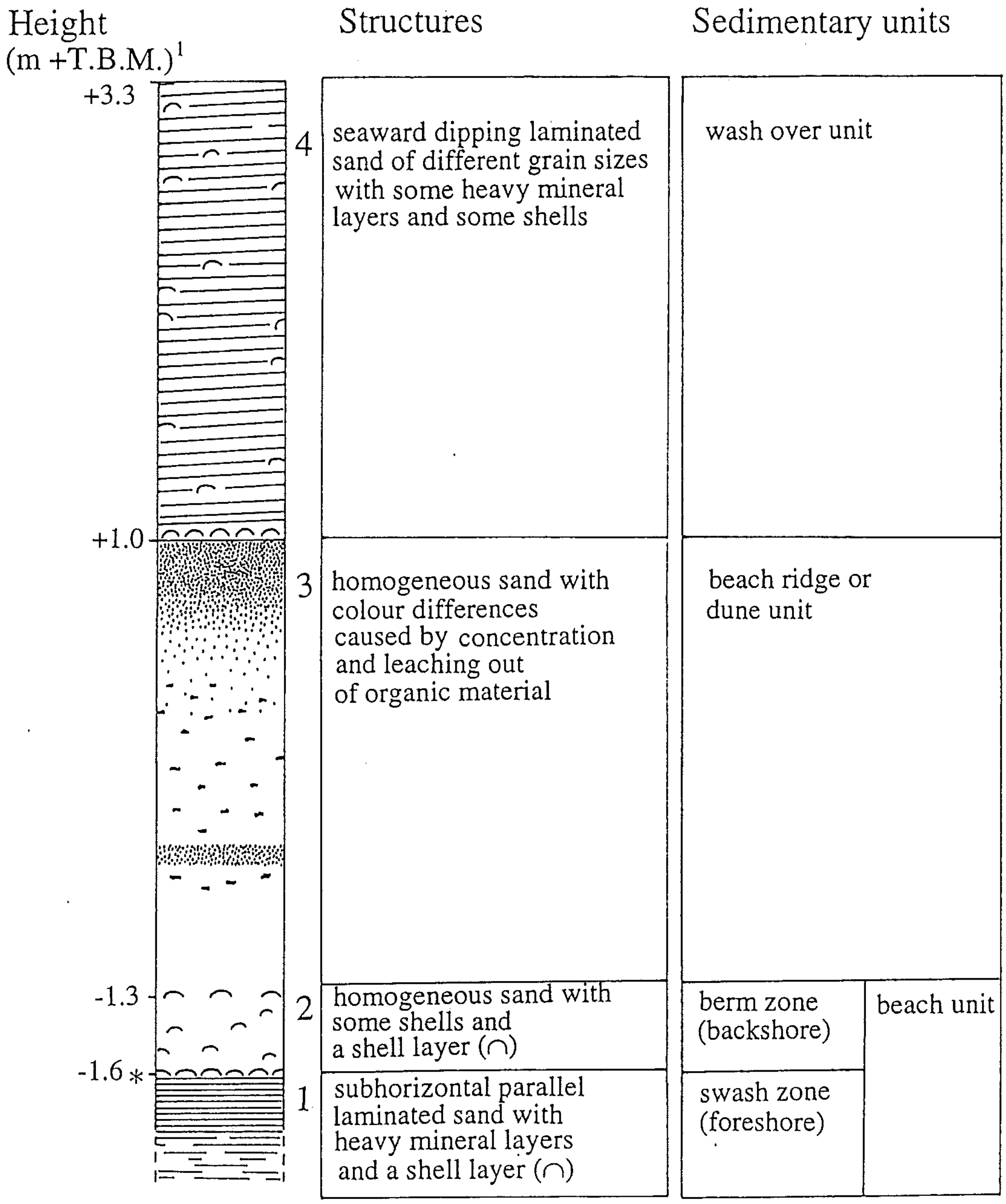


Figure 13: Beach transect at trench site II.

Showing the location of the steps and the basic stratigraphic framework.



[1] T.B.M. = Temporary Benchmark

Figure 14: Stratigraphic profile of trench site II.

Profile illustrating the structures, thickness and sedimentary units of trench site II. The asterisk denotes the location of the sample used for ^{14}C-analyses.

