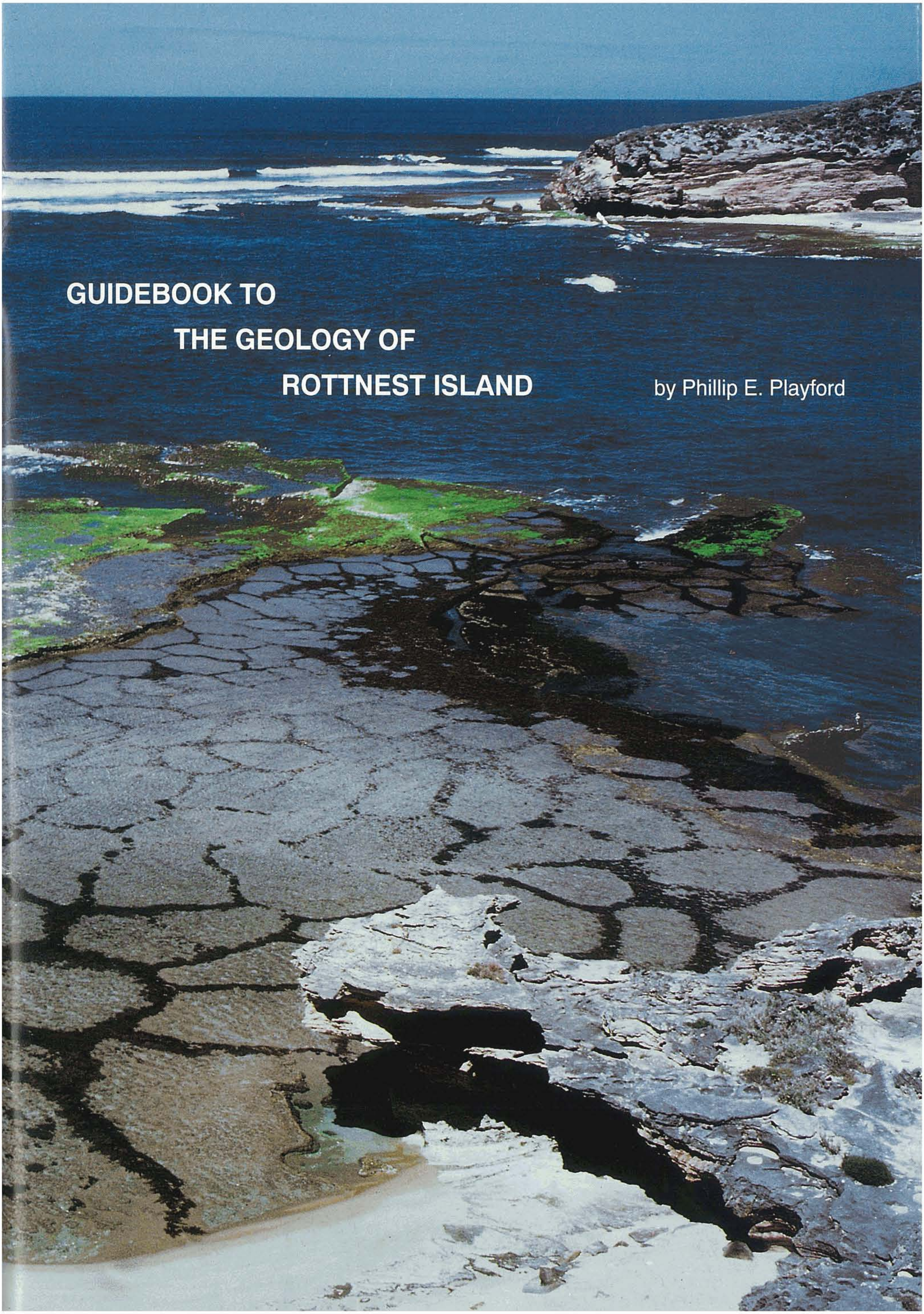
GUIDEBOOK TO THE GEOLOGY OF ROTTNEST ISLAND

by Phillip E. Playford



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Phillip E. Playford

Geological Survey of Western Australia

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Cover photo: View of Wilson Bay, Rottnest Island, taken in October 1985, showing a wide shoreline platform cut in eolianite of the Tamala Limestone. Conspicuous algal polygons occur over much of the platform, and paddy-field terraces are developed along the platform margin. Tamala Limestone also outcrops in the foreground and on the headland in the right background.

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PLATE 1: Geological map of Rottnest Island (in pocket)

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INTRODUCTION

The purpose of this guidebook is to provide an up-to-date account of the geology of Rottnest Island, with a field guide to key geological localities. It is hoped that this will be of interest not only to professional geologists, but also to teachers, students, and members of the general public who wish to learn something about the geology while holidaying on the island.

Brief early references to the geology of Rottnest were made by Somerville (1921), Aurousseau and Budge (1921), and Clarke (1926), but the first detailed account was by Teichert (1950). This dealt mainly with the eastern part of the island, concentrating especially on the evidence there for Quaternary changes in sea-level. Hassell and Kneebone (1960) studied the island as an honours-thesis project, and their preliminary work was summarized by Glenister, Hassell, and Kneebone (1959).

Research on Rottnest by the Geological Survey began in 1976, initially as part of an investigation into the groundwater potential (Playford, 1976). My observations on the geology, which formed the basis of the Geological Survey studies (Playford and Leech, 1977; Playford, 1983), had largely been made during earlier holiday visits. Since the 1983 paper was published I have undertaken further field studies, and arranged for additional radiocarbon datings to be made. The results of this recent work have served to clarify some important aspects of the Holocene geological history, which are outlined here for the first time.

I would like to acknowledge the valuable assistance of the following persons in carrying out this project: R Black for discussing the fauna of the shoreline platforms and notches; A E Cockbain for discussing the geology and helping to edit the manuscript; G A Dixon, G Geste, J Klinge, and T A Maloney for surveying the modern and elevated shoreline platforms; W B Hill and R M Hocking for assisting with the editing; E P Hodgkin for discussing his work on modern shoreline features; G W Kendrick for identifying fossils and modern marine faunas, and for discussing the significance of Quaternary faunal changes; L M Marsh for identifying fossil corals and providing information on the modern coral faunas; A Pearce for discussing the Leeuwin Current; T Perrigo for facilitating field visits ; R A Smith and J S Moncrieff for providing information on groundwater management; P M Thorpe for his radiocarbon determinations, and D Wallace for advising on tides. I also wish to thank the Surveys and Mapping Division of the Mines Department for drafting the figures, and the Fisheries Department for making a vehicle available on several occasions.

HISTORICAL REVIEW

Aborigines have lived in the southwest of Australia for some 40 000 years, and must have occupied the area of the present island while it was connected to the mainland during the late Pleistocene and early Holocene, when sea-level was much lower than it is today. They ceased visiting the island, known to the Nyungah Aborigines as *Wadjemup*, after it separated from the mainland about 6 500 years ago.

Rottnest Island was first sighted by Europeans in the 17th century, when ships of the Dutch East India Company visited and charted the southwestern coast of Australia during their trading voyages to the Indies (Heeres, 1899). The first recorded landing on the island was in 1658 by crew members of the vessel *Waeckende Boeij*, skippered by Samuel Volckersen, while looking for survivors of the wrecked ship *Vergulden Draak* ("Gilt Dragon"). The island was named *Rottenest* by Willem de Vlamingh, who visited there in December 1696 as the commander of an expedition of three ships, the *Geelvink*, *Nijptang*, and *Wezeltje*, that had been despatched to search for the lost ship *Ridderschap van Holland.* Vlamingh's chart, the first detailed map of the South Land (*Zuÿdlandt*) showed Rottnest (*Eÿlandt Rottenest*) and the Swan River (*Swane*

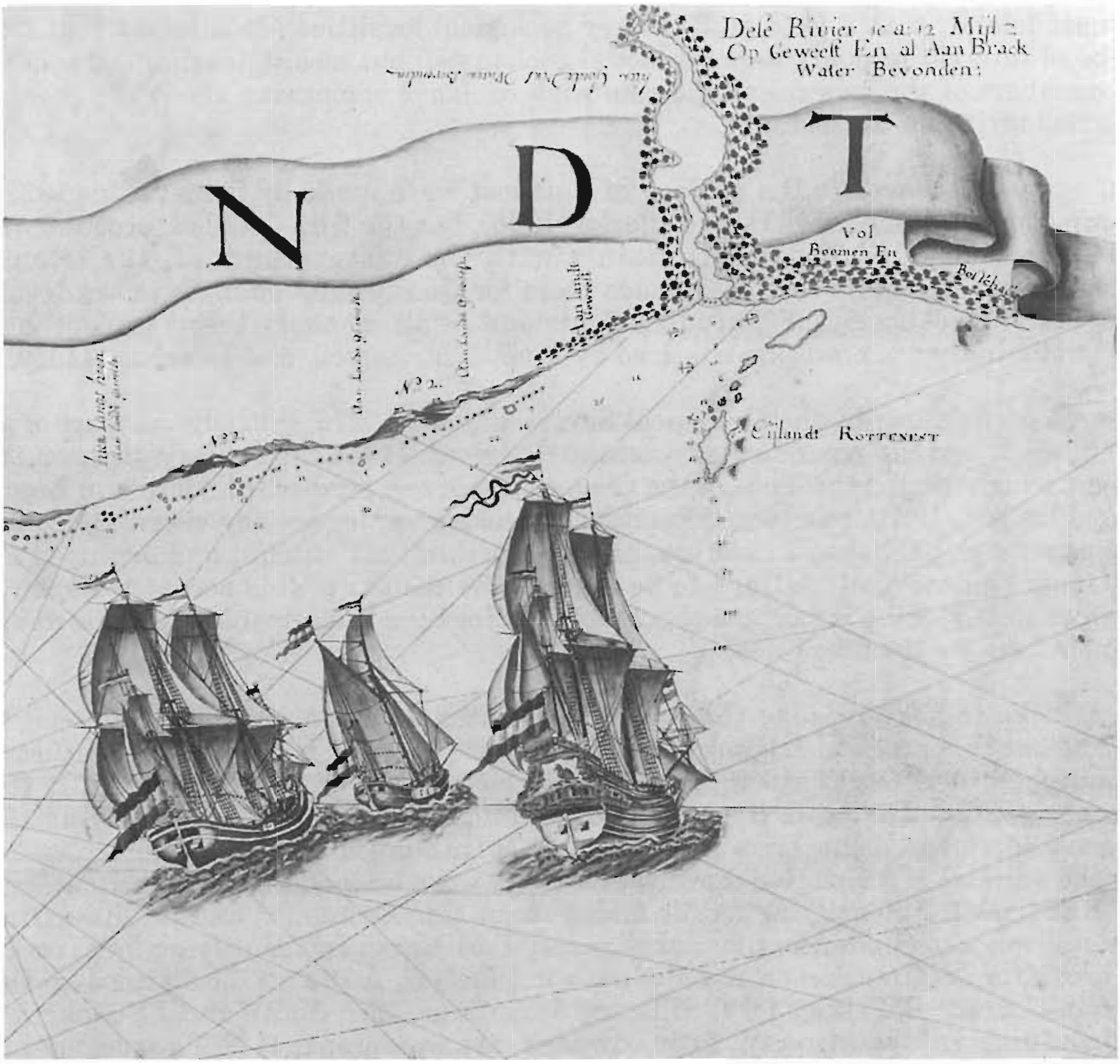

Figure 1: Part of a chart of the South Land (*Zuÿdtlandt*), mapped bÿ Willem de Vlamingh in 1696-97, showing *Eÿlandt Rottenest* (Rottnest), *Swane Rivier* (Swan River), and his ships, the *Geelvink*, *Wezeltje*, and *Nijptang* (right to left). Negative by courtesy of the Algemeen Rijksarchief, The Hague.

Rivier) (Fig. 1). Vlamingh mistook the abundant quokkas (small marsupials) found on the island for large rats - hence the name *Rottenest,* meaning "Rats' nest".

Rottnest was first settled for agriculture in 1831, two years after the founding of the Swan River colony, but all private landholdings were resumed in 1839, following the establishment of a prison for Aborigines on the island in the previous year. Rottnest continued to be used as an Aboriginal prison for some 70 years, and many of the buildings of this period remain today.

It was decided in 1903 to close the prison and develop the island as a holiday resort, although some prisoners remained there until 1931 (Somerville, 1949). The growth of holiday facilities at the Thomson Bay Settlement proceeded slowly until soon after World War II. Since then there has been major expansion in the available accomodation, especially through the establishment in 1976 of a second settlement at Geordie and Longreach Bays.

The Australian Army built the Kingstown Barracks on Rottnest in 1936-37, together with several gun emplacements designed to protect the approaches to Fremantle harbour. During World War II up to 2 500 service men and women were stationed on the island. In 1984 the Army agreed to withdraw from the island, and the facilities at Kingstown Barracks were transferred to the control of the Rottnest Island Board. They have been used since then as an environmental education facility. The two largest guns, at Oliver Hill, have recently been restored, and remnants remain of the railway that ran from these guns to Kingstown Barracks and the army jetty (Plate 1).

There are currently about 220 permanent residents on the island, and nearly 292 000 visitors went there in 1986/87.

GEOGRAPHY AND PHYSIOGRAPHY

MORPHOLOGY

Rottnest Island forms part of a chain of limestone islands and reefs, including Garden, Carnac, and Penguin Islands and Five Fathom Bank, on the continental shelf opposite Perth (Fig. 2). Rottnest, the largest of the islands, is about 10.5 km long (east-west), up to 4.5 km wide, and covers an area of about 1 900 ha. The highest point, Wadjemup Hill, is 45 m above sea level.

The coastline of the island is characterized by alternating bays and rocky headlands, the bays generally having wide, sandy beaches backed by sand dunes (Figs 3, 4). Much of the coast is fringed by shallow shoreline platforms cut in the Pleistocene to early Holocene Tamala Limestone (Fig. 4). This formation, which forms most of Rottnest, is prominently exposed on the headlands, but is largely obscured in the interior by a veneer of residual or wind-blown sand.

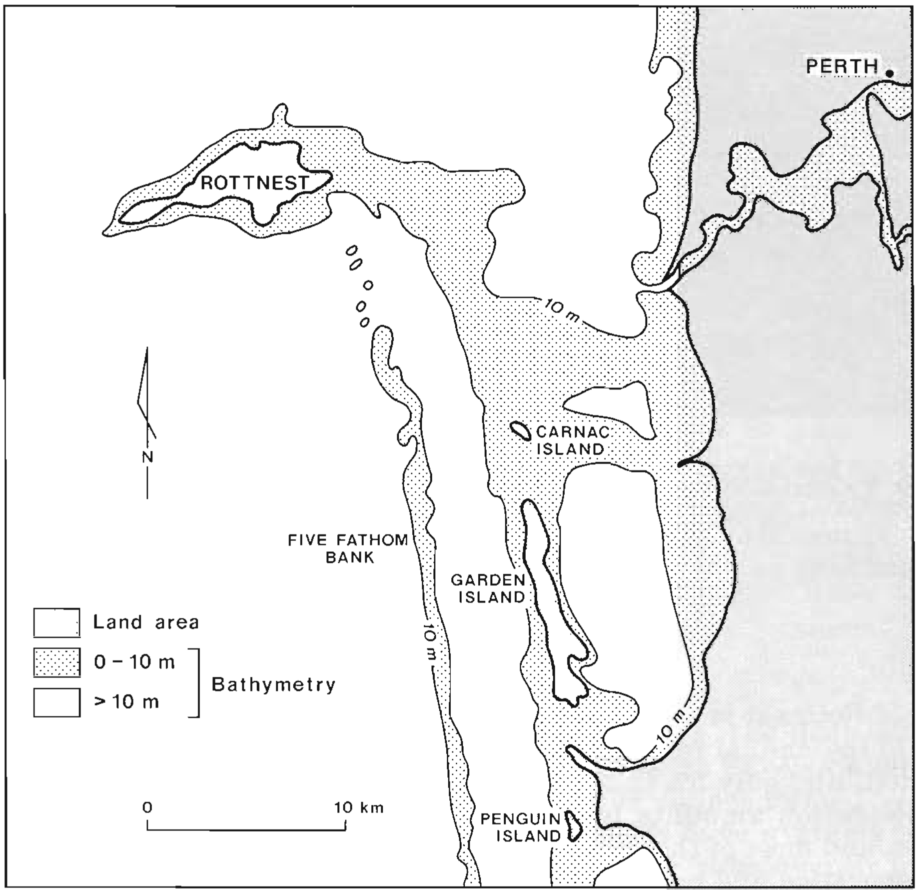

Figure 2: Locality map showing the offshore bathymetry and relationship of Rottnest to the chain of islands and reefs opposite Perth.

Figure 3: Aerial view looking west over Rottnest Island from Philip Point, 1976. Photo by courtesy of the Department of Land Administration, Perth.

CLIMATE

The climate of Rottnest is characterized by wet winters and extremely dry summers. Nearly 75% of the annual rainfall (average 719 mm) falls in the winter months, from May to August, and only 5% in the summer months, from November to February. Annual evaporation amounts to about 1 500 mm. The island has no significant watercourses, and most of the rainfall is absorbed into the surface sand. Part of this is lost by evaporation and part by plant transpiration; the rest moves laterally below the water table to the ocean and salt lakes. Small fresh-water seepages occur around some of the lake margins.

Figure 4: View looking east over The Basin, during a very low tide, showing well-developed shoreline platforms, rocky headlands, beaches, and sand dunes.

VEGETATION

Early descriptions of Rottnest Island indicate that prior to European settlement it was extensively wooded with low forests of Rottnest Island pine (*Callitris preissii*), tea tree (*Melaleuca lanceolata*), and wattle (*Acacia rostellifera*) (Pen and Green, 1983). N G Marchant (quoted in Playford and Leech, 1977) estimated that forest once covered about 65% of the island. Air photos show that by 1941 this had been reduced to 23%, while today native forest covers only about 5%, with an additional 6% occupied by reforested areas (indigenous and exotic species).

The rest of the island is now covered by a low heath, characterized by the prickly scrub *Acanthocarpus preissii* and the native grass *Stipa variabilis*. These vegetation changes can be attributed to human activities, primarily a combination of repeated bush fires and widespread wood cutting. Intensive grazing by quokkas prevented regeneration of the deforested areas (Storr, 1963).

SALT LAKES

About 10% of Rottnest Island is occupied by salt lakes, the deepest of which, Government House Lake, is up to 8.5 m deep. The lakes have elongate-ovoid to sub-circular shapes (Fig. 5), and are believed to overlie dolines formed by rainwater solution of the limestone and subsequent collapse of cave systems during the Pleistocene periods of lowered sea-level. The dolines were subsequently largely filled by Holocene sediments, as sand dunes accumulated over the old karst surface. The "blue holes" of the Houtman Abrolhos (Fig. 6), and comparable features known elsewhere in the world (Purdy, 1974), are believed to have formed in a similar way.

Figure 5: Aerial view looking south over the salt lakes, with Point Clune in the foreground. Note the characteristic ovoid to sub-circular shapes of the salt lakes. Photo by courtesy of the Department of Land Administration, Perth.

Water levels in the lakes rise to about mean sea-level in winter and fall more than a metre in summer as a result of evaporation. The larger lakes commonly have late-summer salinities exceeding 150 000 mg/L (see analyses quoted in Playford and Leech, 1977). Lake Timperley has the lowest summer salinity (68 000 mg/L in March 1976), as it is fed by several freshwater springs sourced by the Oliver Hill groundwater lens, immediately to the west (Fig. 7). The level of this lake in summer is higher than that of the adjoining Serpentine Lake, so that a small stream of water flows continuously from one to the other.

It is interesting that such high salinities can be maintained in the lakes when they are separated from the ocean by only narrow strips of porous limestone or sand. At Little Geordie Bay the strip is a mere 100 m wide. The explanation for this isolation of the hypersaline lake waters is believed to be the presence of impervious algal layers on the lake floors, which together with the muddy bottom sediments effectively seal the lakes.

Figure 6: Aerial view looking east over Noon Reef, Houtman Abrolhos, showing "blue holes" in the reef platform. These holes are up to 25 m deep, and probably represent dolines developed during the Pleistocene low sea-levels. They compare in shapes and sizes to the Rottnest salt lakes (Fig. 5), and are believed to have had a similar origin.

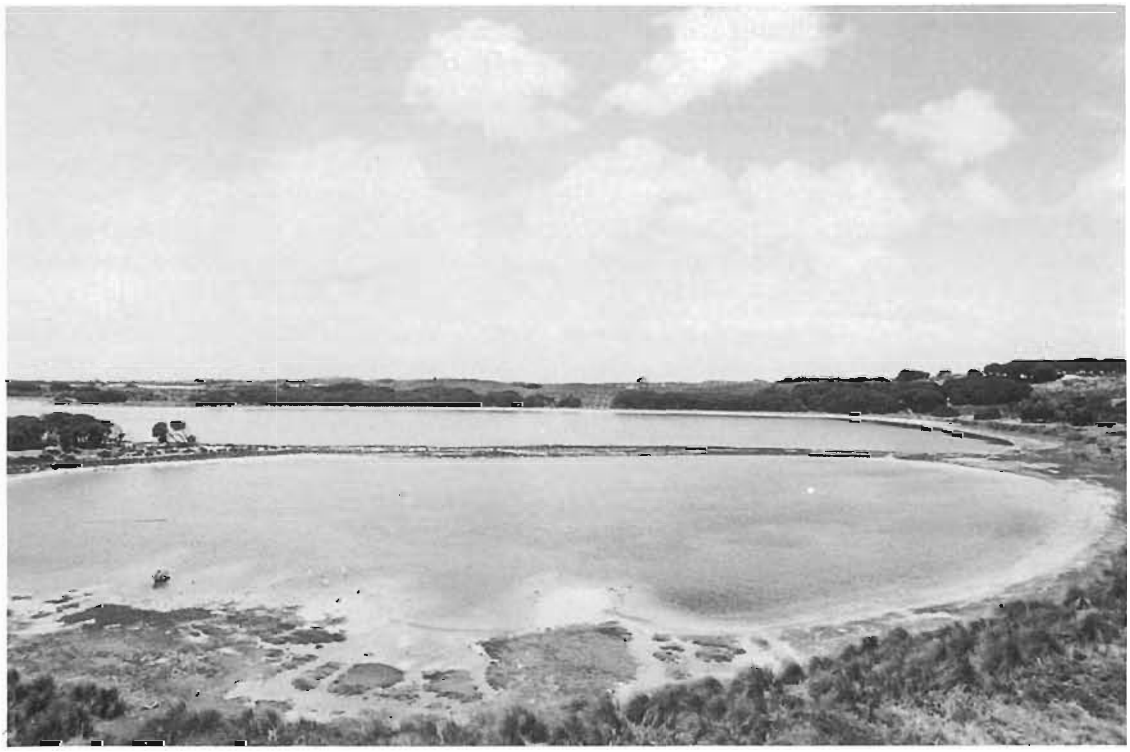

Figure 7: View looking east over Lake Timperley to Serpentine Lake, showing fresh-water springs in the foreground. During summer a small stream of water flows out of Lake Timperley into the other lake through a small channel visible near the right-hand end of the divide between them.

Some of the smaller lakes (Lake Sirius, Lake Negri, Pink Lake, and the Pearse Lakes) dry out completely by the end of summer, leaving a salt crust. For more than 100 years salt was gathered commercially from Pearse Lakes, and during much of this period they were the only source of salt production in Western Australia. The usual annual yield was about 700 t, and the last recorded production was in 1952. The historic salt works, built in 1869, were demolished in 1959.

The three deeper lakes (Serpentine, Government House, and Herschell) become meramictic ("hot lakes") during winter and spring, the bottom waters being up to 10°C warmer than the surface waters (Bunn and Edward, 1984). The stratification of the water body that causes meromixis is due to fresh water from springs and rainfall spreading over the surface, above the heavier hypersaline lake water. This stratification is destroyed by evaporation and wind action during summer and autumn.

SWAMPS

There were once eight fresh- to brackish-water swamps on the island, which formed important habitats and watering points for the native fauna. However, all but three of these - Barker Swamp (Fig. 8), Airport Swamp, and the smaller Rifle Range Swamp - were excavated during the 1970s to obtain road-building material, thereby converting them into hypersaline pools and eliminating their fresh-water biotas (Edward, 1983).

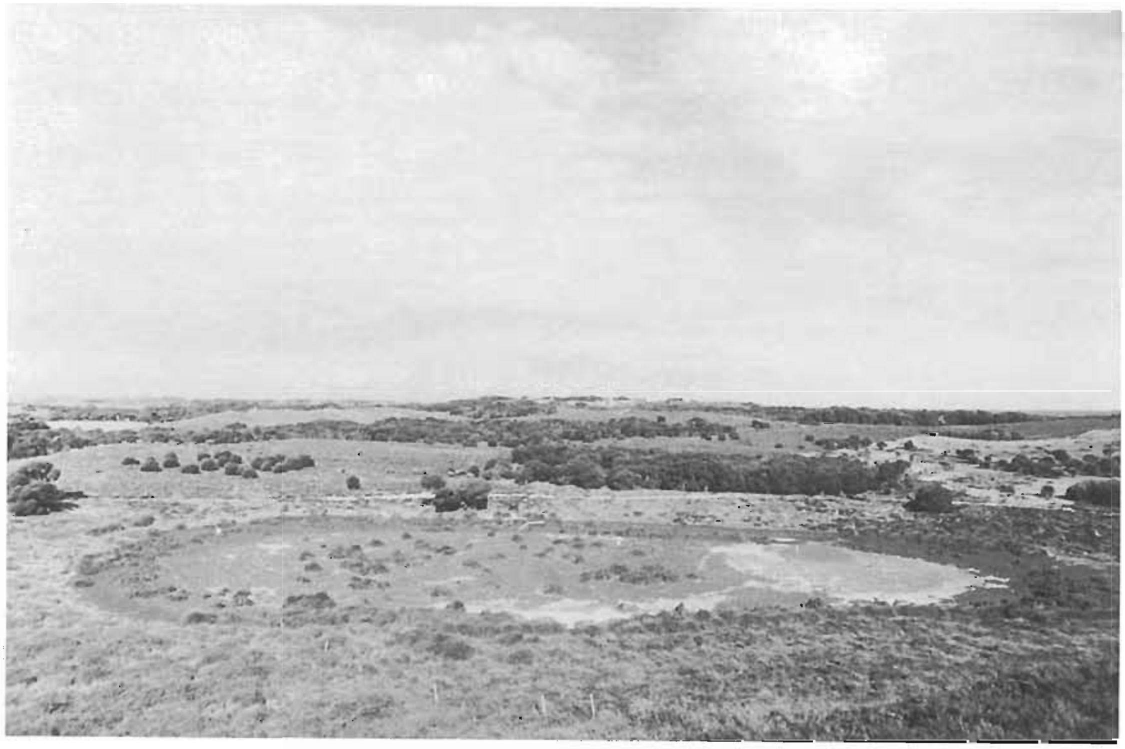

Figure 8: View looking south over Barker Swamp, one of three remaining fresh-water swamps on the island.

MARINE ENVIRONMENT

The maximum daily tidal range at Rottnest amounts to about 1 m, and the extreme range is about 1.5 m. Sea-level along this part of the Western Australian coast is strongly influenced by air pressure, water temperature, and the prevailing winds (Hodgkin and Di Lollo, 1958). Highest tides are associated with low-pressure systems and lowest tides with high-pressure systems.

Water temperatures during autumn and winter are increased significantly by the southerly flowing Leeuwin Current, which brings warm tropical water over the continental slope and outer shelf. As a result the waters around Rottnest are significantly warmer (up to 3°C) than those off Fremantle during the autumn and winter months (Pearce and Cresswell, 1985; Pearce, 1987).

SHORELINE FEATURES

Shoreline platforms ("reefs") which fringe most of the island range from a few metres to about 200 m in width (Figs 4, 9, 10). They are cut almost horizontally into eolianite of the Tamala Limestone, and the elevations of platforms surveyed at eight localities around the island show a range from 0.18 to 0.56 m below Australian Height Datum (AHD, mean sea-level) (Fig. 11). The mean of these elevations is -0.41 ± 0.11 m, which is about 0.2 m below mean low-water level. A platform at this level would be exposed for about 3% of the time each year (D F Wallace, pers. comm., 1988).

The highest platform (-0.18 m), and one of the widest, is at the west end of the island near Cape Vlamingh, where wave action is also strongest. Observations elsewhere along the Western Australian coast have shown a similar situation - shoreline platforms are highest where wave action is strongest. This is most pronounced along the Zuytdorp Cliffs, 600 km north of Rottnest, where shoreline platforms commonly stand more than a metre above mean sea-level.

The platforms normally meet limestone headlands and cliffs either at undercut shoreline notches, which are from 1 to 2.5 m high and extend back some 1 to 2 m below an overhanging visor (Figs 9, 10, 12), or at sloping shoreline ramps (Fig. 13). Where the shore is backed by a cliff there is commonly a narrow storm bench above the shoreline notch and visor, about 2 to 4 m above mean sea-level, which has formed as a result of erosion by storm waves (Figs 9, 10, 13, 14).

The limestone below each shoreline platform is strongly indurated through marine cementation (Fig. 9). Each shoreline notch, visor, and ramp is also indurated, although generally to a lesser extent than the platforms. Alternate wetting and drying of the rocks, through tide and wave action, apparently causes precipitation of calcium carbonate . Most of the rest of the Tamala Limestone above the wave-splash zone is only weakly cemented, and it is for this reason that storm waves erode benches in the softer limestone above the indurated shoreline notches and visors (Figs 9, 10, 13, 14). Sea spray and storm waves surging over these benches in turn tends to cement and preserve them, although they are subject to karst erosion by solution in rainwater.

Because wave splash and consequent strong induration reaches higher on the headlands, the storm benches are highest there, and fall progressively in elevation passing back into the bays. This is well seen in the small bay immediately east of Hayward Cape (Fig. 14).

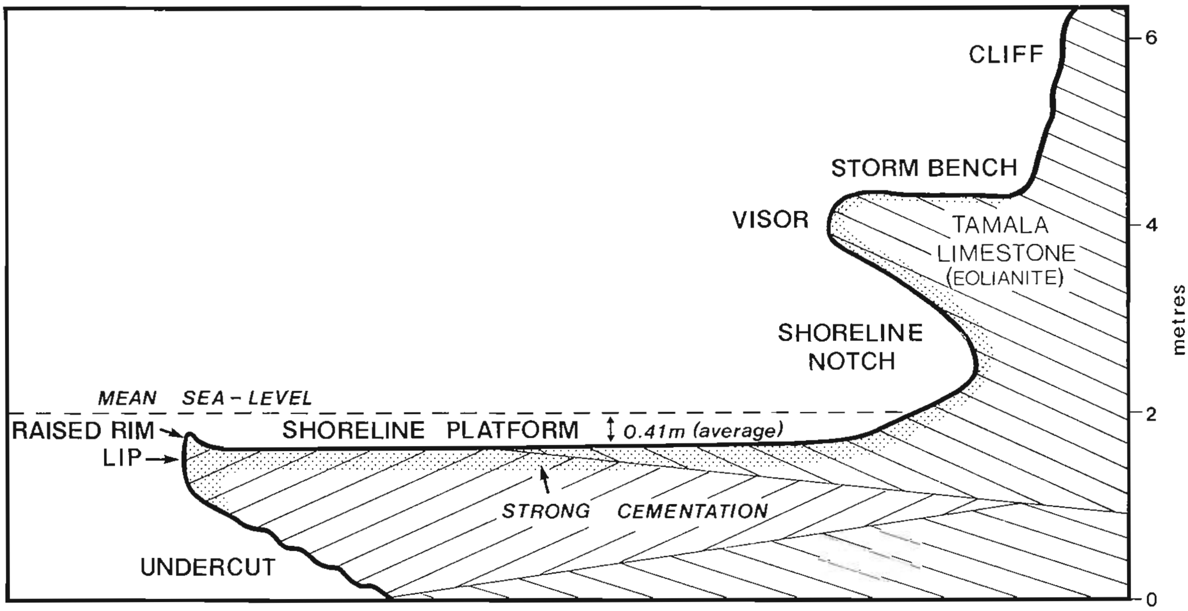

Figure 9: Diagrammatic cross-section illustrating shoreline platforms and associated features developed around the coastline of Rottnest Island.

Figure 10: View of the western side of Fish-hook Bay, showing the shoreline platform, notch, and visor, and a well-developed storm bench above the visor.

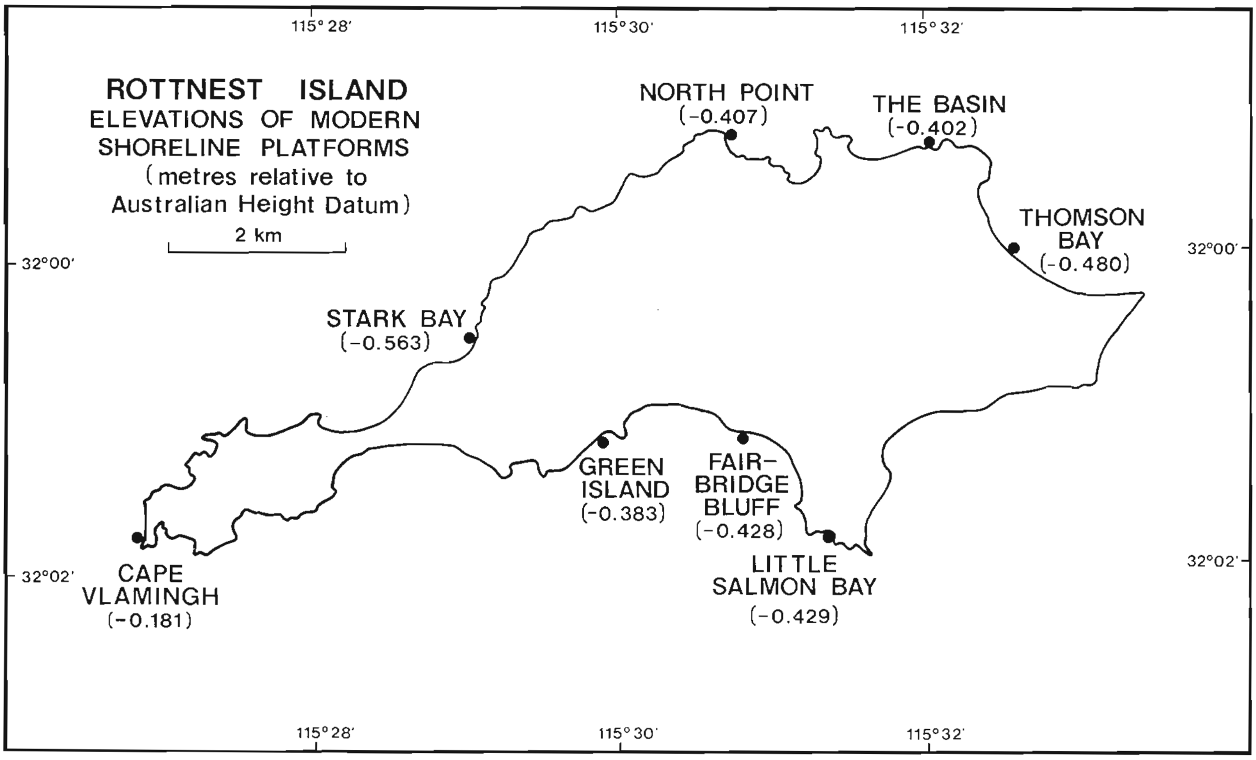

Figure 11: Elevations of shoreline platforms at eight sites around Rottnest Island. The mean elevation is -0.41 ± 0.11 m.

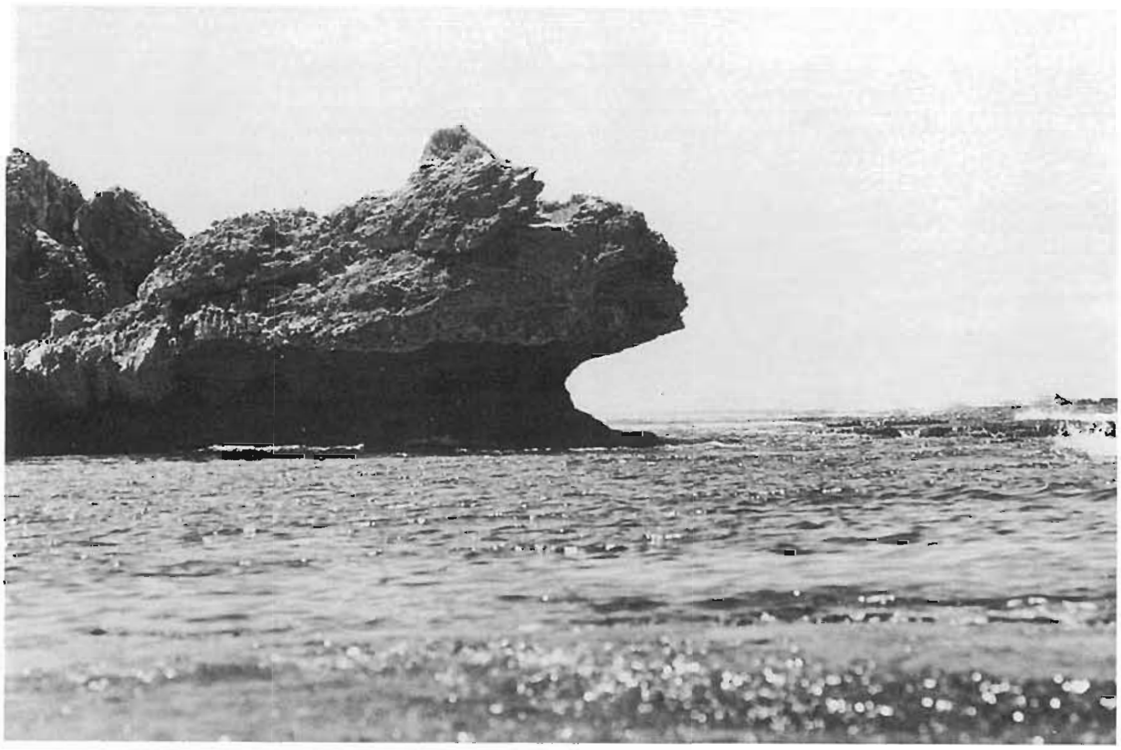

Figure 12: Shoreline notch, visor, and platform at the east end of Fish-hook Bay.

Figure 13: Shoreline ramp and storm bench adjoining Radar Reef.

Figure 14: Storm bench in a small bay east of Hayward Cape. The bench has been eroded into soft limestone above the indurated shoreline notch and visor. Note that the bench is highest (about 3.5 m above the modern shoreline platform) at the entrance to the bay, and falls progressively (to a minimum of about 2 m) within the bay.

The outer edge of each platform commonly has a raised rim of limestone (Fig. 15), which in some cases is coated by the coralline alga *Lithothamnion*, but in others is quite bare. The raised rims are clearly primarily erosional rather than constructional, but details of their origin have yet to be determined. The most likely explanation is that the platform margins are the most strongly cemented parts of the platforms, and are therefore more resistant to erosion, "lagging behind" as the rest of the platform is lowered.

Stepped paddy-field terraces are conspicuous on the outer platforms at a few places (Figs 16-18), extending through a maximum vertical range of as much as 70 cm above the general platform level. Each terrace has its own raised rim, and water from breaking waves cascades down from one terrace to another.

Algal polygons, formed by brown algae, are conspicuous in some areas on the platforms, but the reason for their distinctive growth forms (Figs 16, 17, 19) is unknown. They are not associated with any jointing in the underlying limestone, despite their resemblance to shrinkage cracks. Although some algal polygons are known to persist with the same shapes and positions for prolonged periods, others are impersistent. For example, compare the extensive algal polygons in Figure 17, taken in October 1985, with their reduced extent in Figure 16, taken in January 1988, and Figure 6 of Playford (1977), taken in February 1976. Also, Figure 19, taken in October 1985, shows abundant algal polygons on the platform near Green Island, but there was no sign of any polygons at this locality just two years later, in October 1987.

Limestone crusts precipitated by *Lithothamnion* coat the platforms in some areas, while nodules of this alga, known as rhodoliths, are very abundant on the platform northeast of Green Island, where they fill small depressions on the platform surface (Figs 20, 21). They have grown in their sub-spherical shapes as a result of repeated rotation by wave action.

Figure 15: Shoreline platform at The Basin at very low tide, showing the prominent raised rim of the platform.

Figure 16: Shoreline platform at Wilson Bay, January 1988, showing paddy-field terraces on the outer platform, and algal polygons on the inner platform. Note the series of curved lines between the terraces and algal polygons, marked by rows of regular echinoids in their excavated holes, apparently following foreset bedding in the Tamala Limestone.

Figure 17. The same view as Figure 16, taken in October 1985. Note that the algal polygons were far more extensive in 1985, but those that have persisted to 1988 are still in their same positions.

Figure 18: Closer view of the paddy-field terraces at Wilson Bay. Each has a raised rim, and water cascades from one to another. They extend over a vertical interval of about 0.7 m.

Figure 19: Algal polygons (defined by lines of brown algae) on the shoreline platform opposite Green Island in October 1985.

Figure 20: Rhodoliths (nodules of the coralline alga *Lithothamnion*) filling small depressions on the surface of the shoreline platform opposite Green Island.

Figure 21: Close-up view of rhodoliths collected at the site of figure 18.

Hermatypic corals occur on the platforms in some places, generally only as scattered colonies in holes or on the outer platform edges, but in a few areas they are more extensive, forming isolated coral reefs (notably Pocillopora Reef beside Parker Point, Fig. 22). The coral fauna comprises some 22 hermatypic species, dominated by *Pocillopora damicornis*, and 4 ahermatypic species (small forms, some semi-solitary, living under overhangs or in caves) (L M Marsh, written comm., 1988). *Acropora*, the dominant reef-building coral in the Rottnest Limestone at Fairbridge Bluff, is represented by only a few scattered living colonies in the waters around the island today. This genus is not known to form living reefs any further south than the Houtman Abrolhos, 350 km north of Rottnest. Details of some other aspects of the fauna and flora of the shoreline platforms at Rottnest are given by Hodgkin and others (1959) and Black and Johnson (1983), in the Royal Society of Western Australia's volumes on Rottnest research edited by Hodgkin and Sheard (1959) and Bradshaw (1983).

The processes of erosion that form the shoreline platforms and their associated notches and ramps at Rottnest and elsewhere along the Western Australian coast are not yet fully understood, but they apparently result from a combination of bioerosion by marine organisms, aided by mechanical erosion by wave action, and perhaps partly by some form of chemical corrosion. Such mechanisms have been discussed by Fairbridge (1952), Revelle and Fairbridge (1957), Hodgkin (1964, 1970), Black and Johnson (1983), and Semeniuk and Johnson (1985).

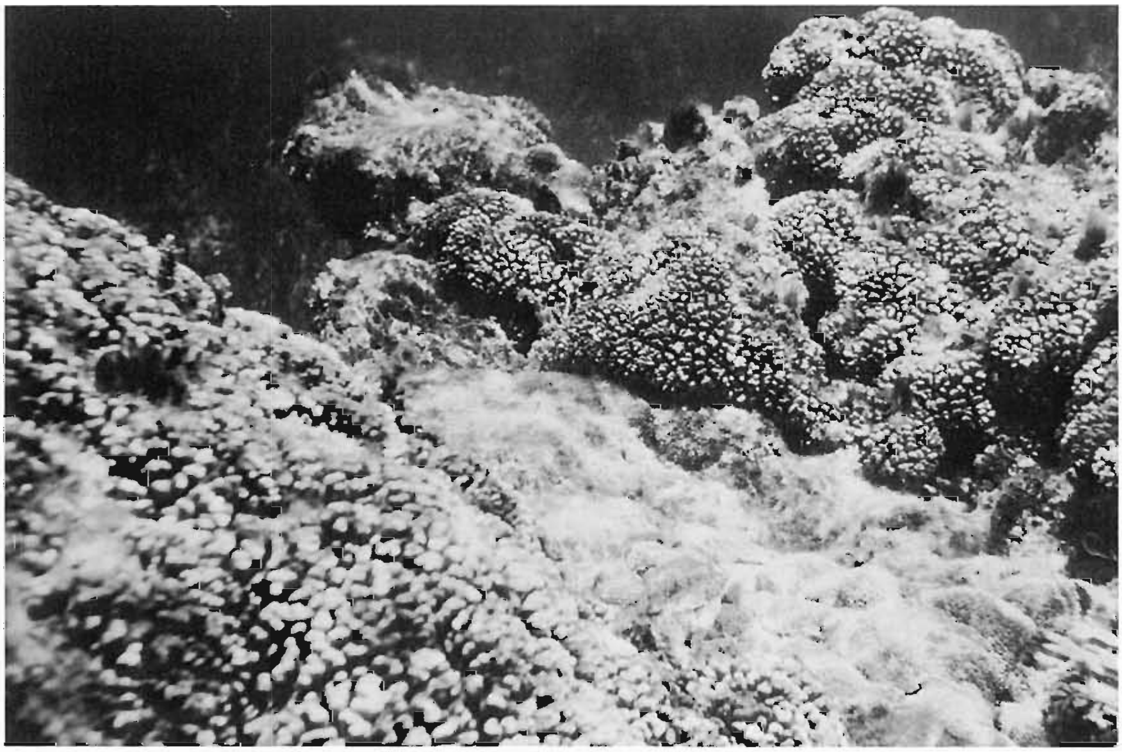

Figure 22: *Pocillopora damicornis* colonies forming a small coral reef beside Parker Point.

Figure 23: The black gastropod *Nerita atramentosa* and limpet *Patelloida alticostata* on the lower part of the shoreline notch at Wilson Bay. Both species graze on algae, abrading the limestone as they do so, causing the notch to retreat and the platform to expand.

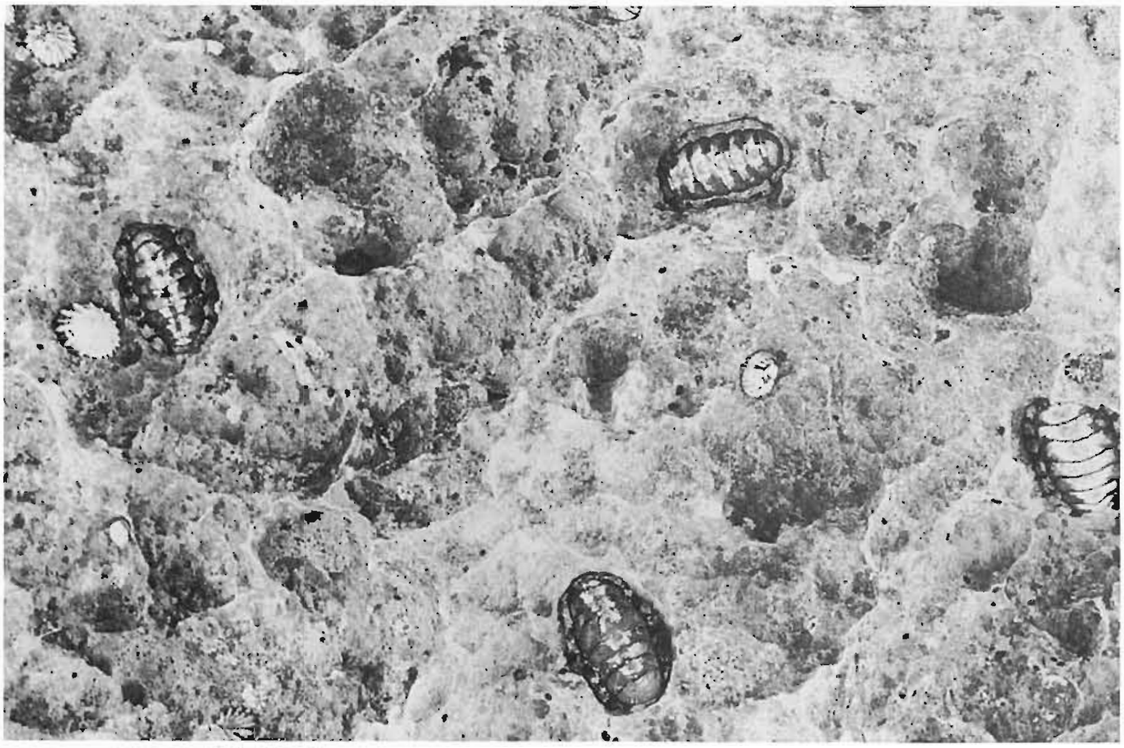

Figure 24: The chiton *Clavarizona hirtosa* and small limpets on the lower part of the shoreline notch at Wilson Bay. The chitons also graze on algae and thereby abrade the limestone.

Figure 25: Regular echinoids (*Heliocidaris erythrogramma*) on the shoreline platform at Wilson Bay, living in holes that they excavate in the *Lithothamnion* crust and underlying limestone of the platform.

I am impressed by the observations by Hodgkin (1970), and Black and Johnson (1983) on the major role of molluscs in eroding the notches and platforms. Limpets, other gastropods, and chitons actively abrade the limestone with their teeth while scraping away the algae on which they feed (Figs 23, 24). In addition, some of the algae are endolithic - their filaments extend into the limestone - and several species of molluscs evidently scrape away the surface limestone in order to feed on these filaments. The degree to which individual species erode limestone in this way can be estimated by determining the inorganic content of their faeces (Black and Johnson, 1983). Other organisms that are important in eroding limestone on the platforms include sea urchins (regular echinoids), boring bivalves (*Lithophaga*), and boring clionid sponges (Figs 25, 55, 56).

The stepped paddy-field terraces are puzzling features, which are far from being understood, and they clearly warrant more research. They are best developed at the foot of the Zuytdorp Cliffs (600 km to the north), where the terraces can extend over vertical intervals of several metres. They represent progressive phases in the downward erosion of platforms, but it is not clear why they should form such a succession of stepped terraces.