Figure 15: Photograph of trench site III

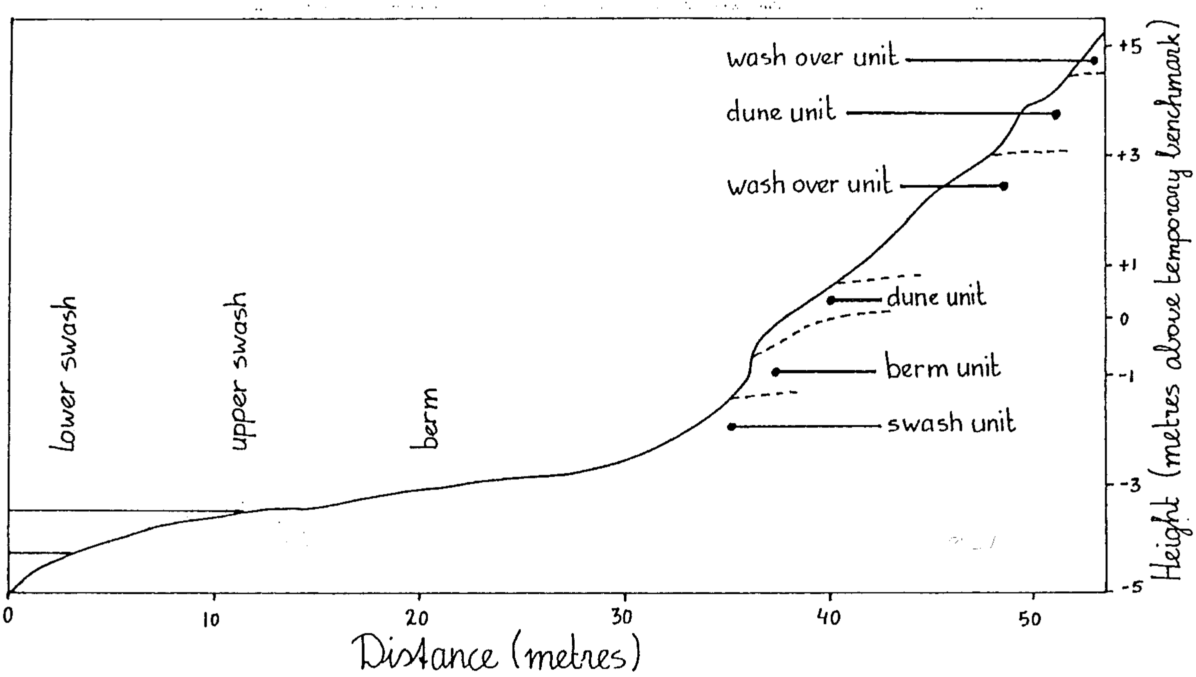