Hodgkin (1964) showed that the notch adjoining the shoreline platform at Point Peron, south of Perth, was retreating at a rate of about 1 mm per year, and he suggested that this rate applied generally to similar notches elsewhere. At this rate of erosion, if the platforms develop solely by lateral retreat of notches, there would be insufficient time since sea-level stabilized near its present level to erode the very wide shoreline platforms at Rottnest and elsewhere along the Western Australian coast. At the postulated rate of 1 mm/year, platforms that are 200 m wide would require 200 000 years to form, but sea-level at Rottnest has been within about 2.4 m of its present level for only some 6 000 years.

Figure 26: Deposit of shells transported by birds on a small headland immediately west of Parker Point. It consists almost entirely of nacreous fragments and opercula of the gastropod *Turbo intercostalis*, together with a few limpets. This deposit has been described previously as a possible Aboriginal kitchen midden.

Figure 27: Deposit of shells transported by birds on a low headland overlooking Wilson Bay. This deposit is older than that shown in Figure 26 - the nacreous shell material of *Turbo intercostalis* has weathered away, leaving only the resistant opercula, together with the giant limpet *Patella laticostata* and the common limpet *Patelloida alticostata*.

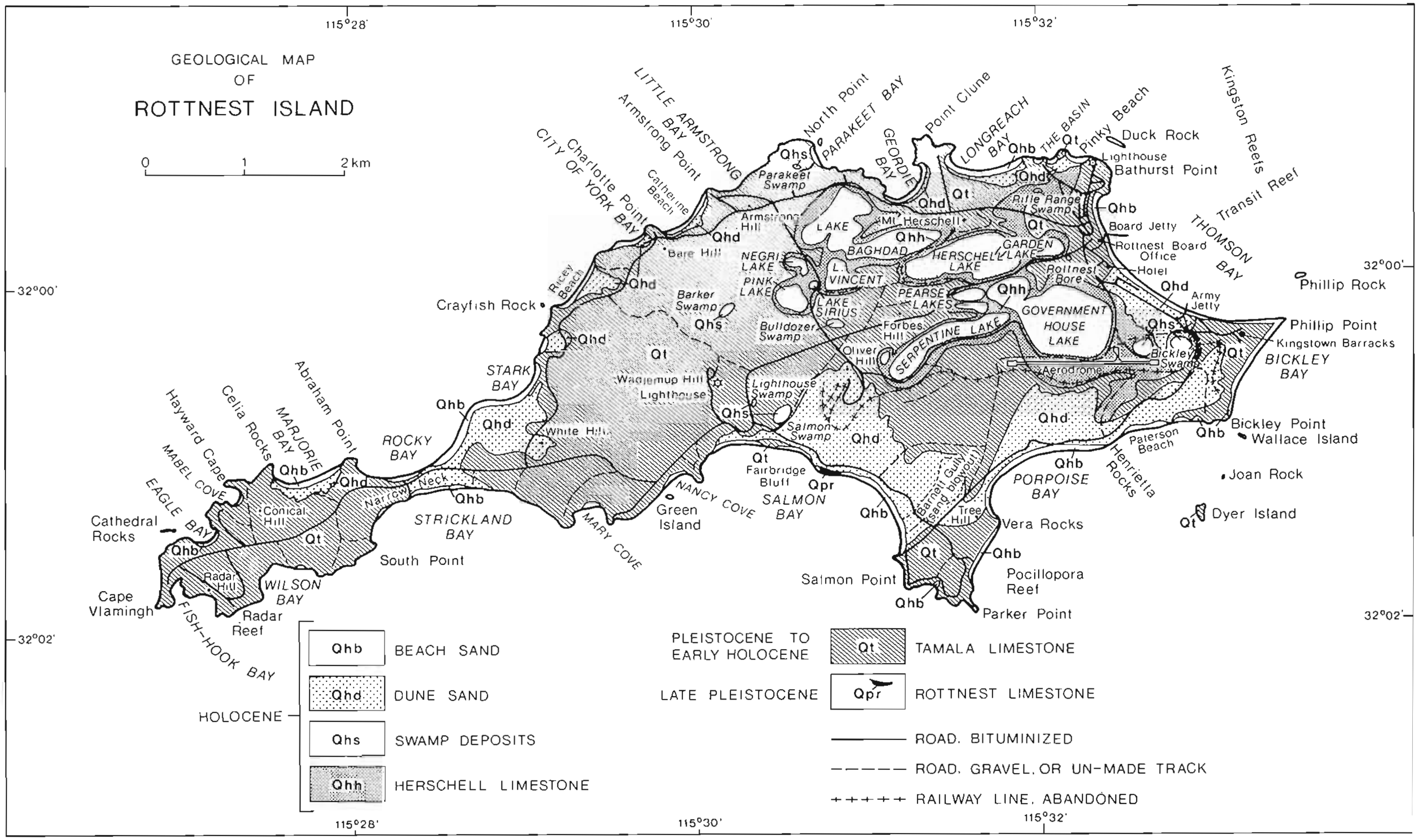

Figure 28: Simplified geological map of Rottnest Island.

However, platform development clearly involves both vertical and horizontal erosion; the varying heights of shoreline platforms around the island testify to this, as do the paddy-field terraces. The modern platforms must have developed over about 6 000 years as a consequence of combined vertical and horizonal erosion (biological, mechanical, and ?chemical).

The shoreline platforms are the source of food for a number of bird species, one of which, the Pacific gull, has been primarily responsible for the shell deposits that occur on many of the exposed headlands around the island. The birds pick up gastropods (mainly *Turbo intercostalis*), which they break open by dropping them onto the rocks from considerable heights (Teichert and Serventy, 1947). The nacreous *Turbo* shells (Fig. 26) afterwards weather away rapidly, but their opercula are very resistant and tend to accumulate in large numbers (Fig. 27). Such shell deposits at Rottnest and elsewhere have sometimes been mistaken for Aboriginal kitchen middens (for example the deposit shown in Figure 26; Hughes and others, 1978).

GEOLOGY

INTRODUCTION

Rottnest Island is built of late Pleistocene to early Holocene dune limestone (Tamala Limestone), with a thin intercalation of late Pleistocene coral-reef limestone (Rottnest Limestone), overlain by thin middle and late Holocene shell beds (Herschell Limestone), dune sand, beach sand, swamp deposits, and lake deposits. The oldest rocks exposed on the island, belonging to the earlier part of the Tamala Limestone, are probably not more than about 140 000 years old.

The surface geology of the island is illustrated on Figure 28 and Plate 1 (from Geological Survey Report 6, by Playford and Leech, 1977).

TAMALA LIMESTONE

The Tamala Limestone (pronounced <u>Tar</u>-mala) is a unit of eolian calcarenite, composed of wind-blown shell fragments with variable amounts of quartz sand, and is characterized by large-scale eolian cross-bedding, marking successive dune slopes (Figs 29, 30). This formation is recognized along the coastal strip and adjoining islands from Shark Bay to the south coast, and was formerly known as the "Coastal Limestone". It accumulated as belts of coastal sand dunes during the Pleistocene and early Holocene. The type locality is situated on the Zuytdorp Cliffs on Tamala Station (Playford and others, 1976).

Over most of Rottnest Island the Tamala Limestone is mantled by residual quartz sand derived by weathering of the sandy limestone. The limestone varies from strongly lithified on the shoreline platforms to moderately lithified on the adjoining notches and visors, and weakly lithified above the splash zone and away from the coast. Hard calcrete horizons occur in places, and these are normally underlain by softer limestone with abundant rhizoliths (fossil root structures, Fig. 31) and may be overlain by grey to brown fossil soils. The fossil soils commonly contain fossil land snails (*Bothriembryon*) and weevil pupal cases (*Leptopius*).

Rhizoliths were initiated by lime precipitation around roots of trees and shrubs that grew in the original dunes, the cavities left after decay of the roots being filled by clastic limestone and cement, although in some cases the wood of the root is replaced by calcium carbonate. This process can be seen to occur around living roots below modern dunes, where these have been exposed in blow-outs (Fig. 32).

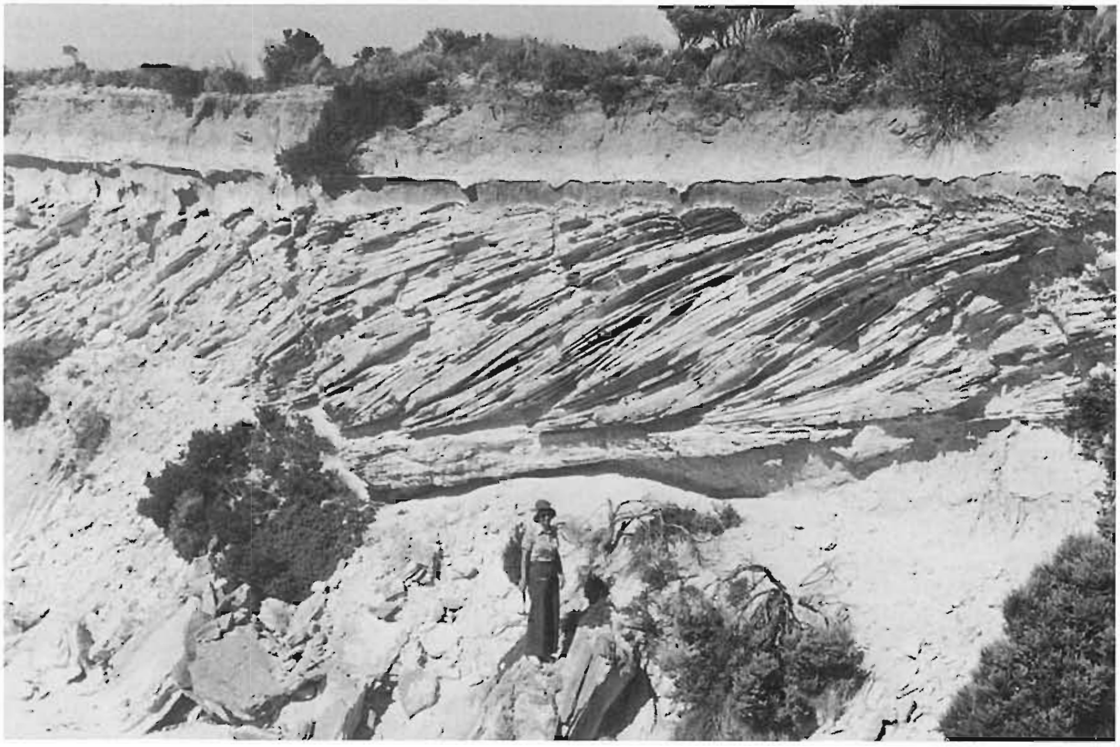

Figure 29: Tamala Limestone on the west shore of Strickland Bay near South Point showing a section through a small dune that has migrated across the area from north to south, with well-developed topset, foreset, and bottomset bedding. A thin fossil soil is preserved above the dune.

Figure 30: Tamala Limestone on the north shore of Salmon Bay, west of Fairbridge Bluff, showing well-developed eolian cross bedding.

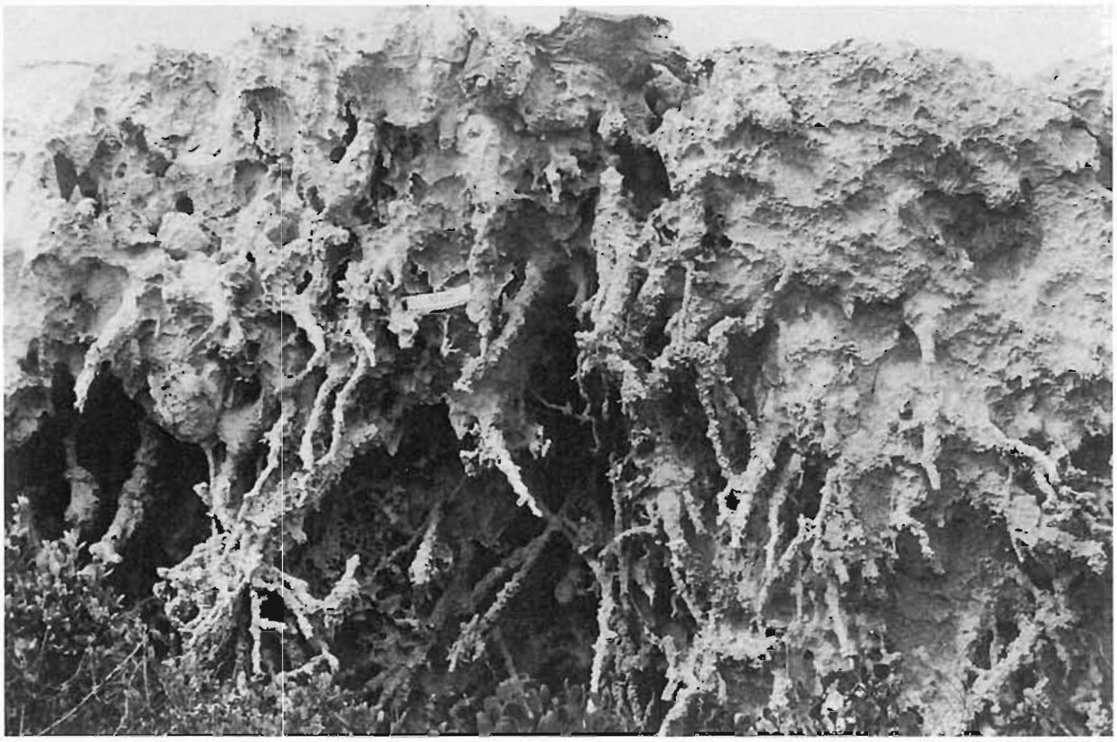

Figure 31: Rhizoliths (fossil root structures) below calcrete in Tamala Limestone, just north of Salmon Point.

Figure 32: Small blowout in modern dune sand beside the road south of Salmon Swamp, showing calcification around roots - the first stage in the development of rhizoliths.

The rhizolith horizons commonly include conspicuous "solution pipes" - cylindrical bodies up to 0.5 m in diameter and originally several metres long (Fig. 33). They are believed to have formed around the tap roots of large trees (probably mainly eucalypts). The outside casing of the pipes is generally strongly cemented, while the inside is composed of softer calcified roots (Figs 34, 35) or clastic material that has entered from above when the original root rotted away. "The Pinnacles" in Nambung National Park are believed to have formed in this manner.

The fossil soils, calcretes, and rhizolith horizons mark periods of local interruption in dune building, which allowed time for soils to develop and vegetation to become established, before being overwhelmed again by a new advancing dune. The calcretes are thought to have formed during humid periods of the Pleistocene (Semeniuk, 1986). The thickness of the Tamala Limestone in the Rottnest area is probably up to about 115 m, including some 70 m of section below sea-level, overlying older Pleistocene or Tertiary sands. Most of the exposed formation is believed to be younger than the Rottnest Limestone coral reef, which is about 130 000 years old (Szabo, 1979). However, part of the Tamala Limestone exposed near Fairbridge Bluff underlies the reef, and must be a little older than it (perhaps about 135 000 - 140 000 years old). The youngest part of the Tamala Limestone is of Holocene age, laid down during the Flandrian transgression. The contact with overlying modern dune sands is transitional, as cementation of those sands is progressing gradually below the surface. Possible fossil emu footprints can be seen on a foreset bedding plane in the Tamala Limestone on the north-western side of Fish-hook Bay. If this interpretation is correct, the footprints must have been left here by an emu walking on a wet dune slope, at a time when Rottnest was still connected to the mainland.

Figure 33: Small headland 100 m north of Salmon Point showing indurated calcrete crust at the top of the cliff, with well-developed solution pipes extending through the underlying rhizolith horizon. A rubble zone covers the slope above the shoreline notch, visor, and platform, and some large blocks have recently rolled onto the platform.

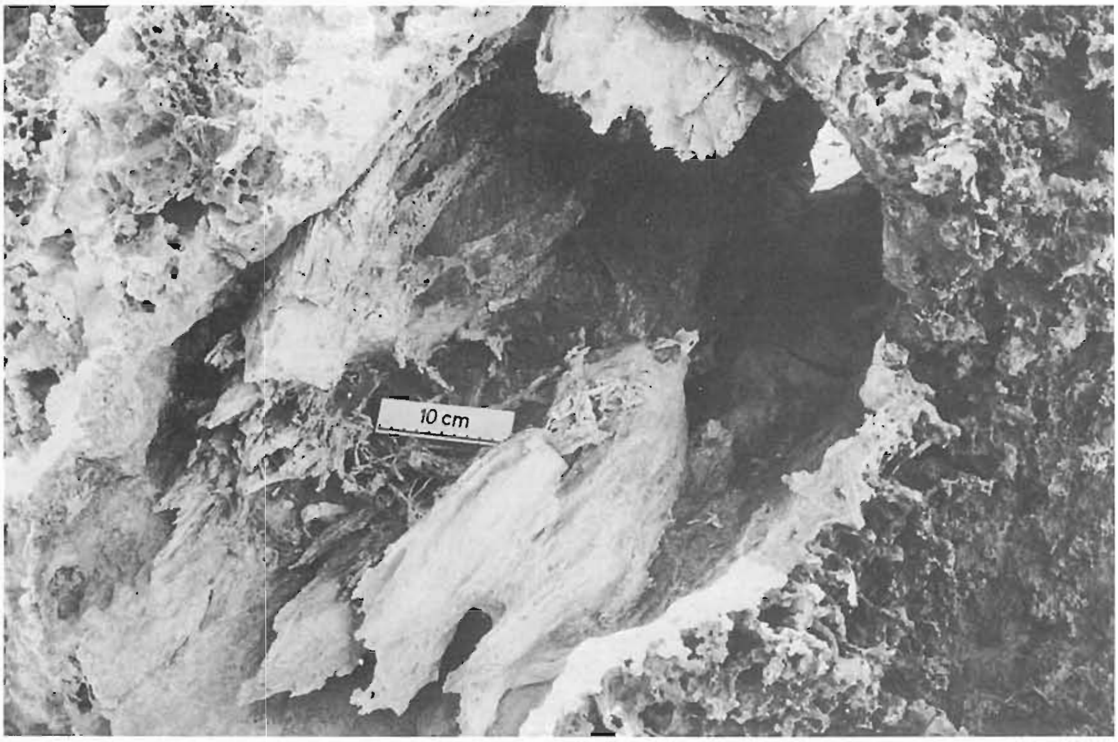

Figure 34: Solution pipe in a talus block at the same locality as Figure 33, showing a well-developed calcified root that largely filled the pipe.

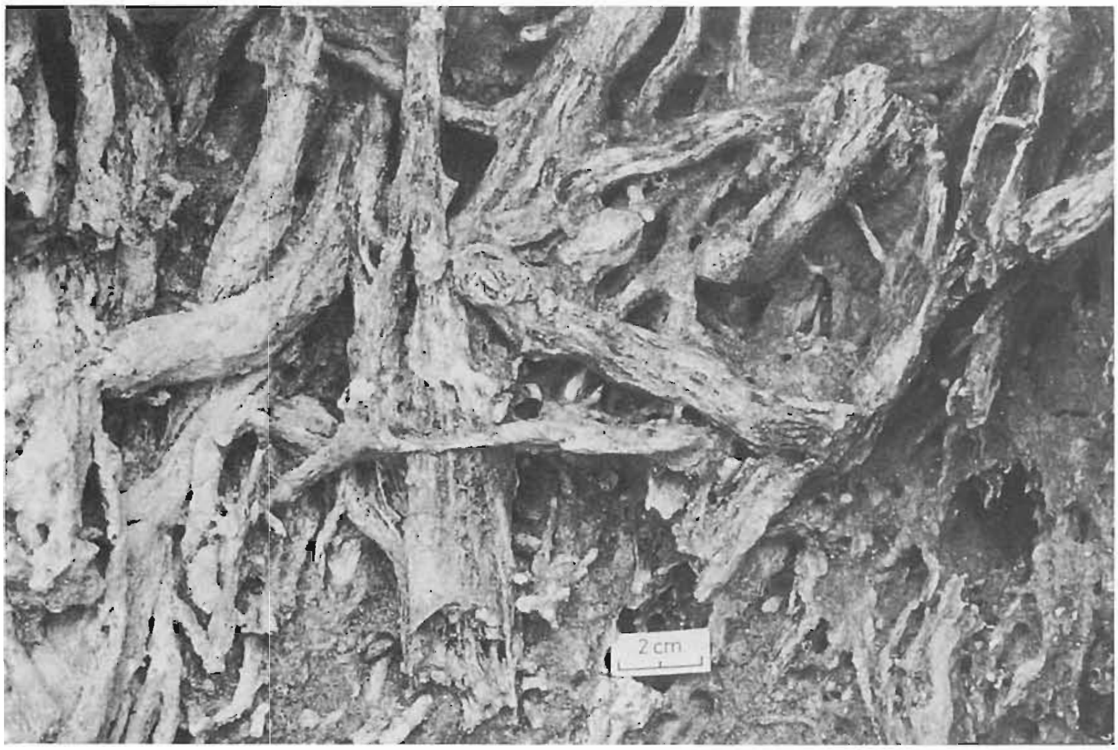

Figure 35: Mass of calcified roots filling a solution pipe at Fairbridge Bluff.

ROTTNEST LIMESTONE

The Rottnest Limestone (Fairbridge, 1953) is a late Pleistocene unit of coral-reef limestone and associated shelly (gastropod-rich) limestone exposed at Fairbridge Bluff in Salmon Bay. The formation is overlain and underlain by Tamala Limestone, and is believed to represent a marine tongue intercalated in that formation. The total outcropping thickness of the Rottnest Limestone is 3 m, but the lowest part is not exposed as it extends below sea-level on the erosional contact with the underlying Tamala Limestone. The formation outcrops for about 150 m along the low sea cliff forming Fairbridge Bluff; it is not exposed elsewhere.

Branching and platy species of *Acropora* predominate in the reef (Figs 36, 37), and there are also colonies of *Goniastrea* (Fig. 38), *Pocillopora*, and cf. *Monomyces* (L M Marsh, written comm., 1988). Coralline algae (*?Lithothamnion*) encrust most of the corals, and contributed significantly as binding organisms in the reef framework. Shelly calcarenites are associated with the reef and contain at least 23 species of gastropods, of which *Turbo intercostalis* is the most abundant (Fig. 39), and 5 species of bivalves (G W Kendrick, written comm., 1988). Some shells are heavily encrusted and bound into the reef framework by coralline algae.

The Rottnest Limestone has been dated by uranium/thorium methods as 132 000 ± 5 000 years B.P. (Szabo, 1979). A previous dating had been given as 100 000 ± 20 000 years B.P. (Veeh, 1966), but the new figure is more in accord with current views on the age of the last interglacial period. At that time sea-level must have been at least 3 m higher relative to Rottnest Island than at present. However, it could have been significantly higher than this, as it is quite possible that the reef as now exposed at Fairbridge Bluff grew in water up to a few metres deep.

HERSCHELL LIMESTONE

The Herschell Limestone (Playford, 1977) is a unit of Holocene marine shell beds with interbedded lime sand, ranging from friable to strongly cemented, which is exposed around margins of the salt lakes on Rottnest Island. It overlies and abuts the Tamala Limestone and is overlain by superficial Holocene deposits. The unit is at least 2.5 m thick, and is believed to have been deposited in subtidal to intertidal environments when the salt lakes formed lagoonal arms of the sea, and sea-level was up to about 2.4 m higher than today.

It is now proposed to subdivide the formation into two members: the lower Vincent Member and upper Baghdad Member, both of which have their type sections in the Mt Herschell quarry (Figs 40, 41).

The Herschell Limestone has a very rich fauna, primarily molluscan. G W Kendrick (written comm., 1987), as a result of collecting since his 1977 report was published (Kendrick, 1977a), has now recorded 223 species from the formation, of which 203 are molluscs (146 gastropods, 51 bivalves, 4 chitons, and 2 scaphopods). Others are arthropods (10 species), echinoderms (5 species), fish (2 species), and one species each of foraminifers, corals, and polychaetes. He has collected 142 species from the Vincent Member and 99 from the Baghdad Member, and there are 66 further species collected in the past from the formation that have not yet been assigned to individual members.

Kendrick further reports that the presence in both members of the large benthic foraminifer *Marginopora* sp. cf. *M. vertebralis* suggests that sea grasses, probably *Posidonia*, grew in the lagoon systems.

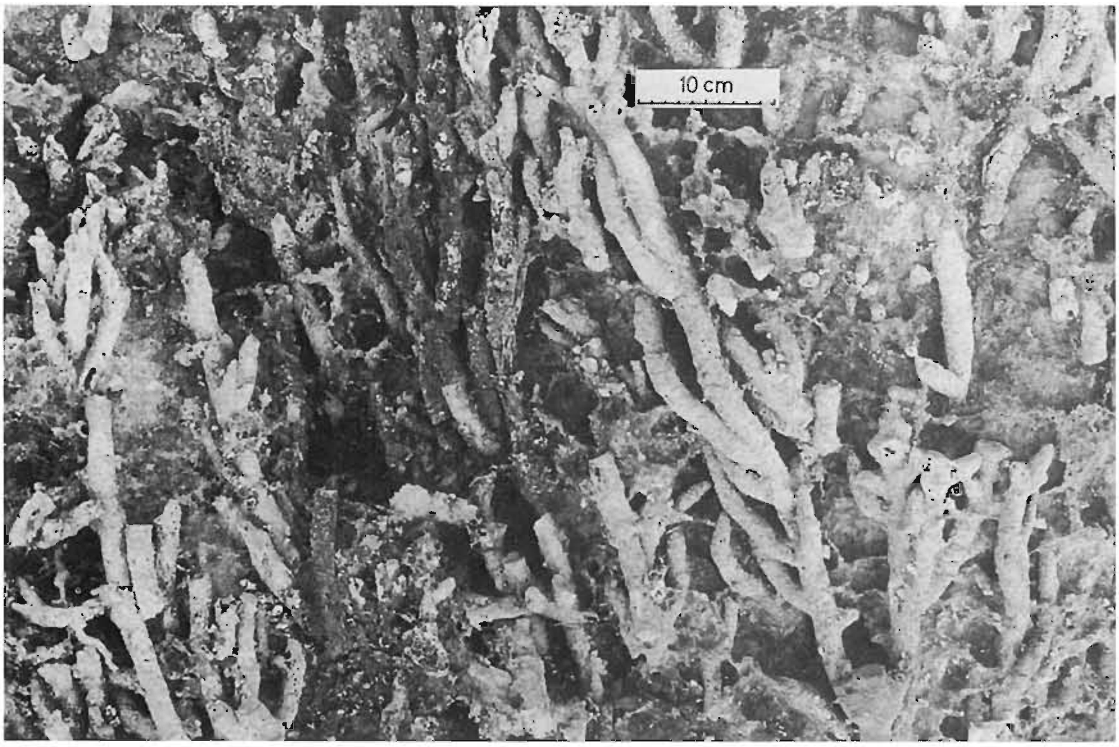

Figure 36: Staghorn corals (*Acropora* sp.), coated by coralline algae, in the fossil coral reef of the Rottnest Limestone at Fairbridge Bluff.

Figure 37: Tabular corals (*Acropora* sp.) and gastropod rubble, coated and bound by coralline algae, in the fossil coral reef of the Rottnest Limestone at Fairbridge Bluff.

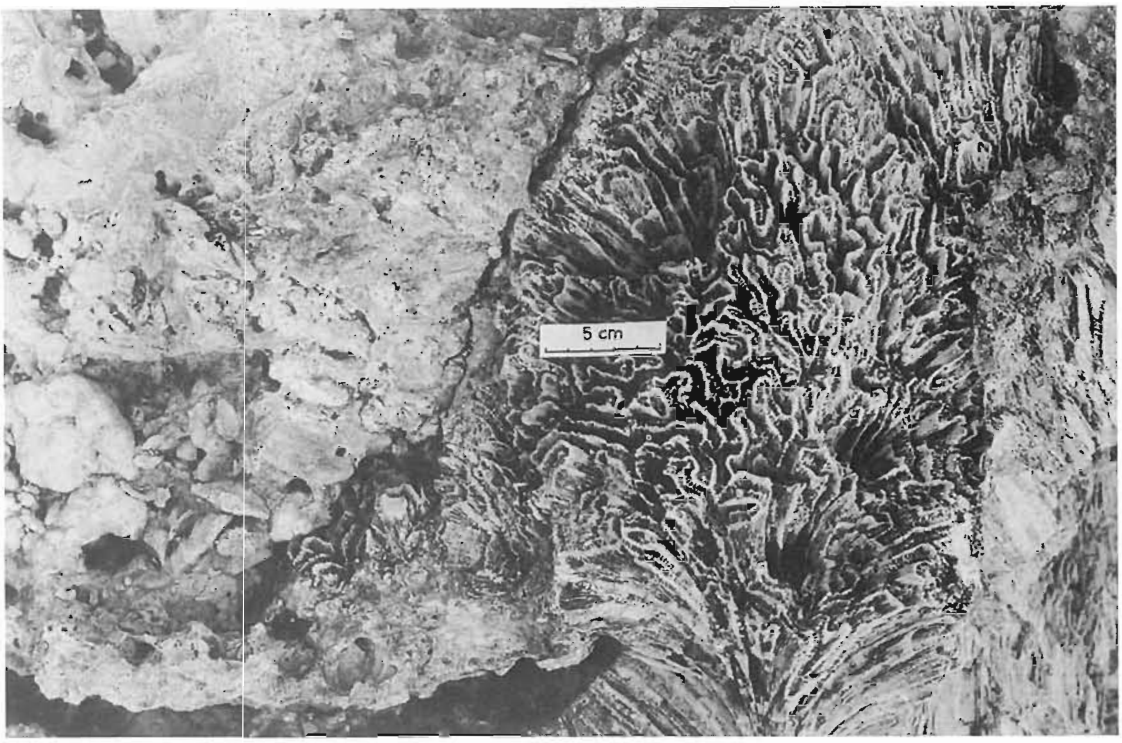

Figure 38: Brain coral (*Goniastrea* sp.), and coralline algae coating and binding coral and gastropod rubble, in the fossil coral reef of the Rottnest Limestone at Fairbridge Bluff.

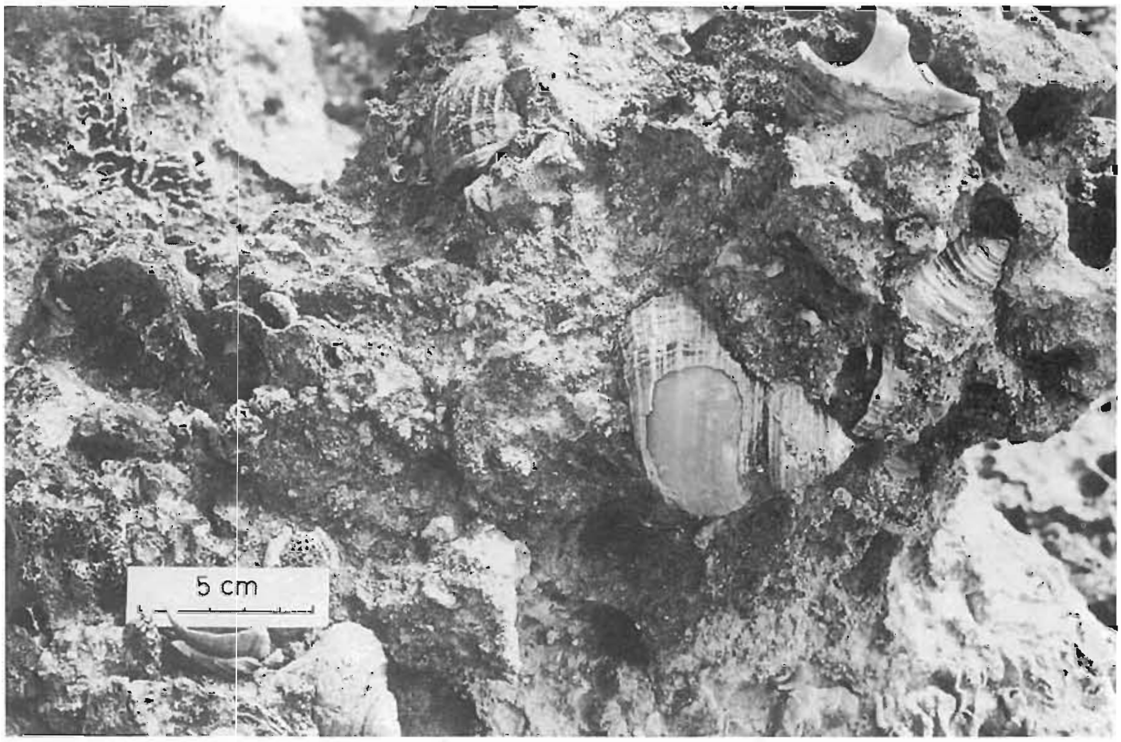

Figure 39: Gastropods (*Turbo intercostalis*) and fragmentary corals in Rottnest Limestone, central part of Fairbridge Bluff.

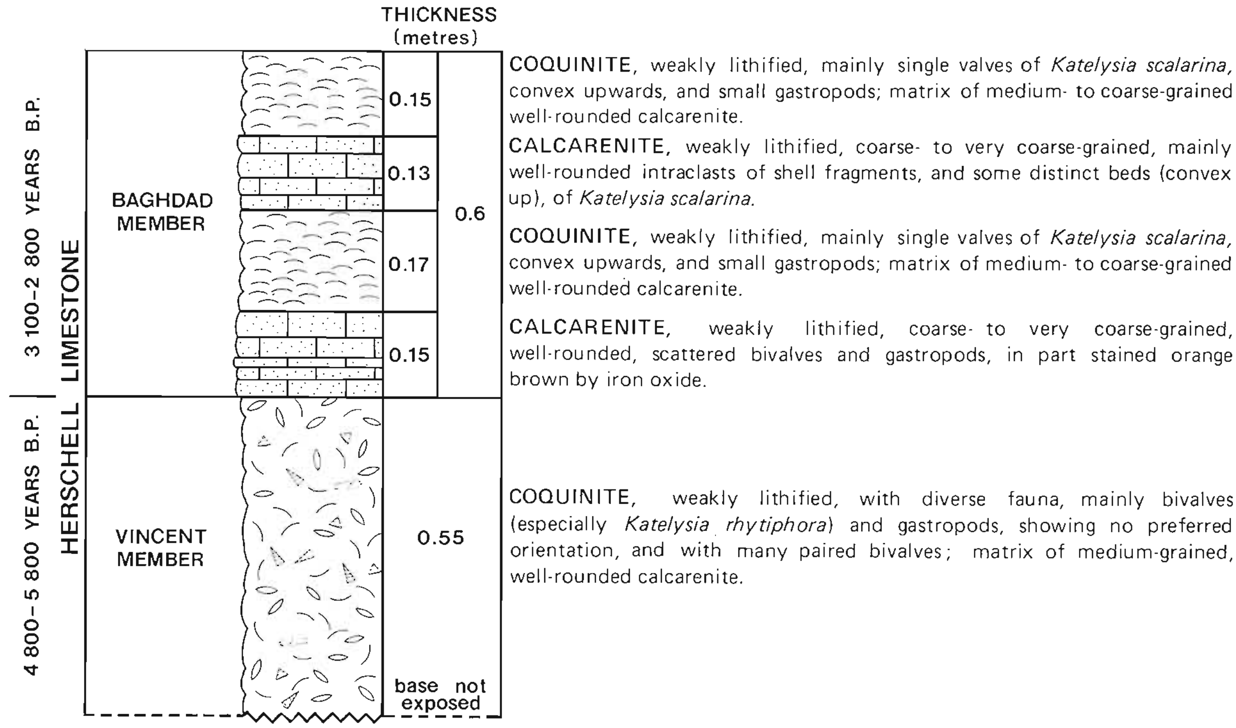

Figure 40: Type section of the Herschell Limestone at Mt Herschell quarry.

Figure 41: Herschell Limestone at Mt Herschell quarry, showing the Vincent Member (below the scale) and Baghdad Member (above). Note the convex-upward orientation of single valves (*Katelysia scalarina*) in coquinite of the Baghdad Member, and the lack of any preferred orientation in the Vincent Member.

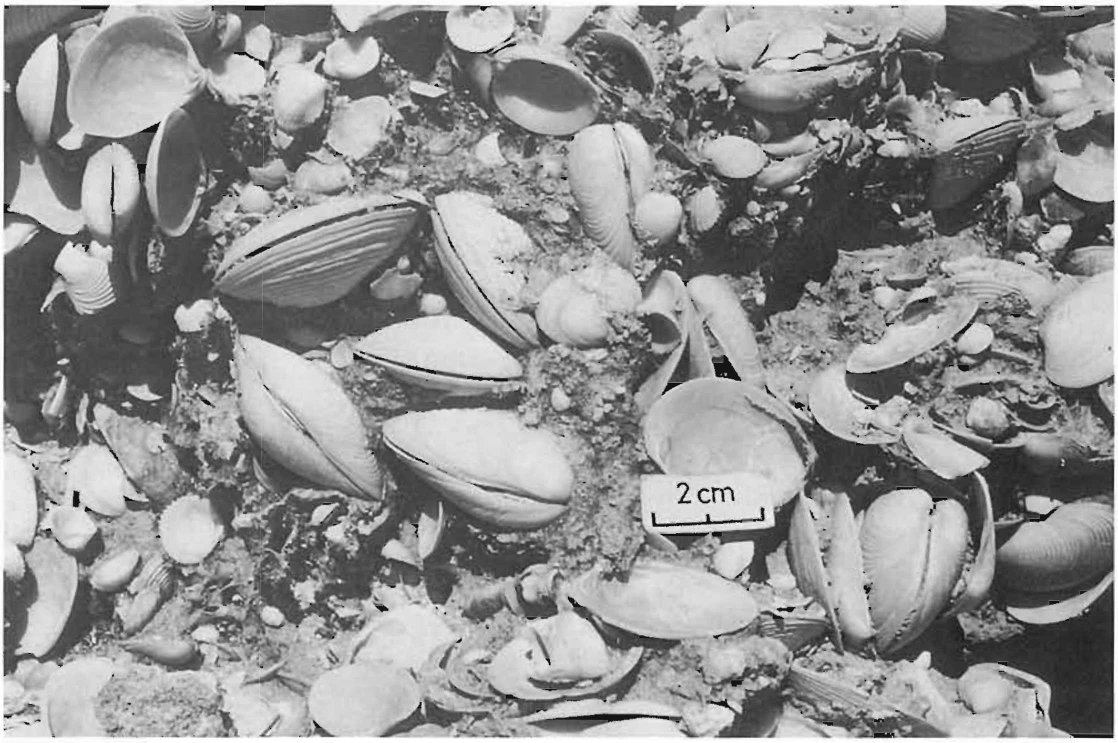

Figure 42: Close-up view of part of the Vincent Member shown in Figure 41, showing many undisturbed paired shells (mainly *Katelysia rhytiphora*) and a lack of orientation in single valves, indicating deposition in a subtidal environment, below effective wave base. The small valves are mainly *Fragum erugatum*.

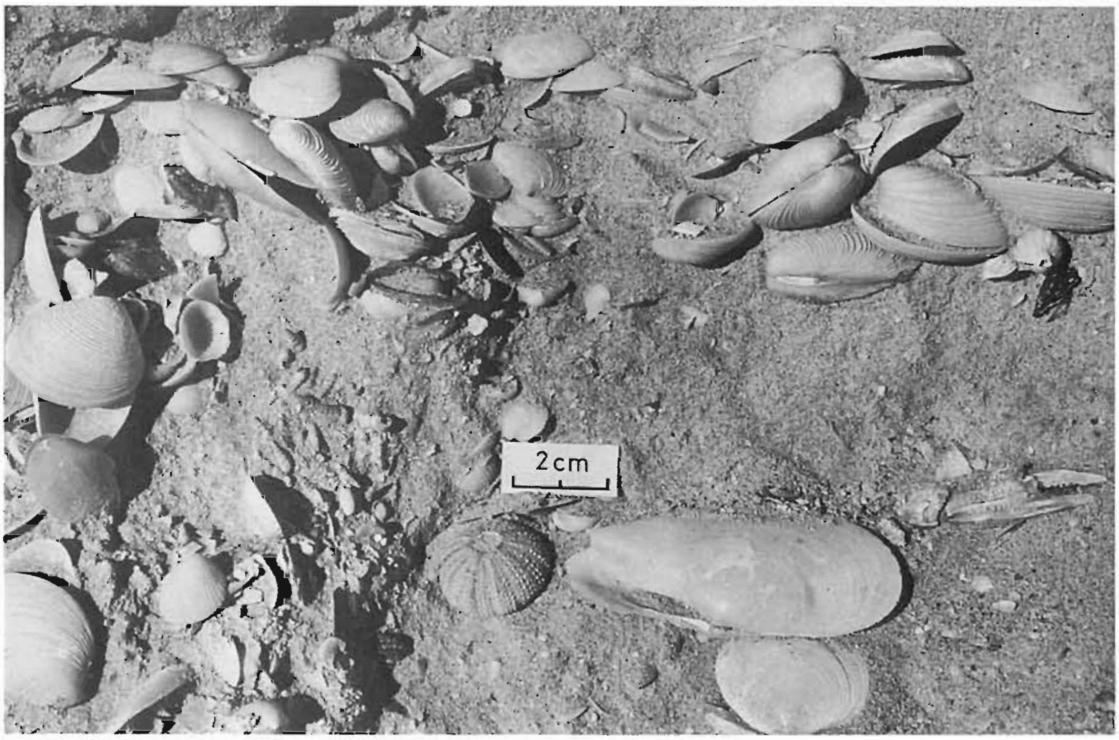

Figure 43: Part of the type section of the Vincent Member in the Mt Herschell Quarry, showing a diverse fauna of bivalves, gastropods, a regular echinoid, and a crab claw.

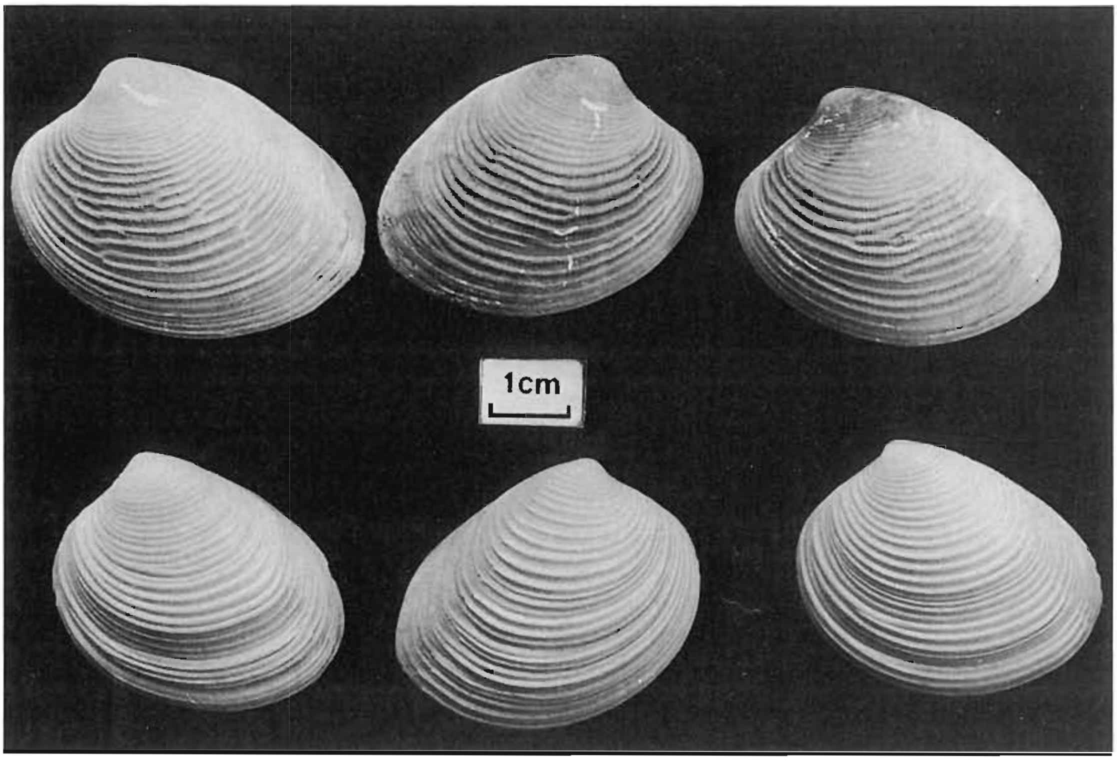

Figure 44: *Katelysia scalarina* (bottom) and *Katelysia rhytiphora* (top). The principal differences between them are that *K. scalarina* has simple ribs, whereas *K. rhytiphora* has anastomosing ribs and faint radial striations. They are also slightly different in shape. *K. rhytiphora* is regarded as an indicator fossil of the Vincent Member.

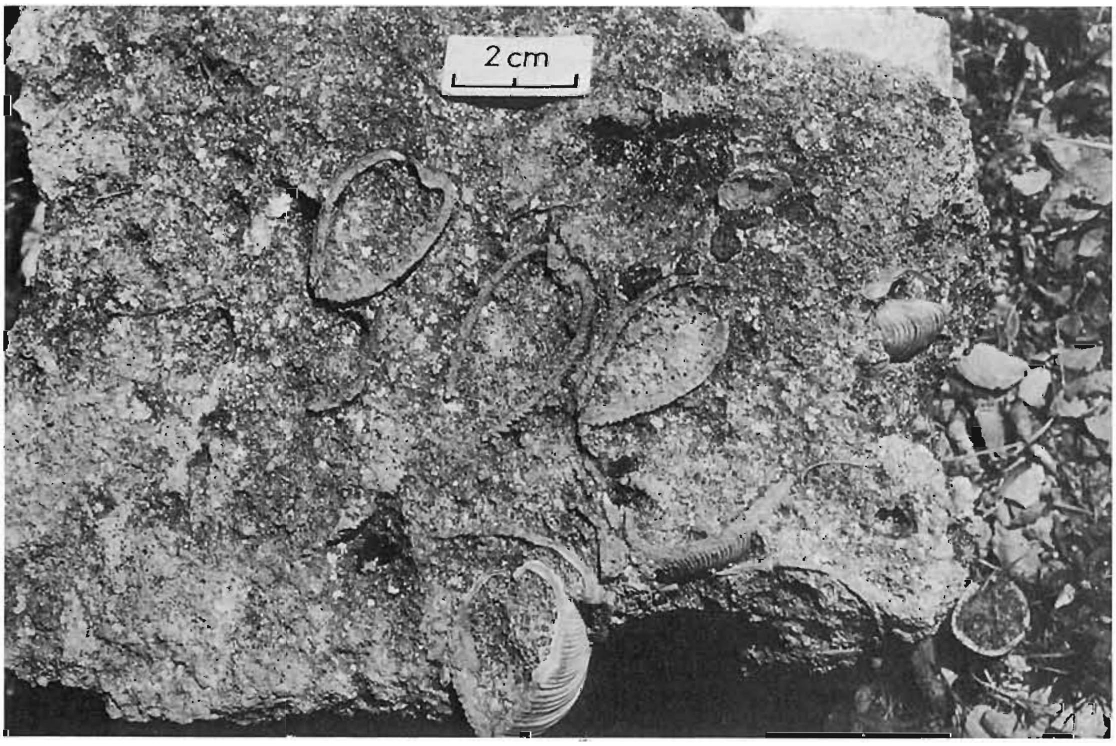

Figure 45: Planed-off indurated surface marking the top of the Vincent Member in the Lake Vincent quarry, truncating paired shells of *Katelysia*. This indicates that the member at this locality was lithified and eroded before the overlying Baghdad Member was deposited.

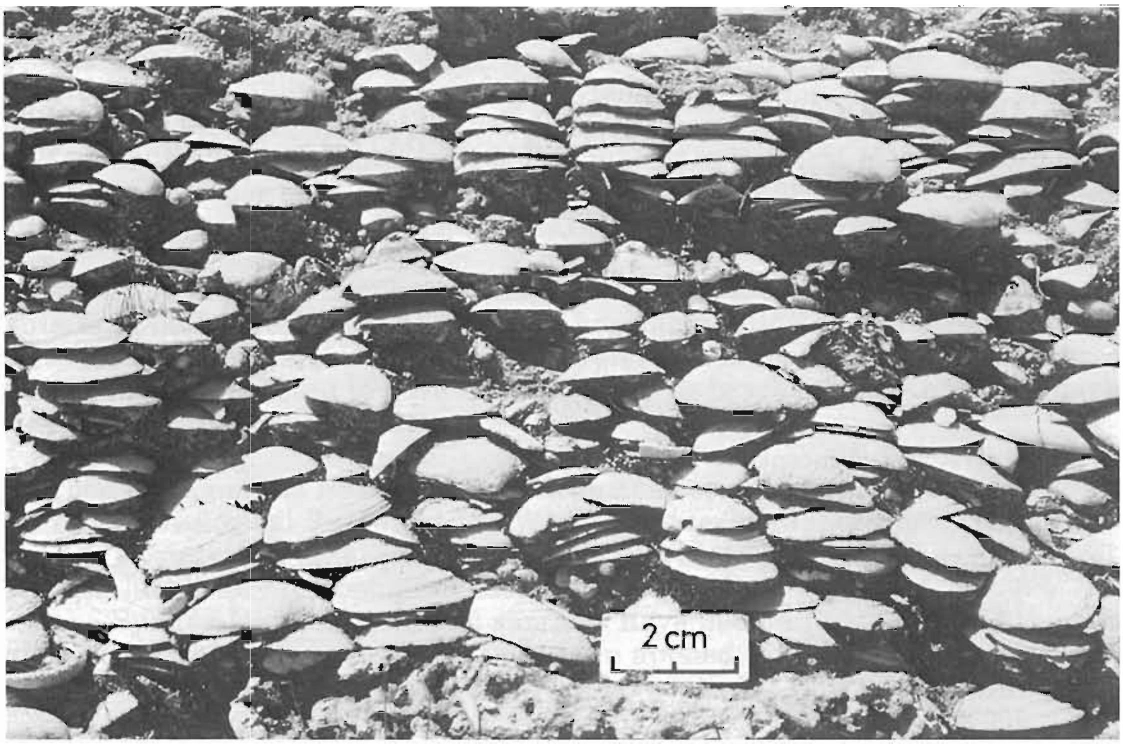

Figure 46: Baghdad Member at its type section in the Mt Herschell quarry showing very abundant single valves of *Katelysia scalarina*, oriented convex upwards (as a result of wave action). The member at this locality is believed to be a beach deposit.