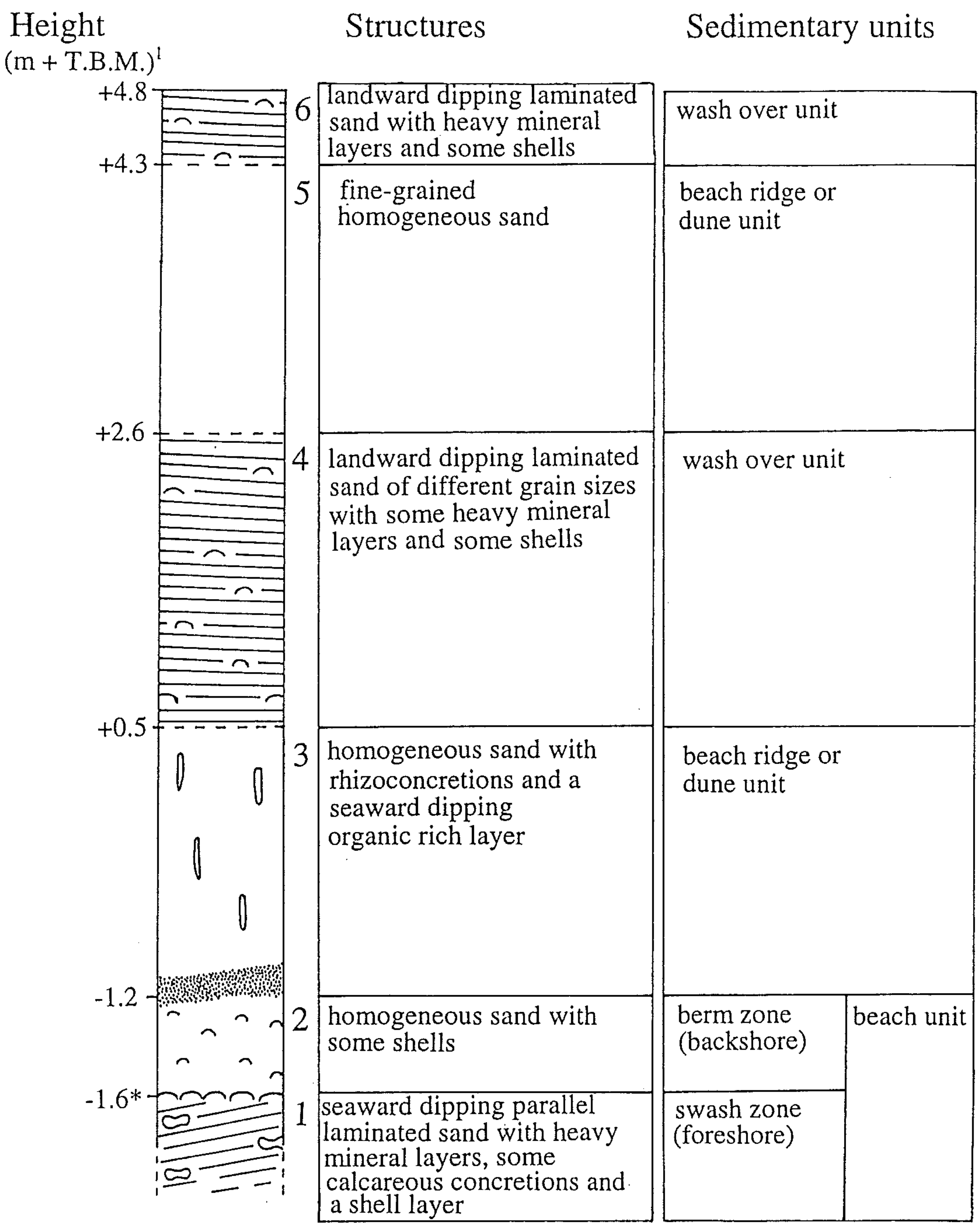