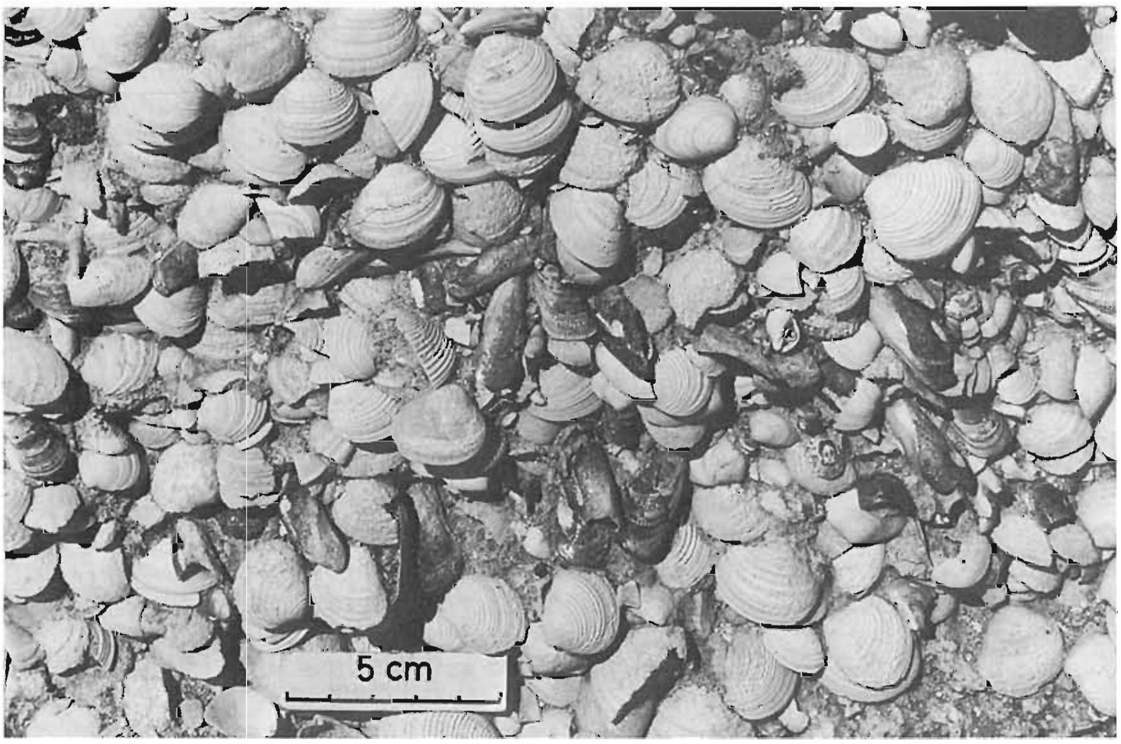

Figure 47: Bedding-plane view of part of the Baghdad Member at its type section in Mt Herschell quarry showing convex-upwards single valves of *Katelysia scalarina*, and sub-parallel valves of the mussel *Brachidontes ustulatus*, oriented in the direction of wave translation, and with their umbonal ends pointed towards the shore.

TABLE 1: ^{14}C DATES, HERSCHELL LIMESTONE AND SERPULID LAYER

LAB. NO.	COLL. NO.	LOCATION	MEMBER & POSITION	FOSSIL DATED	ELEV. (m above AHD)	CORRECTED ^{14}C DATE
WAIT 78	GSWA 79607	Airport Quarry	BAGHDAD 0.5-0.75 m below top	*Katelysia scalarina*	0.65-0.9	2210 ± 180
WAIT 79	GSWA 79606	"	BAGHDAD 0.05-0.3 m below top	"	1.1-1.35	2300 ± 220
WAIT 80	GSWA 79605	L. Vincent Quarry	BAGHDAD 0-0.2 m below top	"	0.46-0.66	2250 ± 210
WAIT 122	GSWA 46680	G. House L.-Serpentine L. Quarry	BAGHDAD	"	?ca. 0.1	2640 ± 310
WAIT 114	GSWA 79695	Mt Herschell Quarry	BAGHDAD 0.55-0.8 m above base	"	1.44-1.69	2770 ± 240
WAIT 84	GSWA 79601	"	BAGHDAD 0.2-0.3 m above base	"	1.09-1.19	3090 ± 330
WAIT 81	GSWA 79604	L. Vincent Quarry	VINCENT 0.15-0.3 m below top	*Katelysia rhytiphora*	0.99-1.14	5050 ± 450
WAIT 83	GSWA 79602	Mt Herschell Quarry	VINCENT 0-0.25 m below top	"	0.64-0.89	4940 ± 280
WAIT 115	GSWA 79694	"	VINCENT 0-0.1 m below top	"	0.79-0.89	5190 ± 280
WAIT 82	GSWA 79603	"	VINCENT 0.45-0.7 m below top	*Tellina perna*	0.19-0.44	5840 ± 230
WAIT 123	GSWA 46681	Army Jetty Quarry	VINCENT	*Paphies cuneata*	ca. 1.0	5790 ± 350
WAIT 113	GSWA 79696	North Shore Pearse Lakes	Encrustation intermediate notch	serpulid tubes	ca. 1.5	5040 ± 290
SUA 1904	WA MUS. C	Mt Herschell Quarry	BAGHDAD 0.2-0.3 m above base	*Katelysia scalarina*	1.09-1.19	2790 ± 90
SUA 1903	WA MUS. B	"	VINCENT 0-0.2 m below top	*Katelysia rhytiphora*	0.69-0.89	4810 ± 100
SUA 1902	WA MUS. A	"	VINCENT 1.0-1.2 below top	*Tellina perna*	- 0.31 to - 0.11	5930 ± 110

None of the species known from the Herschell Limestone are extinct, but G W Kendrick advises that 12 of them are not known living in waters around Rottnest today. Six of these now have northern-tropical affinities, and the other 6 have southern-temperate affinities. The southern-temperate forms include the two most abundant bivalves, *Katelysia scalarina* and *Katelysia rhytiphora*, which are now confined to inlets along the south coast of the State. On Rottnest *K. rhytiphora* occurs in the Vincent Member only, and is regarded as an indicator fossil of that member. The differences between these two species of *Katelysia* are illustrated on Figure 44.

The fauna of the Baghdad Member is less diverse than that of the Vincent Member, and this may be because the lagoons had become shallower when the Baghdad Member was being deposited. The lowest diversity of faunas in this member are in those parts that are believed to have been deposited as beach ridges, the shells having been transported there by wave action.

Radiocarbon dating of the Herschell Limestone has been carried out recently by P M Thorpe of the Geological Survey at the WAIT radiocarbon laboratory. His results, together with previous determinations by M Barbetti of the Sydney University radiocarbon laboratory (on behalf of the WA Museum), are shown on Table 1. The ages of the Sydney University (SUA) samples have been adjusted using the same oceanic-reservoir correction factor that has been applied to the WAIT samples (480 ± 30 years).

The samples reported on by Deevey and others (1959) and Tamers and others (1964), and quoted by Playford (1977), are not accurately positioned within the Mt Herschell quarry. The datings of Tamers and others' samples are approximately consistent with the recent results for the age of the Vincent Member. However, Deevey and others' date of 3 330 ± 120 years for the sample from the "10-foot level" does not match the ages of any other samples from the formation.

The new results indicate that the two members of the Herschell Limestone have distinct groupings of dates: the Vincent Member is 4 800 to 5 900 years old, and the Baghdad Member is 2 200 to 3 100 years old. Thus the dated parts of the two members were deposited over intervals of some 1 100 and 900 years respectively, and the time break between them is about 1 700 years.

Vincent Member

The name Vincent Member is proposed for the lower unit of the Herschell Limestone, which consists of richly fossiliferous coquinite (shell beds) and lesser calcarenite. The type section is in the Mt Herschell quarry, and the name is taken from Lake Vincent. The unit is also well exposed in a small quarry beside the west shore of Lake Vincent, and in scattered exposures around the shores of other lakes.

At its type section in the Mt Herschell quarry the exposed part of the member is 0.55 m thick (Fig. 40), but a previous excavation at this site had exposed a total of 1.2 m. The member consists of pale yellow, weathering grey, weakly cemented coquinite, having a matrix of medium-grained calcarenite composed of well-rounded shell fragments. Bivalve shells in the member commonly occur as closed pairs (Figs 41-43), and single valves show no sign of current orientation. This indicates that the member at this locality was deposited in quiet-water conditions, below effective wave base.

Of the 142 species known to occur in the Vincent Member the most common are the bivalves *Katelysia rhytiphora, Katelysia scalarina, Brachidontes ustulatus, Fragum erugatum, Tellina perna,* and *Circe sulcata*; and the gastropods *Bembicium auratum, Serpulorbis sipho, Batillaria estuarina,* and *Clypeomorus bifasciata* (G W Kendrick, written comm., 1988). As previously mentioned, *Katelysia rhytiphora* is regarded as an indicator of this member.

The top of the Vincent Member in the type section is 0.89 m above AHD, and it seems likely that sea-level when the member was being deposited was about 1.5 m higher, or 2.4 m above AHD (i.e. that it reached the level of the upper shoreline platform, to be discussed later). In the Lake Vincent quarry the member outcrops to 1.29 m above AHD.

As noted previously, radiocarbon dating indicates that the unit was deposited between 4 800 and 5 900 years ago. The youngest date is from the top of the type section, the oldest is from a pit dug below the base of that section.

The upper boundary of the Vincent Member in the type section has been placed at the top of the coquinite, so that the overlying bed of sparsely fossiliferous calcarenite is taken as the basal unit of the Baghdad Member (Figs 40, 41). In the Lake Vincent quarry the top of the Vincent Member is an indurated coquinite which was planed off by erosion, truncating closed shells, before the overlying Baghdad Member was deposited (Fig. 45).

An exposure of sparsely fossiliferous calcarenite, dated as 5790 ± 350 years B.P., and tentatively assigned to the Vincent Member, occurs in a small quarry on the beach of Thomson Bay about 100 m west of the army jetty. I had not known the purpose of this quarrying operation, but it has now been shown that stone from there was used in the facade of Parliament House, Perth. Word-of-mouth advice had indicated that some of the stone for this building had come from Rottnest, but the exact location was not known. The correlation was established by comparing the lithologies in the quarry and the building, and by showing that the same small bivalve, *Paphies cuneata*, occurs in the stone from both (G W Kendrick, written comm., 1985).

Baghdad Member

The name Baghdad Member is proposed for the upper unit of the Herschell Limestone, which consists of weakly lithified coquinite and interbedded calcarenite. The type section is in the Mt Herschell quarry, and the name is taken from the adjoining Lake Baghdad. Other good sections are exposed in the shell quarry 300 m north of the airport terminal, and in a small quarry adjoining the road on the divide between Serpentine and Government House Lakes.

At its type section in the Mt Herschell quarry the member is 0.60 m thick (Fig. 40). It consists of beds of weakly cemented white coquinite with a coarse to very coarse calcarenite matrix, interbedded with white, weathering grey, medium- to very coarse-grained, weakly cemented calcarenite, composed of well-rounded shell fragments.

The fauna of the coquinite is dominated by the bivalve *Katelysia scalarina,* which occurs in most localities almost exclusively as single valves, laid down convex upward (Figs 41, 46, 47). In addition, elongate mussel shells are parallel to one another, approximately at right angles to the original shoreline (Fig. 47). These features indicate that this part of the unit was laid down above wave base, probably as a beach deposit in the upper intertidal zone. Such an origin is consistent with the crude foreset bedding seen in the unit on the north face of the Mt Herschell quarry, and with the morphology of the unit on the west side of Lake Vincent. However, the part of the

Baghdad Member exposed in the quarry between Serpentine and Government House Lakes (at a lower level) has a much more diverse fauna, rivaling that of the Vincent Member, and is believed to have been deposited under subtidal conditions. Bivalves at this locality show no current orientation, and closed pairs are common.

The major elements of the 99 species recorded from the Baghdad Member are the bivalves *Katelysia scalarina, Fragum erugatum, Brachidontes ustulatus,* and *Tellina perna*; and the gastropods *Batillaria estuarina, Bembicium auratum, Patelloida insignis, Notoacmea conoidea, Cominella tasmanica,* and *Nassarius pyrrhus* (G W Kendrick, written comm., 1988).

At the Mt Herschell quarry the top of the exposed unit is about 1.5 m above AHD, and if this part was indeed laid down in the upper intertidal zone, it may have formed when mean sea-level was approximately 1 m higher than today. As previously mentioned, the Baghdad Member is dated as being 2 200 to 3 100 years old. The youngest dates were obtained at the top of the airport quarry, the oldest from the lower part of the type section.

DUNE SAND

Late Holocene and modern dune sand occurs in various parts of the island, the main developments being in the vicinity of Salmon Bay, Porpoise Bay, Paterson Beach, Thomson Bay, Stark Bay, and Narrow Neck. The dunes consist of lime sand composed of fragmentary molluscan material, foraminifers, and small amounts of quartz sand. The dunes are up to 35 m high, and generally form only a thin layer over Tamala Limestone or (in a few areas) Herschell Limestone. The maximum thickness of dune sand is probably about 20 m, at Oliver Hill.

Most dunes are firmly fixed by low scrub, and they are being gradually cemented, from shallow depths below the surface, by percolating rainwater. Consequently there is a transition into the underlying lithified dunes of the Tamala Limestone. Sand blowouts occur in some areas where the vegetation cover has been lost, the most noteworthy example being Barnett Gully, north of Salmon Point, which has recently been successfully stabilized by vegetation.

BEACH SAND

Modern beach sand at Rottnest has essentially the same composition as the dune sand. Most consists of skeletal-fragment lime sand, although quartz sand dominates in a few areas.

SWAMP DEPOSITS

Holocene swamp deposits on the island consist of thin layers of lime sand, marl, peat, and algal sediments. They are described by Hassell and Kneebone (1960), who also examined the palynology of the deposits. They determined that the maximum thickness of swamp deposits ranges from 2.6 m in Salmon and Parakeet Swamps to 4.4 m in Barker Swamp.

Pollen from tuart, jarrah, marri, white gum, sheoak, peppermint, banksia, and zamia palm occur in the deposits at depths of more than a metre below the surface (Hassell and Kneebone, 1960). This shows that tuart woodland typical of the modern mainland coast opposite Rottnest was present on the island in the recent past. A blackboy (*Xanthorrhoea*) stump recovered in 1939 from a well (locality unknown) on Rottnest, at a depth of 5.8 m, was radiocarbon dated as 7 090 $\pm$ 115 years B.P. (Grant-Taylor and Rafter, 1963). This suggests that the tuart-woodland association that is now typical of the mainland coast was still present on Rottnest about 7 000 years ago. It is thought to have disappeared after separation of the island from the mainland, perhaps during the maximum transgression of the Vincent Member, about 5 000 years ago, when the series of smaller islands then occupying the Rottnest area (Fig. 59) were swept by salt-laden winds. It also seems that the climate at that time was significantly drier than at present (Kendrick, 1977b), and this factor may also have contributed to extinction of the tuart woodland.

SALT-LAKE DEPOSITS

Modern salt-lake deposits, consisting of algal, cyanobacterial, and evaporitic sediments, form veneers on the floors of the salt lakes and around their margins, overlying the Herschell and Tamala Limestones.

Hassell and Kneebone (1960) describe algal gyttja in the lake deposits. This consists largely of gel-like material from the green alga *Botryococcus* (Hodgkin, 1959) mixed with gypsum and lime mud. Edward (1983) records benthic microbial mats up to 10 cm thick on the floors of the lakes, constructed by *Botryococcus* and the cyanobacteria *Aphanothecae halophytica, Oscillatoria* sp., and *Spirulina* sp, together with the diatom *Navicula* sp. These mats form living stromatolites in a few areas, notably beside the old bathing groyne on the north side of Government House Lake (Fig. 48).

Stromatolites occur on the shallow shelf immediately east of the groyne at depths (relative to summer water levels) of about 0.2 m to 3 m. Nodular, branching columns and smooth undulous forms occur. Most are only about 5 - 10 cm high, but some are as much as 20 cm high. The stromatolites become progressively sparser in deeper water, and do not extend beyond depths of about 3 m. Some grew on water-logged tree branches and other debris. Bubbles of oxygen can be seen on the living microbial mats, which are greenish to yellow-grey and black in colour.

From the thickness of stromatolites growing on old soft-drink bottles (brands that were current in the 1920s and 1930s when bathing in the hypersaline water was still fashionable) it is deduced that the stromatolites grow at rates of as much as 1.5 mm per year.

Dead and eroded domal stromatolites up to 0.5 m across are exposed along the shoreline at the west end of Serpentine Lake (Fig. 49). Their growth at this locality may have been linked to seepages of fresh water, from the Oliver Hill groundwater mound, that also occur there. These stromatolites may have grown at some time in the past when the lake level was a little higher than it is today.

SEA-LEVEL CHANGES

The most striking feature of the geology of Rottnest Island is the evidence displayed there of Quaternary sea-level changes (Teichert, 1950; Churchill, 1959; Fairbridge, 1958, 1961; Hassell and Kneebone, 1960; Playford, 1977, 1983). This evidence is in the form of elevated marine deposits, elevated shoreline platforms and notches, and subaerially formed features that now extend below sea-level.

As discussed earlier, the modern shoreline platforms average about 0.41 m below mean sea-level. Elevated shoreline platforms and associated notches have been related to this level in order to estimate the approximate relative changes in sea-level that have occurred. It is important to note that these apparent changes in sea-level are *relative* to the land, and could be due to either sea-level rising or the land subsiding, or vice versa as the case may be.

Figure 48: Undulous stromatolites in benthic microbial mats on the floor of Government House Lake, east of the old bathing groyne, in water less than one metre deep.

Figure 49: Domal stromatolites, now dead and eroded, rimming the western end of Serpentine Lake.

ELEVATED MARINE DEPOSITS

Fossil Coral Reef

The fossil coral reef represented by the Rottnest Limestone extends to 3.02 m above the adjoining shoreline platform. Consequently it is deduced that sea-level relative to Rottnest during the last interglacial was at least that amount higher than it is today. However, this is a minimum figure, because the top of the outcropping coral reef could have grown in water several metres deep.

As noted previously, the Rottnest Limestone reef was built mainly by *Acropora*, which does not form living reefs today further south than the Houtman Abrolhos, 350 km to the north. Its reef-building role in the Rottnest Limestone probably indicates warmer-water conditions in this area during the last interglacial period. This is consistent with global evidence of a higher sea-level at that time (Fig. 58), presumably as a consequence of greater melting of the polar ice caps than is the case today.

Herschell Limestone

Marine shell beds of the Vincent Member of the Herschell Limestone (about 4 800 to 5 900 years old) extend in the Mt Herschell quarry to 0.89 m above AHD, and in the Lake Vincent quarry to 1.29 m above AHD. As previously mentioned, it seems likely that the unit was laid down when sea-level relative to the island was at the level of the upper shoreline platform, about 2.4 m above AHD.

The Baghdad Member (about 2 200 to 3 100 years old) extends to 1.5 m above AHD, and it appears that the upper part of the unit was laid down as beach deposits, when sea-level relative to the island was about 1 m higher than it is today.

ELEVATED PLATFORMS AND NOTCHES

The elevated shoreline platforms and notches on Rottnest have been described by Teichert (1950) and Playford (1977, 1983). Three levels are recognized: an upper level at about 2.4 m, an intermediate level at about 1.1 m, and a lower level at about 0.5 m above the modern shoreline platforms (Fig. 50). The estimated elevations of these three levels have been changed from those given by Playford (1977 and 1983) as a result of additional survey levelling of both the modern shoreline platforms and the elevated shoreline features.

As pointed out previously, the elevations of modern platforms around the island are known to range from -0.18 to -0.56 m, and their mean elevation of -0.41 ± 0.11 m has been taken as datum. For the Holocene upper-level platform the surveyed elevations at seven localities around the salt lakes range from +1.65 m to +2.07 m, and their mean is $+1.96 \pm 0.23$ m. From these figures a relative sea-level change of 2.37 ± 0.34 m can be deduced. Thus, in round figures, the upper-level platform is thought to have developed when relative sea-level was approximately 2.4 m higher than at present.

The upper level is represented by remnants of emerged shoreline platforms (and weakly developed notches), about 2.4 m above the modern platforms, that are best preserved around the salt lakes (Figs 51-53). These upper-level platforms probably formed 4 800 to 5 900 years ago when the Vincent Member of the Herschell Limestone was being deposited.

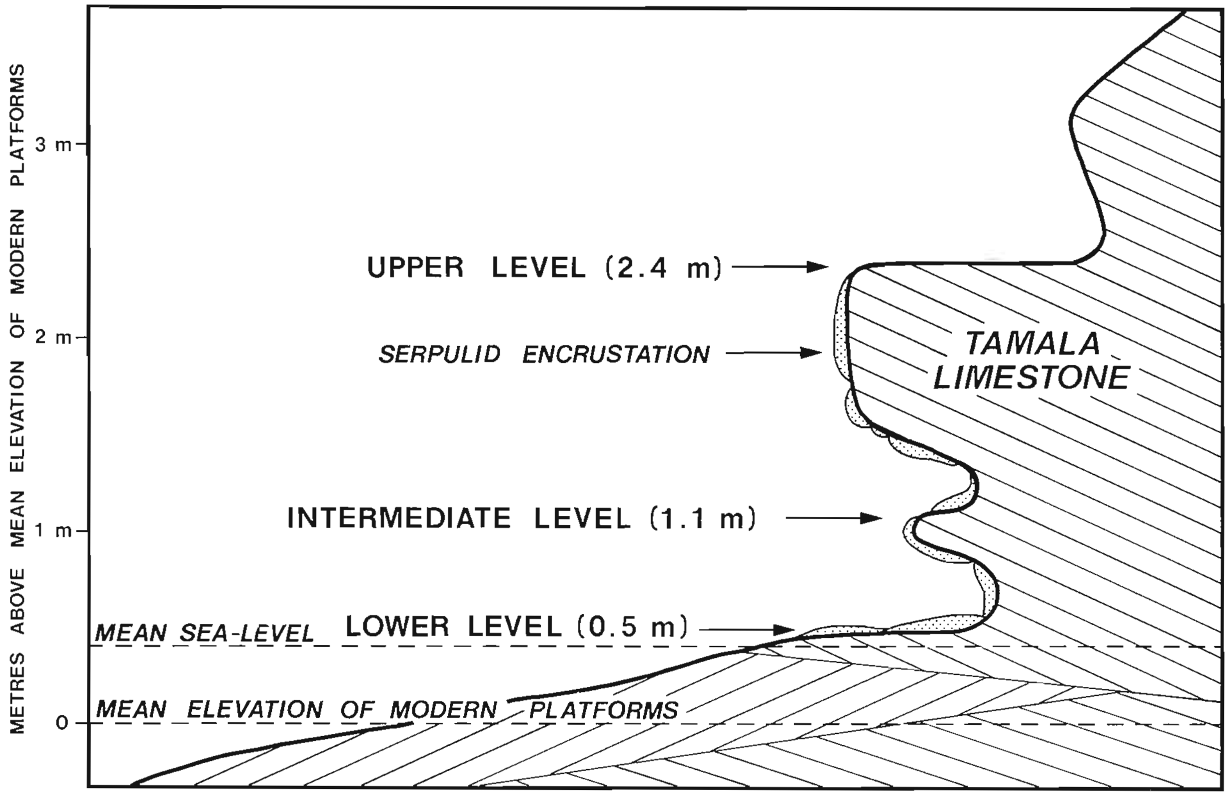

Figure 50: Diagrammatic cross-section illustrating elevated shoreline platforms and notches in Tamala Limestone around the margins of the salt lakes.

Figure 51: View at the eastern end of the causeway, between Government House and Herschell Lakes, showing the upper-level (2.4 m) platform, and the intermediate- and lower-level (1.1 m and 0.5 m) notches. The platform and notches are cut in Tamala Limestone showing prominent foreset bedding.

Figure 52: Closer view at the same locality as Figure 51 showing the upper-level platform and intermediate- and lower-level notches.

Figure 53: The northwest side of Serpentine Lake, showing well-preserved lower- and intermediate-level notches, and eroded lower- and upper-level platforms. Note that the lower-level notch is deeper than the intermediate-level notch.