Figure 16: Beach transect at trench site III.

Showing the location of the steps and the basic stratigraphic framework.



[1] T.B.M. = Temporary Benchmark

Figure 17: Stratigraphic profile of trench site III.

Profile illustrating the structures, thickness and sedimentary units of trench site III. The asterisk denotes the location of the sample used for ^{14}C-analyses.

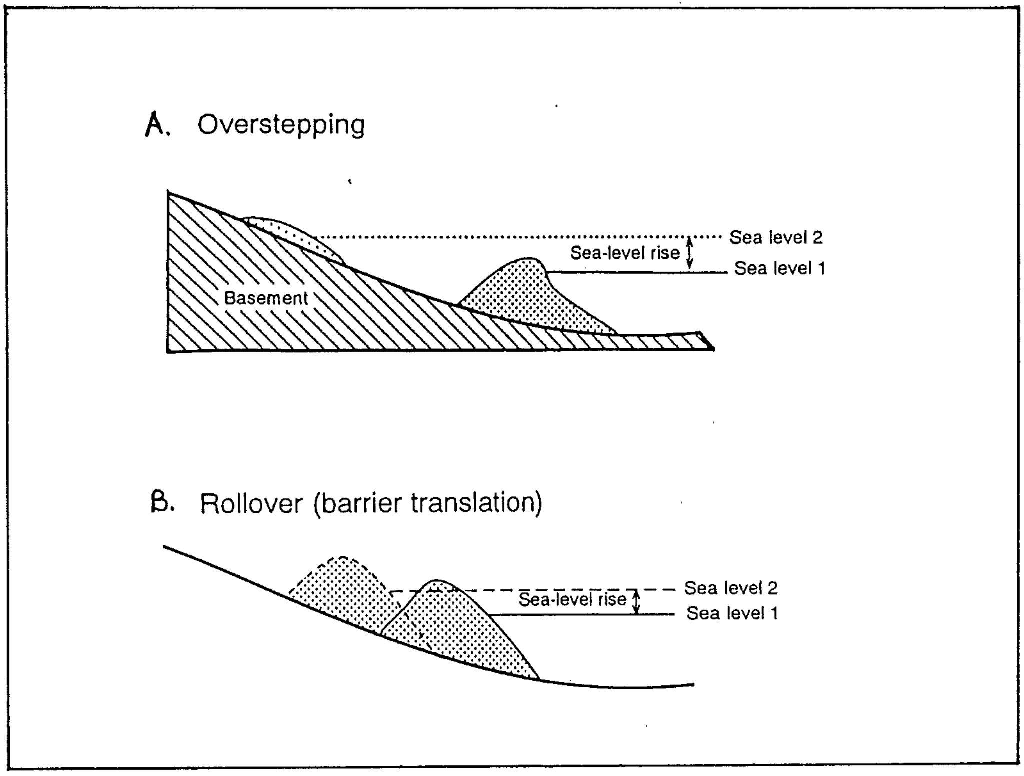


Figure 18: Models of barrier response to rising sea level.

(A) Overstepping (B) Rollover (barrier translation) (after Carter, 1988).

Tables

Table 1: Summary of factors affecting sea level changes.

Global sea level changes	
Volume of ocean basins	tectonics (orogeny, seafloor spreading, plate tectonics, seafloor subsidence)
	marine sedimentation
	isostatic adjustment of seafloor
Mass of the ocean water	glacio-eustasy
	retention of liquid water
	juvenile water
Ocean water density	salinity of the water
	temperature of the water
Geoidal eustasy	gravitational waves
	deformation of the earth-equipotential surface
	changes in the earth's rate of rotation
	tilt of the rotation axis
Local sea level changes	
Local uplift or subsidence of the land	isostatic adjustments
	(thermo-, glacio-, vulcano-, sedimento- and hydro-isostasy)
	tectonic phenomena
	compaction of sediments
	human activities
Dynamic sea level changes	meteorological (atmospheric pressure, winds)
	hydrological (runoff of large rivers)
	oceanographic

Table 2: Summary of former sea level research in southwestern Australia

Area	Maximum sea level (above present level)	Date of maximum sea level	Reference
Shark Bay	1 - 1.5 m	4,000-5,000 ^{14}C yr B.P.	Logan et al., 1974
Geraldton	3 m	6,025±170 yrs B.P.	Brown, 1983
Abrolhos Platforms	1 m	4,000-5,000 ^{14}C yr B.P.	Collins et al., 1993
Whitfords Cusp	as present	present	Semeniuk & Searle (1986)
Rottnest Island	2.4 m	5,900-4,800 ^{14}C yr B.P.	Playford (1988)
Swan River Estuary	0.5 m	5,000 yr B.P.	Kendrick (1977)
Rockingham-Becher Plain	2.5 m	6,645 ^{14}C yr B.P.	Searle, Semeniuk & Woods (1988)
Peel Inlet	2 m	6,910±235 ^{14}C yr B.P.	Semeniuk & Semeniuk (1991)
Leschenault Inlet	3 - 4 m	4,800-3,000 yr B.P.	Semeniuk (1985)
Geographe Bay	1.3 m	4,600±120 yr B.P.	Searle & Logan (1978)

Table 3: Location of the trench sites

Trench	Co-ordinates (AGD)		Distance (m)
I	377149 E	6320514 N	
			562
II	377142 E	6321076 N	
			310
III	377164 E	6321385 N	

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Appendices

Appendix I

Sample 3, taken at Trench site I, step B on June 11 1999

Mollusc identification by G.W. Kendrick on june 25 1999

Situated -2.5 m below T.B.M.

<u>Bivalves</u>

Barbatia pistachia (Lamarck)

Glycymeris striatularis (Lamarck)

Mimachlamys sp. --- calcite shell

Wallucina assimilis (Anges)

Wallucina sp.

Fulvia tenuicostata (Lamarck)

Hemidonax chapmani (Gatliff and Gabriel)

Mactra australis (Deshayes) --- very common

Paphies (Amesodesma) elongata (Reeve)

Tellina (Senelangulus) tenuilirata (Sowerby)

Donax (Deltachion) electilis (Iredale) --- very common

Donax (Tentidonax) sp.

Sunetta excavata (Hanley)

Gomphina undulosa (Lamarck)

Tawera lagopus (Lamarck)

Tawere coelata (Menke)

<u>Gastropods</u>

Amblychilepas sp.

Scutus antipodes (Montfort)

Phasianella sp. (spercula)

Mitrella sp.