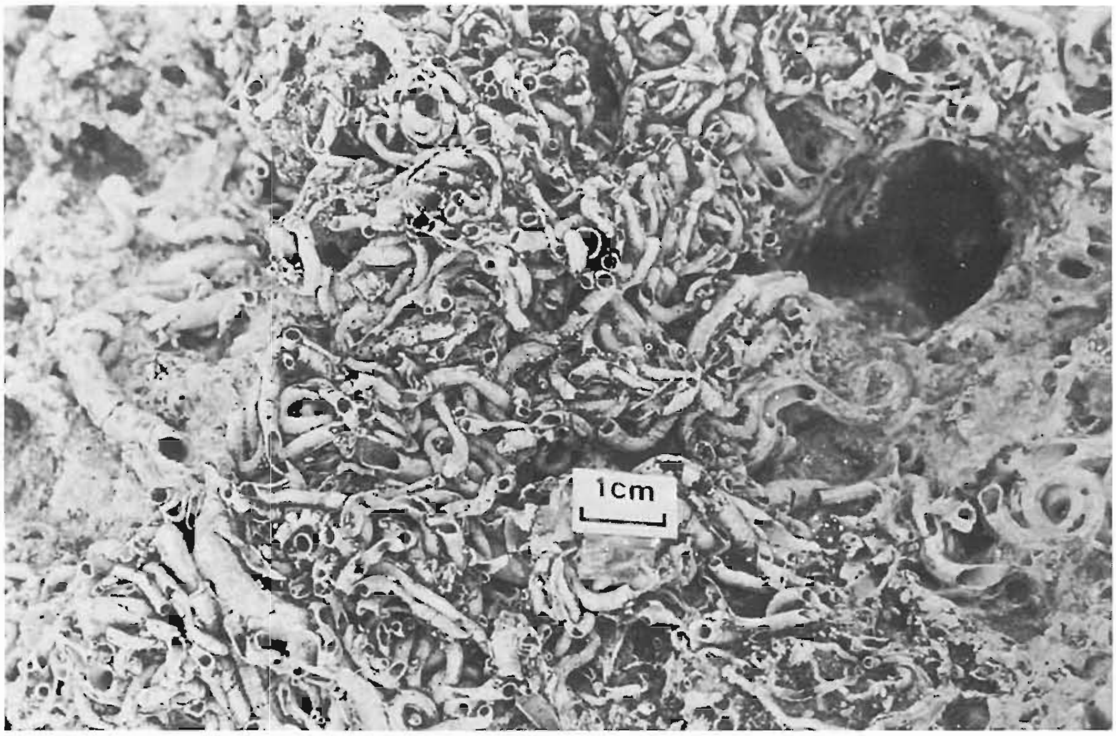

Figure 54: Serpulid worm tubes encrusted below the visor at the top of the intermediate-level notch on the north shore of Pearse Lakes. The serpulid encrustation at this locality has been radiocarbon dated as 5 040 ± 290 years B.P.

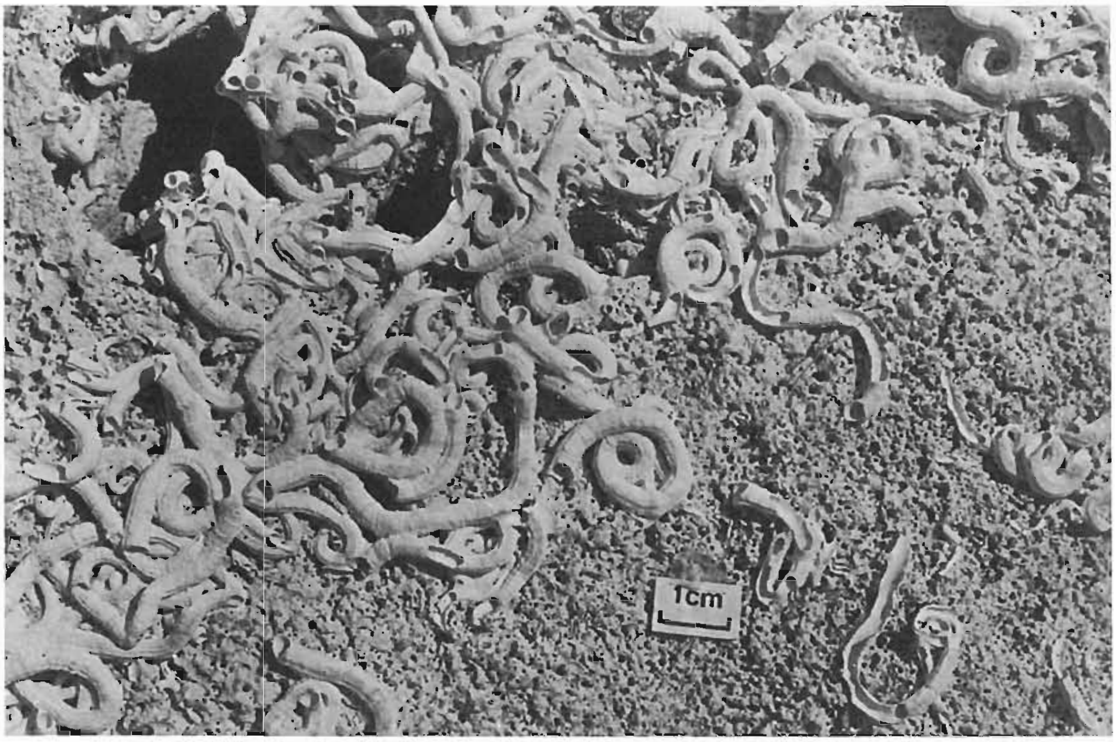

Figure 55: Serpulid worm tubes encrusted on limestone that had been strongly bored by clionid sponges. This is part of a bulldozed block of Tamala Limestone 100 m south of the Mt Herschell quarry.

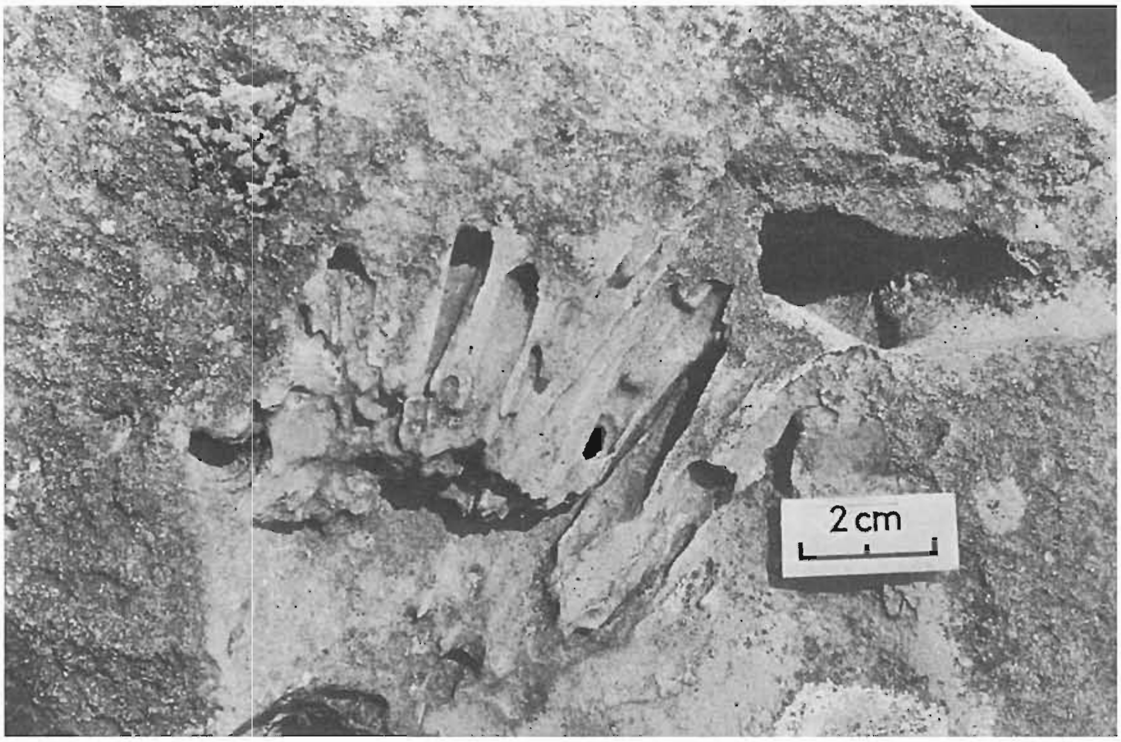

Figure 56: Borings made by the bivalve *Lithophaga* in Tamala Limestone about 20 cm below the upper-level platform, 100 m south of the Mt Herschell quarry.

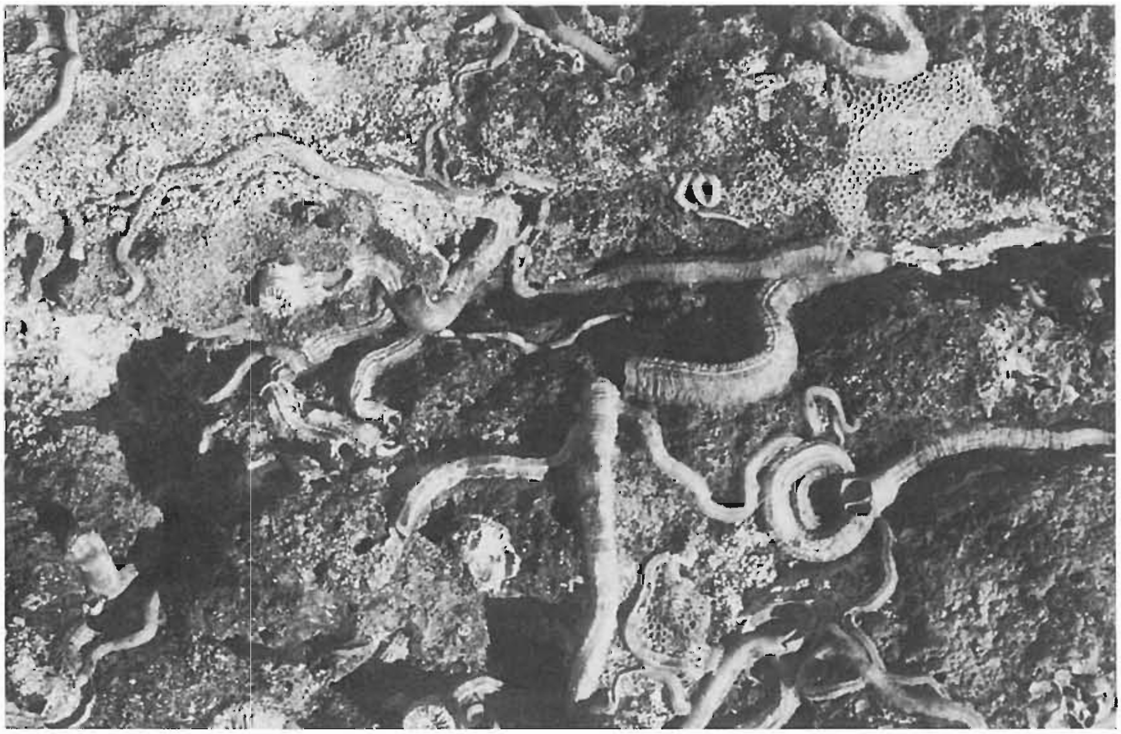

Figure 57: Encrustation of serpulids, bryozoans (cf. *Membranipora perfragilis*), and tiny corals (*Culicea tenella*) in a crevice exposed by bulldozing on the north shore of Herschell Lake, south of the Mt Herschell quarry. The encrustation is a little below the upper-level platform.

The intermediate- and lower-level notches and platforms are preserved around the salt lakes in the form of conspicuous "double notches" with associated weakly developed narrow platforms (Figs 51-53). These notches and the upper-level platform are not recognizable with any confidence around the coast of the island, as there they were subject to modern shoreline erosion and consequently have probably been entirely, or almost entirely, removed. The storm benches that occur at many places around the coast are easily mistaken for elevated shoreline platforms (Figs 9, 10, 13, 14).

At many localities around the salt lakes a layer of entwined serpulid worm tubes up to 50 mm thick is discontinuously preserved, encrusting the two lower notches and platforms, and extending up to the upper level platform (Fig. 54). The serpulids have not been identified, as serpulid taxonomy is based on soft parts of the organisms. However, there appear to be several genera represented (P Hutchins, pers. comm., 1988). The limestone on which the serpulids grew is commonly intensely bored by clionid sponges and bivalves (probably mainly *Lithophaga*) (Figs 55, 56). Some pockets of bivalves and gastropods are associated with the serpulid layer, and there are also some encrustations of small solitary corals and bryozoans (*Culicia tenella* and cf. *Membranipora perfragilis,* L M Marsh, pers. comm., 1988) (Fig. 57). These organisms grew in a fully submerged environment, and the serpulids seem to have once formed an essentially continuous crust over the surface below the upper-level platform. It is therefore deduced that the serpulids grew when the sea was at the upper (2.4 m) level and the Vincent Member of the Herschell Limestone was being deposited. It is also clear that the lower- and intermediate-level notches and platforms were already in existence when the serpulid layer was formed.

A sample for radiocarbon dating was taken of the serpulid layer encrusting the upper part of the intermediate-level notch on the north side of Pearse Lakes. The serpulid tubes in this sample were particularly well preserved, lacking post-depositional cementation or matrix, and were analysed after a reduction of 64% in weight by acid solution. They were found to be 5 040 $\pm$ 290 years old (Table 1), which ties in well with the age of the Vincent Member and the deduced age of the upper-level platform.

Playford (1977, 1983) deduced that the regression from the upper (2.4 m) level must have been abrupt; otherwise the relatively fragile serpulid layer would be expected to have been removed by marine erosion if the sea fell (or the land rose) gradually. Although this deduction still seems valid, there is a problem with respect to the renewed rise of sea-level represented by the Baghdad Member, which is thought to have reached about 1 m above present sea-level. It is tempting to correlate this rise with the intermediate-level (1.1 m) notch, but such a correlation is negated by the evidence of the serpulid layer encrusted on the intermediate-level notch, which has been dated as being about 5 000 years old. However, it is suprising that this fragile serpulid crust was not eroded away to a greater extent when the sea rose to near this level about 3 100 to 2 200 years ago.

SUBAERIAL FEATURES EXTENDING BELOW SEA-LEVEL

Lithified sand dunes of the Tamala Limestone extend below sea-level at many localities around the coast of Rottnest Island, and probably reach depths of 70 m or more. Most of the formation is believed to have accumulated during the last glacial period of the Pleistocene and the following Flandrian transgression, when relative sea-level was considerably lower than it is today (Fig. 58).

Solution pipes, thought to have been localized by major tree roots, extend below sea-level at several localities around the coast, such as Fairbridge Bluff. They must have formed when sea-level relative to the land was lower than at present.

As discussed previously, the salt lakes may overlie major dolines formed by solution during the periods of greatly lowered sea-level (as much as -130 m) associated with the Pleistocene glaciations. Some semi-circular bays on Rottnest, such as Eagle Bay, Mabel Cove, and Geordie Bay, may be influenced by similar dolines.

The modern shoreline platforms around Rottnest are commonly undercut (Fig. 9), and Fairbridge (1961) ascribed this to a period of eustatic lowered sea-level, about 2 m below present sea-level, during the past few hundred years. However, these undercuts are commonly much deeper than modern shoreline notches, and it seems more likely that they are products of contemporary submarine erosion (mechanical and biological) of the softer limestone below the strongly cemented platforms.

Carrigy and Fairbridge (1954) have also described a series of terraces on the continental shelf in the Perth Basin that they considered to represent successive periods of still-stand during Quaternary eustatic sea-level changes.

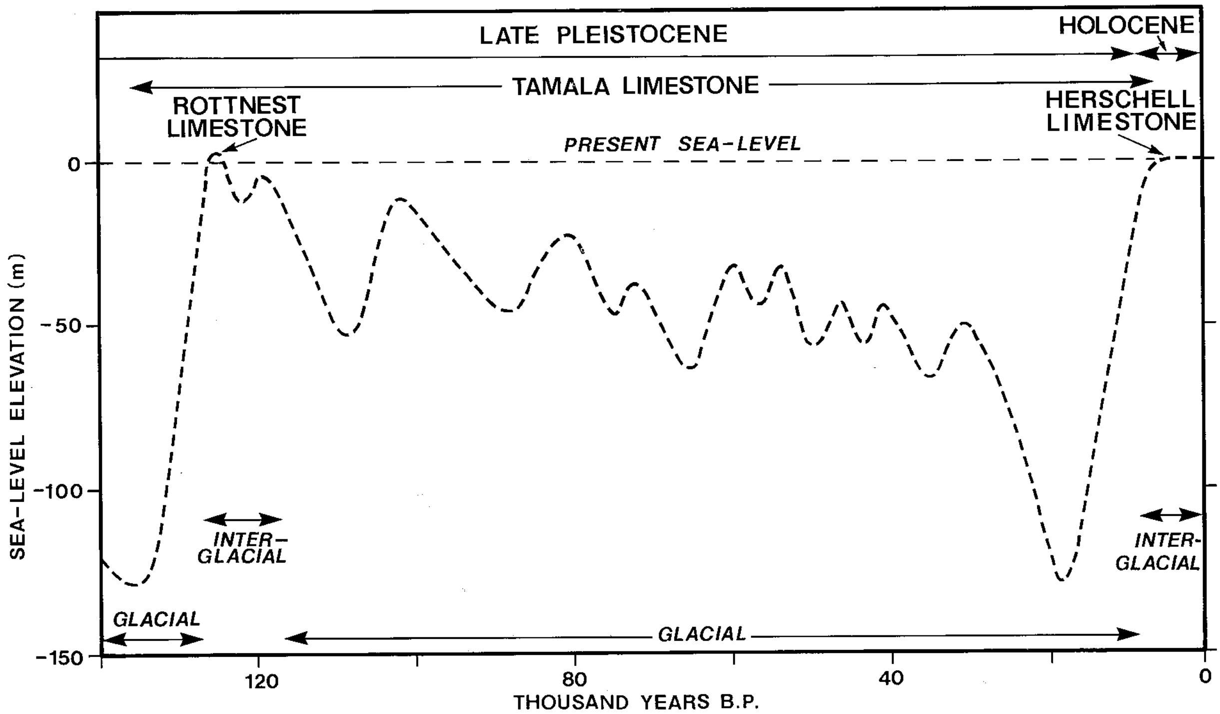

Figure 58: Eustatic sea-level curve for the past 140 000 years, modified from Chappell and Shackleton (1986), shown in relationship to deposition of the Rottnest, Tamala, and Herschell Limestones.

ORIGIN OF SEA-LEVEL CHANGES

The major changes of sea-level affecting the Swan Coastal Plain and adjoining continental shelf during the Pleistocene clearly resulted from eustatism associated with waxing and waning of the continental ice sheets. The Holocene "high sea-levels" recognized at Rottnest were similarly ascribed to world-wide eustatic changes by Teichert (1950) and Fairbridge (1961). However, Playford (1977, 1983) cast doubt on their supposed eustatic origin, as they have no generally accepted correlatives elsewhere in Australia (Thom and Chappell, 1975) or the world (Mörner, 1976). Playford suggested the alternative possibility of a local tectonic origin for these Holocene relative changes in sea-level.

However, it still remains to be proved whether these changes were of local or regional extent in the Western Australian context. If they were regional (e.g. over the whole of the south west of Western Australia), did they result from epeirogenic movements, regional changes in the shape of the geoid, changes in water circulation and temperature in the Indian Ocean, or some other cause? If the relative sea-level changes were of local extent, did they result from fault movements on or adjoining the continental shelf, possibly triggered by rapid loading of water during the Flandrian transgression; alternatively, were they associated with movements along the Darling Fault or some other fault in the area?

Confident answers to these questions must await further precise work to correlate the sea-level stands demonstrated by the emerged platforms and notches at Rottnest with evidence from other localities in Western Australia and elsewhere. Some recent research and observations relevant to these questions are summarized below.

Cope (1975) pointed to uplift of the Yilgarn Block east of the Perth Basin, amounting to some 300 m since the Eocene, which may be continuing today. Playford and others (1976) cited warping of late Tertiary to early Quaternary shorelines on the Swan Coastal Plain as evidence of Quaternary earth movements in the area. There has been important tectonic activity in historic times along the South West Seismic Zone, within the Yilgarn Block, manifested especially by the Meckering earthquake (magnitude 6.9) in 1968 and the Cadoux earthquake (magnitude 6.2) in 1979 (Gordon and Lewis, 1980; Lewis and others, 1981).

Seismic surveys on the continental shelf around Rottnest have shown the presence of a number of important faults cutting the Lower Cretaceous and older rocks, some of which could have moved during the Quaternary (Fig. 61), and which are believed to have acted as hydrologic barriers to movement of artesian water in this area (Playford, 1977).

Semeniuk and Searle (1986), using stratigraphic sea-level indicators, found evidence of Holocene sea-level changes along three transects across the south west coast, north and south of Perth. The sea-levels deduced along each of these transects differs from those along the others, and Semeniuk and Searle believe that this indicates that differential earth movements must have occurred in this area in Holocene times.

Searle and Woods (1986) reported similar stratigraphic evidence to suggest that about 6 400 years ago sea-level on the Swan Coastal Plain near Rockingham was at least 2.5 m higher than today, and that it fell steadily since then to reach its present level some 1 000 years ago. On the other hand, Kendrick (1977), based on evidence in the Swan River valley, concluded that relative sea-level in this area did not reach more than 0.5 m above AHD during the mid Holocene (6 700 to 4 500 B.P.), which also coincided with a period of local aridity. Neither of these two apparently conflicting views can be correlated with the Holocene sea-levels evidenced at Rottnest.

Lambeck (1987) suggested that the progression of shorelines seen on the Swan Coastal Plain points to upward warping of the basin. He concluded that the elevated Holocene shorelines at Rottnest appear too high to be explained by rebound of the crust after glacial unloading and water loading, and that tectonic uplift is the most likely explanation.

Thus it can be concluded that there is increasing acceptance of the hypothesis that tectonism was involved in the Holocene changes in relative sea-level that are evidenced at Rottnest. However, this tectonic hypothesis has still to be adequately proved; there is a need for further studies on the Swan Coastal Plain and adjoining areas (such as the Houtman Abrolhos Islands), in order to clarify the Holocene geological history of south-western Australia. This research should involve careful field study, dating, and surveying of all Holocene and Pleistocene marine horizons, elevated platforms and notches, and stratigraphic sea-level indicators, together with research on the geomorphological evolution of the area. Such detailed studies could point to faults that have moved in Holocene times, and may thus have important human consequences, in outlining high-risk areas for possible future earthquake activity.

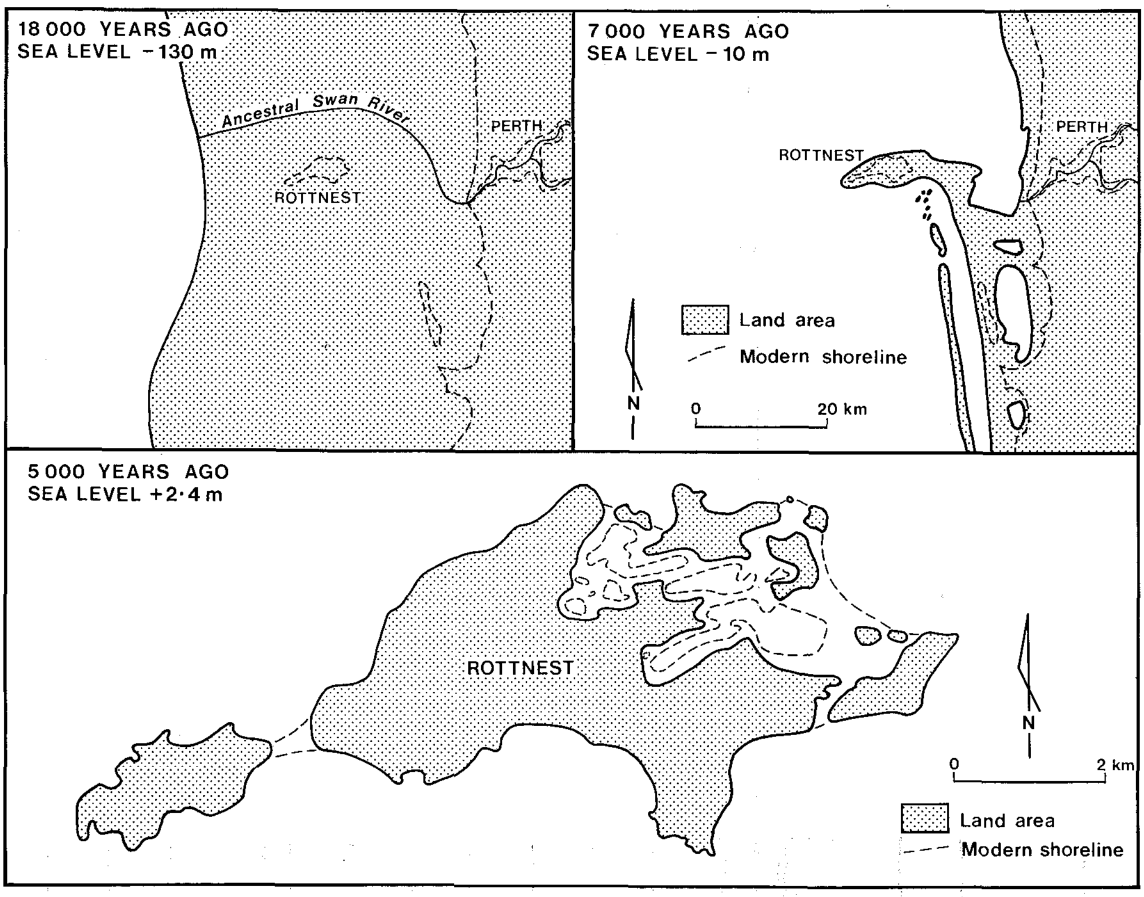

Figure 59: Palaeogeographic maps showing the changing shorelines of the Perth and Rottnest areas, from about 18 000 years ago, when the sea-level was at its lowest, to 5 000 years ago, when it was at its highest.

QUATERNARY GEOLOGICAL HISTORY

The foundation of Rottnest Island may have been a late Tertiary or early Pleistocene sand shoal, perhaps associated with an uplifted area in underlying Tertiary rocks. Calcareous coastal dunes accumulated on this high area during the Pleistocene to form the Tamala Limestone. The earliest dune limestones exposed on the island may date from the penultimate glacial period, about 140 000 years ago, but older Pleistocene dune deposits probably occur in the subsurface.

The dune ridge in turn localized a coral-reef platform when sea-level rose to its highest level during the last interglacial, about 120 000 to 130 000 years ago. Sea-level fell during the ensuing glacial period, reaching its lowest level some 18 000 years ago (Fig. 58). The coastline was then about 12 km west of Rottnest (Fig. 59), and the old dune and reef limestones stood as a conspicuous "mountain", high above the surrounding coastal plain. The ancestral Swan River flowed out to sea north of Rottnest, where it joined a submarine canyon (the Perth Canyon) incised into the continental slope. Strong karst solution by rainwater proceeded in the limestones, with the formation of large cave-collapse dolines that were afterwards to localize the modern salt lakes.

Sea-level rose rapidly during the Holocene Flandrian transgression (Fig. 58). Dune sands of the younger Tamala Limestone accumulated on the Rottnest platform as part of a belt extending through the present Carnac, Garden, and Penguin Islands. As the sea rose towards its present level, Rottnest remained in connection with the mainland along this belt of dunes (Fig. 59), until separation finally occurred about 6 500 years ago. Major changes in the land flora and fauna followed this separation; only a few of the original plants and animals survived. The sole marsupial to remain was the quokka, and all eucalypts disappeared.

There were two brief periods of sea-level still-stand, totalling no more than a few hundred years, when notches and narrow shoreline platforms were eroded at about 0.5 m and 1.1 m above present sea-level, before the peak transgression was reached at 2.4 m (Fig. 60).

The maximum submergence of Rottnest, to about 2.4 m above present sea-level, occurred from about 5 900 to 4 800 years ago. At that time the area of the present salt lakes formed lagoonal arms of the sea between more than 10 separate islands (Fig. 59). Prolific molluscan faunas lived in the warm shallow waters between these islands, and their close-packed shells now form the Vincent Member of the Herschell Limestone. There was abrupt uplift of the island, or sea-level fell, about 4 800 years ago, when the sea probably reached about its present level relative to the island. A subsequent relative rise, to about 1 m above present sea-level, occurred some 3 100 to 2 200 years ago, before the sea regressed again close to its present level. Note on Figure 60 the differences between this interpretation and the eustatic sea-level curves of Fairbridge (1961) and Mörner (1976).

The area of the modern salt lakes may have remained in connection with the sea for some time after the present relative sea-level was reached, before being cut off by the accumulation of beach ridges and sand dunes. Superficial deposits continued to accumulate after that time, but there have probably been no major changes in the configuration of the island over the past several hundred years.

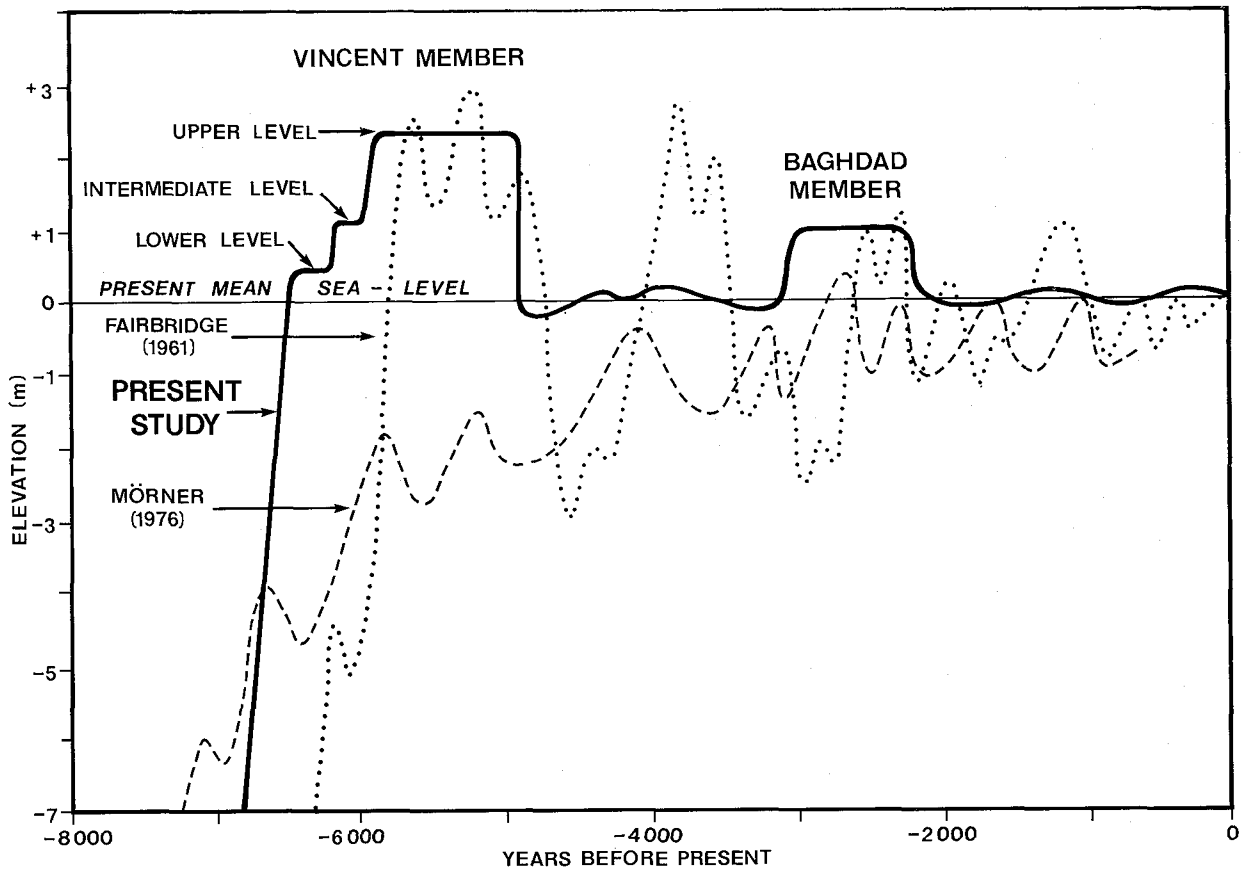

Figure 60: Relative sea-level curve for the Rottnest area over the past 8 000 years, compared with the eustatic curves of Fairbridge (1961) and Mörner (1976).

HYDROGEOLOGY

INTRODUCTION

During the first 70 years of settlement on Rottnest, while it was in use as an Aboriginal penal settlement, the relatively small supplies of water required were obtained from roof catchments and shallow wells at the settlement. However, after a decision was made in 1903 to close the prison and develop the island as a holiday resort, it was realized that larger water supplies would be needed, and that these might be available from artesian sources. At that time there were a number of deep bores on the mainland yielding large flows of potable or brackish water (Fig. 61), and it was hoped that similar water could be obtained below Rottnest.

As a result, a deep bore (the Rottnest Bore) was drilled by the Mines Department near the cemetery in 1911-1913 to a depth of 788 m, but unfortunately it yielded only small flows of salt water and was therefore abandoned (Fig. 62). No other deep bores have since been drilled on the island.

Up to the time of World War II the main source of water on Rottnest for the Thomson Bay settlement continued to be roof catchments, supplemented by shallow wells yielding brackish water, the salinities of which increased steadily during the summer months. Rationing of drinking water was necessary in summer, and there was also some blending of rainwater with well water to extend supplies, although this caused health problems, presumably because of the contamination of groundwater by *Salmonella* bacteria.

In 1939 it was decided by the Australian Army establishment to increase fresh-water supplies for use in Kingstown Barracks and the Thomson Bay settlement by bituminizing an area beside Mt Herschell to provide runoff of rainwater into storage tanks. The Army also installed a supplementary water system supplied by several wells on low ground near Government House and Serpentine Lakes, and another in Hells Gully. A series of old tanks used as part of the storage for this system can still be seen south of Kingstown Barracks. However, it was found that most of the wells became saline with prolonged pumping, especially during the war, when up to 2 500 army and air-force personnel were stationed on the island. After the war the Army catchment area near Mt Herschell was extended by the Rottnest Island Board to cover an area of 7.3 ha, with a storage of 29 550 m^3. The second-class water system for sanitary and ablution purposes was supplied by several brackish to saline wells in the settlement area, and this system is still in use today, although the supplies have become progressively more saline.

By 1961 rainwater supplies from the Mt Herschell catchment had become inadequate for the expanding needs of the Thomson Bay settlement, and in most years between 1961 and 1975 it was necessary to import water by barge from the mainland, at considerable cost. A water-distillation plant was also used to supplement supplies over the period 1963-1966, at rates of up to 1.6 m^3 per hour, but this equipment proved to be unreliable and costly to operate, and its use was therefore discontinued.

The problem of water supplies came to a head when it was announced in 1976 that the construction of a new settlement would begin at Geordie and Longreach Bays. As this would result in major expansion of water consumption on the island, the Geological Survey was requested to re-evaluate the groundwater prospects, and especially to consider a proposal to drill a further deep bore seeking artesian supplies (Playford, 1976).

ARTESIAN WATER

Two main artesian aquifers have been developed on the Swan Coastal Plain: the Early Cretaceous Leederville Formation and the Middle Jurassic to Early Cretaceous Yarragadee Formation. Another aquifer, the Gage Sandstone Member, is present at the base of the South Perth Shale in a number of offshore wells, and some thin sandstone aquifers are also known within this formation. Large volumes of fresh to brackish artesian water are obtained from the Leederville and Yarragadee Formations in the Perth Metropolitan Area and on Garden Island (Fig. 61), whereas in the old Rottnest Bore only a small flow of salt water "equal to sea water" was obtained from the Leederville Formation (Fig. 62).

The probable reason for this difference in the hydrology of the Leederville Formation in the Rottnest Bore compared with that in bores on the mainland is now apparent: a hydrologic barrier is present to the east of Rottnest, in the form of faults cutting the Lower Cretaceous and Jurassic aquifers (Fig. 61). As a result, the Leederville Formation below Rottnest is not in free hydraulic connection with the formation in the Perth area and on Garden Island, so that connate water has not been flushed from the formation below Rottnest, and the hydraulic head is low.

Calculations based on wireline logs from offshore wells drilled for oil near Rottnest show that salinities are high in all the Cretaceous and Jurassic aquifers (Playford, 1977). The only offshore well having low salinities is Cockburn 1, which is situated in Cockburn Sound, east of the zone of faulting. The salinity determinations in offshore wells show that any artesian water below Rottnest is most unlikely to have salinities less than 7 500 mg/L, and would probably exceed 10 000 mg/L. It was therefore concluded that the drilling of another deep bore to test the artesian-water prospects below Rottnest was not warranted (Playford, 1976).

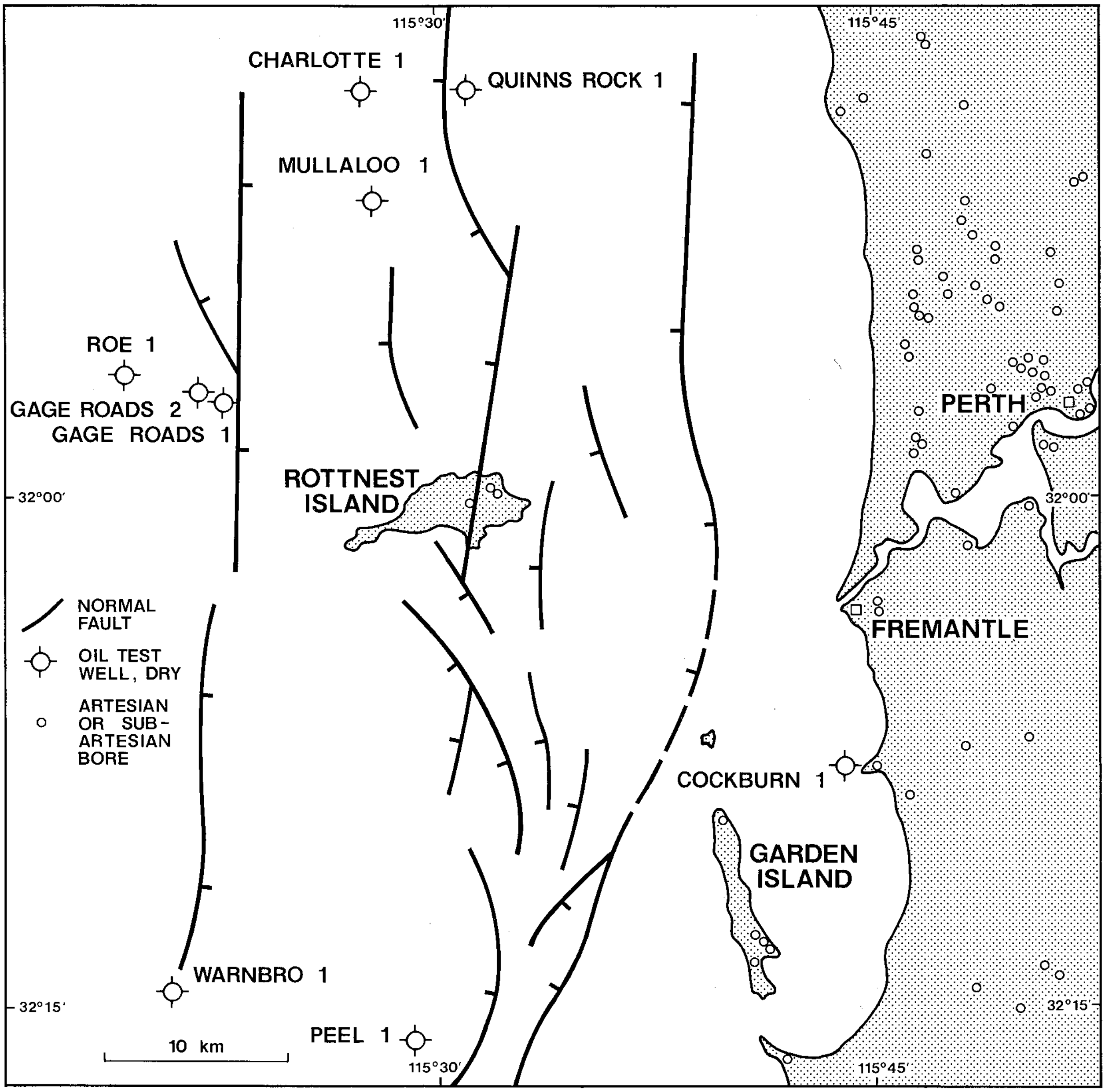

Figure 61: Map of the Perth-Rottnest area, showing faults that cut the Lower Cretaceous and older rocks (as deduced by seismic surveys), and the locations of oil-exploration and artesian bores.

SHALLOW GROUNDWATER

Prior to 1976 there had been a long-standing belief that significant quantities of potable shallow groundwater could not be found at Rottnest, and this was the reason for previous decisions to extend bituminized catchments, install a water-distillation plant, and import water by barge from the mainland. Although some wells dug on the island at first produced small volumes of fresh water, they soon turned salty with continuing production. Most of these wells were situated in low-lying areas, close to the sea or salt lakes. In such areas a very thin layer of fresh water is commonly present, overlying salt water. With prolonged or rapid pumping, a cone of salt water rises and the wells become salty.

Almost all of the wells around the Thomson Bay Settlement are consequently very saline, as they have been over-pumped for many years, but they are still being used to supply second-class water (Playford, 1977). On hydrogeological grounds these wells are situated in one of the worst parts of the island for underground water. The elevation is low, the intake area is small, the area is close to both the sea and the salt lakes, and there are groves of large trees, which must transpire much of the available fresh water.

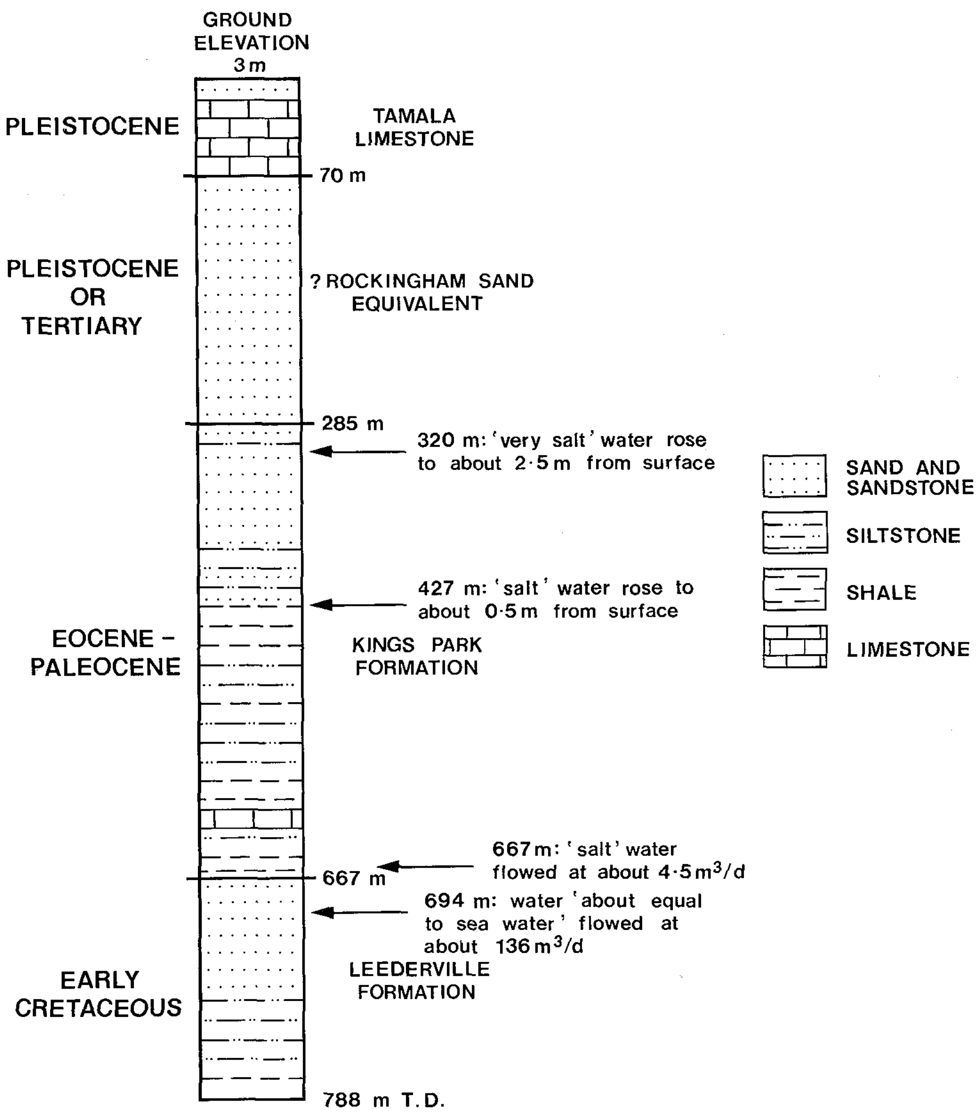

Figure 62: Section penetrated and water encountered in the Rottnest Bore.

Shallow groundwater on an island typically occurs as a fresh-water lens "floating" on salt water, with a mixing zone of brackish water between. This lens will be thickest where the island is widest and highest, and on this basis it was suggested by Playford (1976) that the areas west of Wadjemup Hill and south of Serpentine and Government House Lakes should have the best groundwater prospects. These areas had not previously been tested, and consequently it was recommended that a program of shallow auger drilling should be undertaken there.

This drilling was carried out by the Public Works Department, and it showed that the prediction was correct; two lenses of fresh (less than 1 000 mg/L) to brackish (1 000 to 2 000 mg/L) water, "floating" on salt water, were defined in the two areas (Fig. 63). The principal area, west of Wadjemup Hill, was found to contain sufficient reserves of fresh water, in a lens up to 10 m thick, to be developed for use in the settlements. The necessary bores and a pipeline were completed within a few months. Production began in October 1976, and has continued without major problems since then. The discovery attracted considerable media attention because of the long-standing public interest in Rottnest's water-supply problems (Fig. 64).

The hydrology of the groundwater lens being exploited at Rottnest is described by Leech (1977). Production is obtained from weakly lithified limestone and lime sand of the Tamala Limestone over an area where the lens is at least 5 m thick. The transition from fresh to salt water extends over a depth of 15 to 20 m, and it is interesting from a geological viewpoint that no mixing-zone dolomite has been detected over this interval. The salinity of the water produced has averaged less than 700 mg/L, and has not risen significantly in recent years. The bore water is mixed with catchment water to reduce the salinity for consumers.

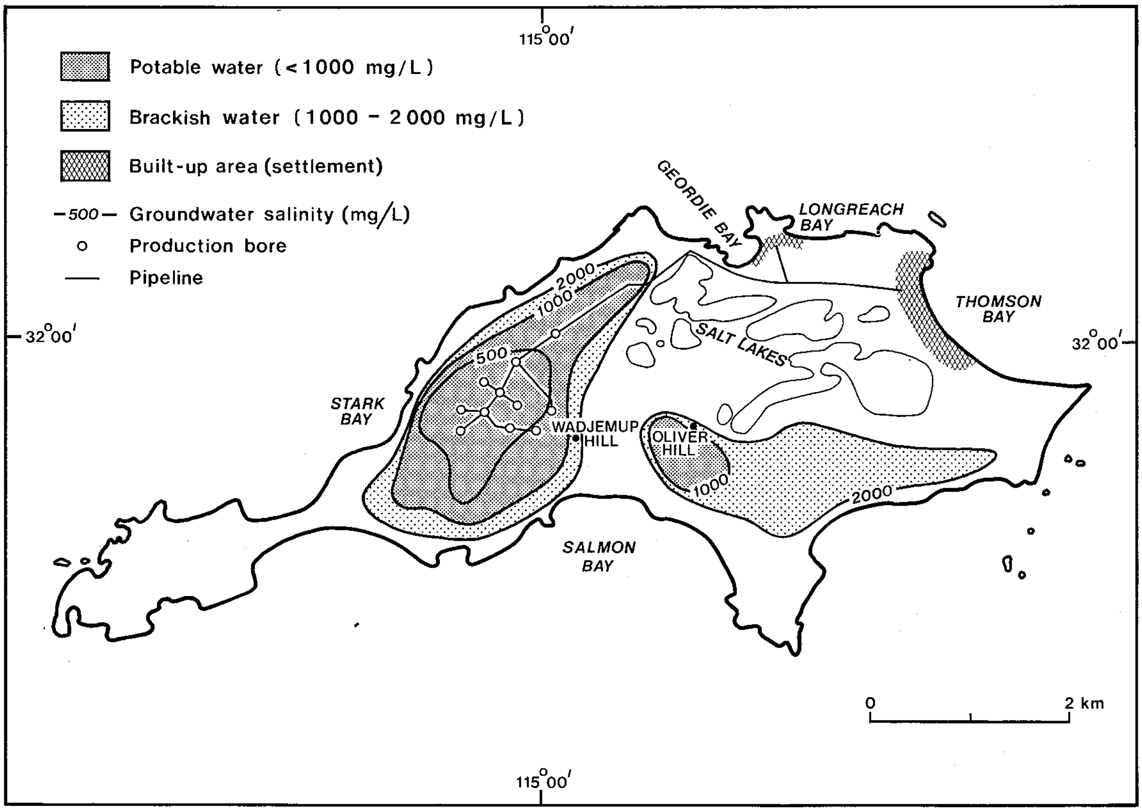

Figure 63: Hydrogeological map of Rottnest Island, showing the locations of development bores and the two principal groundwater lenses.

Fresh-water consumption on the island has risen from 36 000 m^3 in 1975/76 (catchment water and water imported by barge) to 63 600 m^3 in 1985/86 (45 700 m^3 groundwater, 17 900 m^3 catchment water). This is in line with the expectation by Playford (1977) that consumption in 5-10 years from 1976 could rise to about 60 000 m^3.

It is estimated that the annual rate of groundwater abstraction now amounts to approximately 65% of the safe yield, assuming that recharge is about 20% of annual rainfall, the annual rainfall is 600 mm (the approximate average of the years 1976-1986, well below the long-term average of 719 mm), and the safe yield is 50% of recharge (R.A. Smith, written comm., 1987). On this basis total consumption of fresh water on the island could not exceed about 90 000 m^3 per year without recourse to some new source of supply. This limit could well be reached within the next 10 years if current trends of increased consumption are continued.