<u>Cephalopods</u>

Sepiidae, genus and species undetermined

Remarks

The sample also contains material which I consider to have probably or very possibly been reworked from a lagoonal deposit older than the present beach-front bed. This, which has been separated from the other material should not be combined with any other shells for ^{14}C-analysis. It includes a specimen of *Katelysia rhytiphora* (Lamy) which is likely to be of Middle Holocene age and is certainly reworked.

Appendix II

Sample 4, taken at Trench site 1, step B, on June 11 1999.

Mollusc identification by G.W. Kendrick on june 24 1999.

Situated -2.4 m below T.B.M.

<u>Bivalves</u>

Barbatia pistachia (Lamarck)

Limopsis sp.

Glycymeris striatularis (Lamarck)

Mimachlamys sp. --- a calcitic species

Eucrassatella sp.

Hemidonax chapmani (Gatliff and Gabriel)

Mactra australis (Lamarck)

Paphies (Amesodesma) elongata (Reeve)

Donax (Latona) columbella (Lamarck)

Donax (Deltachion) electilis (Iredale)

Gomphina undulosa (Lamarck)

Sunetta excavata (Hanley)

Tawere coelata (Menke)

Corbula sp.

<u>Gastropods</u>

Amblychilepas sp.

Phasianella sp. (sperula)

<u>Cephalopods</u>

Sepiidae, genus and species undetermined (fragments)

<u>Remarks</u>

The above material is representative of inshore and intertidal zones of a sandy open coast with medium to high energy levels. All of the above except *Mimachlamys sp.* have wholly aragonitic shells. I have separated off part of the sample which in my view is reworked from another, older lagoonal deposit. Advise you to excluded this and all such material from any ^{14}C-analysis of the open coast site.

Appendix III

Sample 1, taken at Trench site I, step B on June 10 1999

Mollusc identification by G.W. Kendrick at june 24 1999

situated -2.5 to -2.4 m below T.B.M.

This was a bulk sample of samples 3 (Appendix I) and 4 (Appendix II).

Bivalves

Barbatia pistachia (Lamarck)

Glycymeris striatularis (Lamarck)

Mactra australis (Lamarck)

Paphies (Amesodesma) elongata (Reeve)

Donax (Deltachion) electilis (Iredale)

Donax (Latona) columbella (Lamarck)

Sunetta excavata (Hanley)

Gomphina undulosa (Lamarck)

Tawere coelata (Menke)

Gastropod

Phasianella sp. (spercula)

Remarks

Same as for Sample 4, taken at Trench site I, step B on june 11 1999. Part of this sample is in my opinion reworked from a pre-existing lagoonal deposit and such material should be excluded from ^{14}C-analysis of shells from open coast facies. I have separated most of the reworked material. it includes *Katelysia scalarina* (Lamarck) and *K. rhytiphora* (Lamy) and is probably of Middle Holocene age (4000-6000 yr. B.P.).

Appendix IV

Sample 2, taken at Trench site 1, step C on June 11 1999

Mollusc identification by G.W. Kendrick

Situated -2 m below T.B.M.

This sample was used for ^{14}C-analysis

Bivalves

Modiolus ? sp.

Glycymeris striatularis (Lamarck) --- common

Lima gemina (Iredale) --- calcitic shells

Wallucina sp.

Vasticardium cygnorum (Deshayes)

Fulvia tenuicostata (Lamarck)

Mactra australis (Lamarck) --- abundant

Paphies (Amesodesma) elongata (Reeve)

Donax (Latona) columbella (Lamarck)

Donax (Deltachion) electilis (Iredale) --- abundant

Sunetta excavata (Hanley)

Gomphina undulosa (Lamarck)

Venerupis anomala (Lamarck)

Chioneryx cardioides (Lamarck)

Tawera coelata (Menke)

Chraciopsis subrecta (Cotton and Godfrey)

Gastropods

Amblychilepas sp.

Phasianella sp. (sperula)

Cephalopods

Sepiidae, genus and species undetermined

Spirula spirula (Linnaeus)

Remarks

Though containing a wider range of species, this material is essentially like that of sample 4 (taken at Trench site I on june 11 1999) i.e. open sandy coast shallow sublittoral to beach derived shells, moderate to high energy. All are aragonitic except *Lima gemina*, which has a calcitic shell. Like other gross samples, this contains material believed to be or suspected to be reworked from a pre-existing lagoonal deposit. This I have separated off from the remainder of the sample and it should not be utilised for ^{14}C-analysis in conjunction with the open coast specimens. There are fragments attributable to a species of *Katelysia* in the excluded material, which are probable of Middle Holocene age (4000-6000 yr. B.P.).

Appendix V

Sample 7, taken at trench site 2, step A

Mollusc identification by G.W. Kendrick, on June 28 1999

Situated -1.6 m below T.B.M.

This sample was used for ^{14}C-analysis

<u>Bivalves</u>

Barbatia (Barbatia) pistachia (Lamarck)

Barbatia (Acan) plicata (Dillwyn)

Glycymeris striatularis (Lamarck)

Lima gemina (Iredale) --- calcite

Mimachlamys asperrima (Lamarck) --- calcite

Mesopeplum anguineus (Finlay) --- calcite

Fulvia Tenuicostata (Lamarck)

Mactra (Mactra) australis (Deshayes) --- abundant

Mactra (Mactrotoma) ovalina (Lamarck)

Paphies (Amesodesma) elongata (Reeve)

Donax (Deltachion) electilis (Iredale) --- abundant

Donax (Latona) columbella (Lamarck)

Sunetta excavata (Hanley)

Gomphina undulora (Lamarck)

Irus distans (Lamarck)

Tawera coelata (Menke)

Tawera lagopus (Lamarck)

Corbula sp.

<u>Gastropods</u>

Amblychilepas sp.

Antisabia foliacea (Quoy and Gaimard)

Conus sp.

<u>Cephalopods</u>

Sepiidae, genus and species indetermined

<u>Remarks</u>

Also present is a small quantity of fragmentary shell probably or possible reworked from a pre-existing deposit. Advise that you do not include this with other material in any ^{14}C-analysis. Calcite shells indicated.

Appendix VI

Sample 6, taken at Trench site 2, step F, on June 13 1999.

Mollusc identification done by G.W. Kendrick on june 29 1999.

Situated +1 m above T.B.M.

<u>Bivalves</u>

Barbatia (Barbatia) pistachia (Lamarck)

Glycymeris striatularis (Lamarck)

Lima gemina (Iredale) --- calcite

Mimachlamys asperrima (Lamarck) --- calcite

Hemidonax chapmani (Gatliff and Gabriel)

Mactra (Mactra) australis (Deshayes) --- abundant

Paphies (Amesodesma) elongata (Reeve)

Tellina (Semelangulus) tenuilirata (Sowerby)

Tellina (Semelangulus) subdiluta (Tate)

Donax (Deltachion) electilis (Iredale) --- abundant

Sunetta excavata (Hanley)

Gomphina undulosa (Lamarck)

Tawera coelata (Menke)

Tawera lagopus (Lamarck)

<u>Gastropods</u>

Amblychilepas sp.

<u>Cephalopods</u>

Spirula spirula (Linnaeus)

<u>Remarks</u>

Some possible reworked shelly fragments have been separated from the rest of the sample and I suggest these not be included with others in any ^{14}C-analysis. The sample also includes a piece of pumice.

Appendix VII

Sample 8, taken at trench site 3, step B.

Mollusc indentification by G.W. Kendrick on June 28 1999.

Situated -1.6 m below T.B.M.

This sample was used for ^{14}C-analysis

<u>Bivalves</u>

Lima gemina (Iredale) --- calcite shells

Glycymeris striatularis (Lamarck)

Mimachlamys asperrima (Lamarck) --- calcite shells

Mactra australis (Deshayes)

Paphies (Amesodesma) elongata (Reeve)

Donax (Deltachion) electilis (Iredale)

Donax (Latona) columbella (Lamarck)

Sunetta excavata (Hanley)

Gomphina undulosa (Lamarck)

Tawera coelata (Menke)

Chioneryx cardioides (Lamarck)

Corbula sp.

<u>Gastropods</u>

Amblychilepas sp.

Bulla sp.

<u>Cephalopods</u>

Spirula spirula (Linnaeus)

Sepiid, genus and species indetermined

<u>Brachiopoda</u>

Magellania ? sp. --- calcite shell and non Mollusc

Remarks

Also present in sample is material probably or possibly reworked from an older pre-existing deposit. This I have separated from rest of sample and advise that it be excluded from ^{14}C-analysis seeking to establish age of the present open coast deposit.