There is no doubt that long-term availability of water is a limiting factor on further expansion of accomodation on Rottnest, unless additional supplies are eventually obtained by either a pipeline from the mainland or desalinization of salt water. However, the need for such supplies may not arise, as it seems doubtful that any further major increase in human use of the island can occur without incurring unacceptable levels of environmental degradation.

"I tell you, the island's had it if they start using all that sophisticated stuff!"

Figure 64: Cartoon by Paul Rigby in the *Sunday Times* of 5 September 1976, featuring the discovery of potable groundwater at Rottnest. Reprinted by permission of the *Sunday Times*.

FIELD EXCURSION

INTRODUCTION

This chapter summarizes the geology of key geological localities on Rottnest that are worth visiting by persons wishing to obtain a first-hand understanding of the geology of the island. The localities (Figs 65A, B) are listed in sequence, progressing through the geology: The Rottnest Limestone (locality 1), Tamala Limestone (localities 1, 2, and 3), Herschell Limestone (localities 4 and 5), elevated platforms and notches (localities 4, 6, 7, and 8), salt lakes (localities 9 and 15), shoreline features (localities 10, 11, 12, and 13), modern coral reefs (locality 14), and stromatolites (localities 9 and 15).

Of course it is not necessary to follow the program in strict sequence, and some of the localities can be deleted according to a person's or group's particular interests. The program does not cover all features of the geology of the island (for example the swamp deposits and modern dunes), but it does include those that are of most interest in the field.

The time required to visit all the listed localities will depend on the interests of those concerned, the numbers of persons in a field party, and their means of transport. For a party of about 30 geoscientists, travelling by bus, it is estimated that two full days would be needed to visit and examine all the places listed. Individuals who have only limited time could visit localities 1, 4, 6, 7, and 10 (about one day by bicycle).

Please be sure not to damage any of the features described or photographed, and samples should not be collected unless they are required for authorized research purposes. In any case please do not remove material shown in close-up photographs in this guidebook.

LOCALITIES

1: Fairbridge Bluff and Salmon Bay

Fairbridge Bluff is the type locality of the Rottnest Limestone fossil coral reef, which has been dated as about 130 000 years B.P. It is best to start the field examination at the east end of Fairbridge Bluff, where staghorn and tabular colonies of *Acropora* and the brain coral *Goniastrea* are well exposed (Figs 36-38). At the top of the exposed face there is a sandy calcarenite with abundant gastropods and some fragmentary corals. Note the extensive coatings of coralline algae (*Lithothamnion*) on the corals and some gastropods in the reef, and the abundance of such algae in the surrounding rock, binding coral and gastropod rubble. The top of the outcropping reef extends to just over 3 m above the adjoining platform, and this indicates that relative sea-level was at least this much higher during the last interglacial period, when the reef grew.

Several solution pipes containing calcified tree roots (Fig. 35) and *Leptopius* weevil cases can be seen cutting through the reef and extending below sea-level.

From here walk west to a small beach, where there are some well-preserved colonies of *Goniastrea* and associated gastropod-rich calcarenite (Fig. 39), and from there continue towards the end of Fairbridge Bluff to examine the erosional contact between the Rottnest Limestone coral reef and eolianite of the underlying Tamala Limestone. The contact is marked by a bed of limestone-clast conglomerate, which is well seen in a small sea cave.

Just west of the end of Fairbridge Bluff the Tamala Limestone contains some large solution pipes, thought to have again been localized by tree roots. They extend below present sea-level, indicating that relative sea-level was significantly lower than it is today when this part of the Tamala Limestone was accumulating.

From Fairbridge Bluff continue 400 m further west in Salmon Bay to the next outcrop of Tamala Limestone (Fig. 30), which is typical of the unit on Rottnest Island. The formation shows well-developed eolian cross-bedding, resulting from the migration of successive dunes through the area.

2: *Salmon Point*

This locality is just north of Salmon Point, opposite a prominent sea stack on the shoreline platform, which is capped by an osprey (sea-eagle) nest. Every care must be taken to ensure that the birds are not disturbed; do not approach the nest.

At this locality a strongly indurated cap of calcrete overlies softer limestone with abundant rhizoliths and solution pipes (Figs.31, 33). One pipe (in a fallen block) contains a large calcified root (Fig. 34); another contains pieces of limestone that have entered the pipe from above after the contained root rotted away.

The shoreline platform here meets the cliff at a well-developed notch, which is being actively bioeroded by molluscs and mechanically eroded by wave action (Fig. 33). The platform margin has a well-developed raised rim of limestone, which has a resident fauna of limpets that must be eroding it actively, although more slowly than the rest of the platform. Stronger cementation of the rim, making it more resistant to erosion, seems the most likely explanation.

3: *South Point*

A section through a single small dune within the Tamala Limestone is well exposed at this locality, which is just north of South Point on the west side of Strickland Bay (Fig. 29). It can be reached by walking along the track that terminates north of South Point.

The small dune shows excellent topset, foreset, and bottomset bedding, formed as it advanced across this area from north to south. Note a thin, but well-developed, fossil soil (which contains fossil weevil cases of *Leptopius*) at the top of the exposure.

4: *Mt Herschell Quarry*

The Mt Herschell Quarry is the type locality of the Herschell Limestone. It has been filled in twice in recent years with waste building material, then excavated again (at my request) to preserve it as a geological site. The quarry has now been fenced by the Rottnest Island Board, with a sign directing that there be no dumping, and hopefully the site is now secure.

Examine the two members of the formation - the Vincent Member below and the Baghdad Member above (Figs 40, 41). The Vincent Member has a very diverse fauna, principally molluscan, and the bivalve shells (mainly *Katelysia rhytiphora*) show no evidence of current or wave-induced orientation (Figs 42, 43). Many of the bivalves occur as closed shells. These characteristics indicate that the unit here was laid down below effective wave base, and the water depth is deduced to have been about 1.5 m.

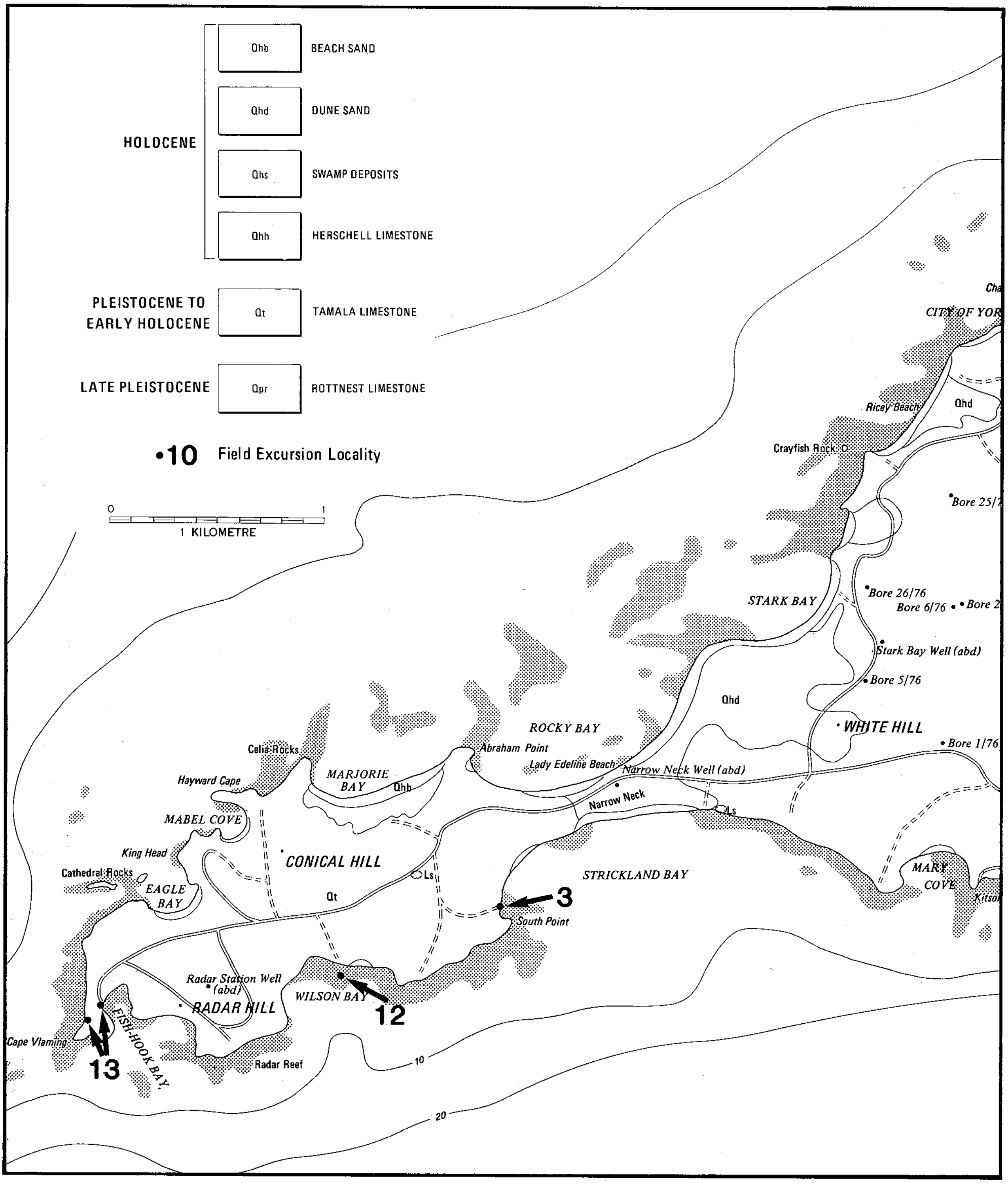

Figure 65A: Map showing localities in the field-excursion program (base from Plate 1).

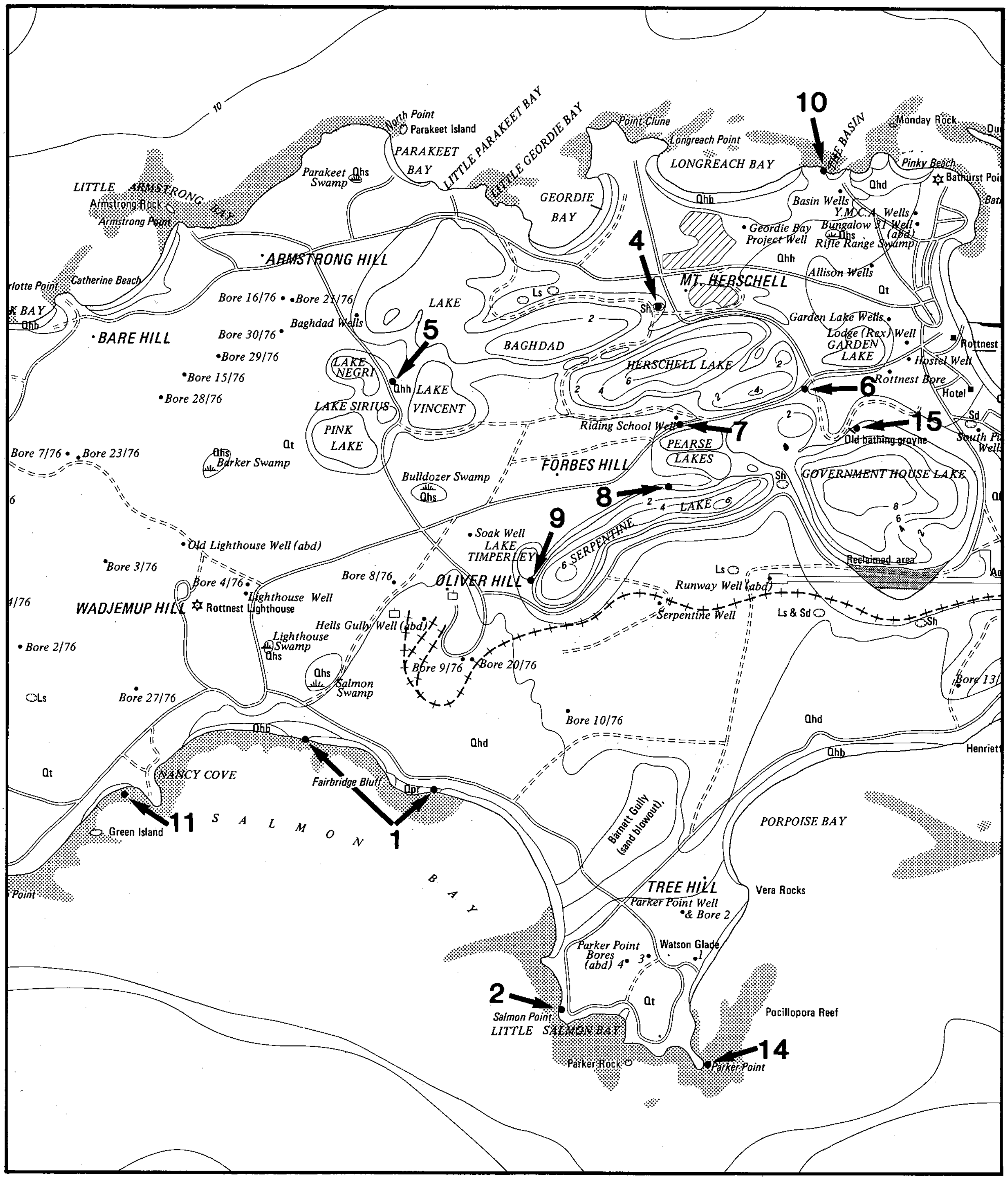

Figure 65B: Map showing other localities in the field-excursion program .

The indicator fossil for the Vincent Member is the bivalve *Katelysia rhytiphora*. For distinguishing characteristics of this species compared with *K. scalarina* (which is the most abundant fossil in the overlying Baghdad Member) see Figure 44.

The upper limit of the Vincent Member is placed at the top of the coquinite, below a bed of calcarenite marking the basal Baghdad Member. A thin indurated bed, about 1 cm thick, occurs 5 cm above the contact, and this was used as datum for measurements in the quarry and surveyed in as being 0.94 m above AHD.

The Baghdad Member is characterized by the abundance of *Katelysia scalarina*. Nearly all valves are oriented convex upward (Figs 40, 41, 46, 47), indicating strong current action (presumably wave action) at the time of deposition. Mussel valves (*Brachidontes ustulatus*) also show current orientation, perpendicular to the palaeoshoreline (Fig. 47). Note the crude foreset bedding visible in the unit on the north wall of the quarry.

It seems probable that the Baghdad Member at this locality was laid down as a beach deposit, in the upper intertidal zone, and that mean sea-level at that time was perhaps about 0.5 m lower than the top of the exposure, or 1 m above present mean sea-level.

From the quarry, walk south along the track for 100 m to see a large bulldozed block of Tamala Limestone, presumed to be from about the level of the intermediate-level notch in this area. It shows abundant well-preserved serpulid worm tubes that have grown on finely bored limestone, thought to have resulted from the boring action of clionid sponges (Fig. 55).

Also to be seen nearby are intensive borings of the mollusc *Lithophaga* (Fig. 56) and encrustations of bryozoans (cf. *Membranipora perfragilis*) and tiny semi-solitary ahermatypic corals (*Culicea tenella*) (Fig. 57). These organisms occur only about 20 cm below the upper-level platform, which here is at an elevation of 2.47 m above the mean elevation of modern shoreline platforms. The corals and bryozoans grew in small cavities and crevices in the limestone that have been exposed by erosion or recent bulldozing. They grew in a permanently submerged environment and are clear evidence of the highest Holocene sea-level represented by the upper (2.4 m) platform.

5: Lake Vincent Quarry

This small quarry exposes both members of the Herschell Limestone, and is the highest known exposure of the Vincent Member, reaching 1.29 m above AHD on the north side of the quarry. The contact with the Baghdad Member is an erosion surface, and it falls to 0.46 m above AHD on the southwestern side of the quarry. At this point the upper layer of the Vincent Member is strongly cemented, and closed *Katelysia* shells were planed off on the top surface before the Baghdad Member was deposited (Fig. 45).

The Baghdad Member at this locality is again characterized by *Katelysia scalarina*, predominantly as single valves laid down convex upward. It appears to have been deposited here as a beach deposit.

6: East End of Causeway

The eastern end of the causeway that divides Herschell and Government House Lakes is the best single exposure to see the upper-level platform and intermediate- and lower-level notches (Figs 50, 51, 52).

The upper-level platform at this locality is well preserved but narrow (generally less than 1 m), at an elevation of 2.32 m above AHD, or 2.74 m above the mean elevation of modern platforms around Rottnest. It does not have a well-developed associated notch - possibly the limestone above the platform did not become indurated enough for a notch to be preserved. The intermediate- and lower-level notches are distinct, and a weakly developed platform (elevation 0.2 m above AHD) is associated with the lower notch.

The serpulid layer is not especially well preserved at this locality, but it can be found extending discontinuously from just below the upper-level platform down to the lower-level platform. Serpulids coat some karst features (solution cavities) in the limestone, which must have developed before the relative rise of the sea to the upper level.

7: North Shore of Pearse Lakes

Pearse Lakes were the site of commercial salt-gathering operations for more than 100 years, up to 1952, and some remnants of the salt works and brine-gathering system remain at the site. A few rails from the tramway that was used to transport the salt can be seen elsewhere.

Good examples of the serpulid crust are exposed on the north shore of the lakes, extending below the upper-level platform over the intermediate- and lower-level notches (Fig. 54). A large sample was taken here of serpulids from the top of the intermediate-level notch. They were found to be 5 040 290 years old, which correlates well with the age of the Vincent Member and the deduced age of the upper-level platform.

8: North Shore of Serpentine Lake

From Pearse Lakes walk over the divide separating them from Serpentine Lake, in order to view the very well-developed "double notches" on the north shore of the lake (Fig. 53). There are also some good developments of the serpulid crust at this locality.

9: Lake Timperley

Climb the hillock immediately west of Lake Timperley to view this lake and part of Serpentine Lake. Note their circular to ovoid shapes (Fig. 5), thought to have been inherited from old "blue holes", which in turn originated as doline (karst) features during the Pleistocene ice ages, comparable with those of the Houtman Abrolhos reef platforms (Fig. 6).

Lake Timperley is fed by a number of strongly flowing fresh-water springs, sourced by the Oliver Hill groundwater lens to the west (Figs 7, 63). As a result, the summer salinities in this lake are about 90 000 mg/L lower than in Serpentine Lake, and the water level is significantly higher, so that a small stream of water flows from Lake Timperley into Serpentine Lake during the summer. The springs form important watering points for wildlife in this area.

Next, visit the adjoining western shore of Serpentine Lake to examine a series of large domal stromatolites, now dead and eroded, which rim the lake (Fig. 49). At this locality there are also seepages of fresh water, and it is conceivable that they were a factor controlling growth of the stromatolite-building cyanobacteria at this locality. It also seems possible that the stromatolites grew when the lake level was a little higher than it is today.

10: The Basin

The purpose of visiting this locality (Fig. 4), and the next three, is to examine features of the modern shorelines and to compare them with some earlier Holocene and Pleistocene features of the island.

The shoreline platform and adjoining notch (Fig. 9) are well developed at The Basin. Note the distinctive raised rim to the platform (Fig. 15), and the clear zoning of molluscs on the notch. The lower notch has abundant limpets (*Patelloida alticostata*) and chitons (*Clavarizona hirtosa*), the middle (most deeply undercut) notch has an abundant and varied assemblage of gastropods (the periwinkle *Tectarius australis* and the limpets *Patelloida insignis*, *Collisella onychitis*, and *Siphonaria kurracheensis*), and the upper notch is characterized by the periwinkle *Littorina unifasciata*. All of these molluscs graze on algae, scraping them from the surface of the limestone, which is thereby abraded. In some cases the rock surface is scraped away by the mollusc in order to reach filaments of endolithic algae that penetrate below the surface. There is no doubt that this bioerosion of the limestone is a major factor in the retreat of the notch and expansion of the platform.

Note the strong cementation of the limestone at the notch, extending as high as the lip of the visor, as a consequence of alternate wetting and drying. However, at this locality there is only a weakly developed and discontinuous storm bench above the notch.

11: Green Island

At this locality walk about 100 m northeast along the beach from the jetty. On the shoreline platform there are abundant rhodoliths (nodules of coralline red algae) in shallow depressions on the platform surface (Figs 20, 21), associated with large gastropods shells (*Campanile symbolicum),* which are themselves coated with coralline algae.

The rhodoliths have formed in their subspherical shapes as a result of being repeatedly rolled around by wave action. They are morphological analogues of the oncolites (formed by cyanobacteria), that are common in ancient carbonate sequences. Scattered colonies of the coral *Pocillopora* can be seen in places on the platform. In some years there are also well-developed algal polygons (Fig. 19), but on most occasions that I have visited this locality they have been only weakly developed or absent.

12: Wilson Bay

This site is reached by walking down the track that extends south from the road to Cape Vlamingh. It is a good locality to see paddy-field terraces, algal polygons, the role of echinoids and gastropods in platform erosion, and deposits of shells transported by birds.

The paddy-field terraces at this locality extend over a vertical height of about 70 cm, situated on the outer part of the shoreline platform. Each terrace has a small raised rim, and water from waves breaking on the platform margin cascades from one to another (Figs 16-18).

The main platform area supports many hundreds of regular echinoids, (*Heliocidaris erythrogramma*) which have excavated holes in which they live (Fig. 25). They must be major agents in the lowering of platforms. The echinoids on part of the main platform reside in curved lines, following planed-off foreset bedding in the underlying Tamala Limestone (Figs 16, 17). Apparently the echinoids have picked out the softer bedding planes in the limestone to excavate their holes.

Also present on the platform, and especially at the base of the adjoining notch, are many black gastropods (*Nerita atramentosa*), limpets (*Patelloida alticostata*), littorinid periwinkles, and chitons (*Clavarizona hirtosa*), all of which are actively eroding the limestone (Figs 12, 23).

Algal polygons, formed by brown algae, are very well developed at this locality, and their shapes (as shown in Fig. 16, taken in January 1988) have remained essentially unchanged over the inner part of the platform for the past 12 years (see comparison with Figure 6 of Playford, 1977). However, the more extensive developments of algal polygons that were present on the outer part of the platform in October 1985 (Fig. 17 and cover photo) were absent in 1977, October 1987, and January 1988. The origin of the polygons, and the reasons why they are more extensive in some years than in others, are not known.

On a small low headland at Wilson Bay there are some conspicuous deposits of shells transported by birds (Fig. 27). The most common components of these deposits are opercula of the large gastropod *Turbo intercostalis*, which are very resistant to erosion and have hence survived when the rest of the shell has disappeared. Other conspicuous elements include the giant limpet *Patella laticostata,* and the common limpet *Patelloida alticostata.*

13: Fish-Hook Bay and Cape Vlamingh

Fish-hook Bay is a good locality to see a narrow storm bench developed above the lithified limestone of the shoreline notch and visor (Fig. 10). The bench ranges from about 3.5 m above the modern platform near the entrance, to 2.5 m within the bay.

Also at Fish-hook Bay look for the possible emu footprints on a foreset bedding plane about half way down the cliff on the northwest side of the bay.

At Cape Vlamingh note the very wide shoreline platform, which is also the highest that has been measured on the island (-0.18 m). The height can be correlated with the size of the waves that break on the platform at this westernmost and therefore most exposed locality on the island. Note the well-developed but discontinuous storm benches at the foot of the cliff, which are partly covered with blocks of limestone derived by erosion of the cliff front.

Also to be seen on the shoreline platform near Cape Vlamingh is the wreck of the Japanese tuna fishing boat *Kyro Maru* which ran aground there in 1984.

14: Parker Point

Parker Point and the adjoining Pocillopora Reef are the best places to view modern coral reefs at Rottnest (Fig. 22). The most convenient way to get there is to climb down the east side of the promontory from the road immediately northwest of Parker Point. Before doing so, view the shell deposits transported by birds that are preserved on the small headland below Jeannie's Lookout (Fig. 26).

A face mask, snorkel, and flippers are needed to view the coral reefs. Swim short distances east and southeast of the point, over holes in the platform, and north over Pocillopora Reef. The coral faunas are dominated by *Pocillopora damicornis*, which forms some impressive colonies in this area. Several other species can also be seen in a large hole near the platform margin, a short distance southeast of the point.

15: Government House Lake

This locality is at the old bathing groyne (dating from the 1920s), which is reached by following the track along the north side of Government House Lake.

A swim at this locality during late summer is an interesting experience because of the buoyant effect of the hypersaline water (about 160 000 mg/L). However, it can be painful if you have any skin injuries; also, avoid swallowing water and keep it out of your eyes. Use a face mask and snorkel to view the stromatolites.

Benthic microbial mats are well developed on the floor of the lake around its shallow margins. The mats swell into stromatolite mounds (Fig. 48) in the vicinity of the old bathing groyne, and are best seen near its east side, where they extend to depths of about 3 m. The mats are built by cyanobacteria and the green alga *Botryococcus*, with contributions from diatoms. Note the presence of oxygen bubbles on the surface of the mats, resulting from photosynthetic activity. The stromatolites here are believed to grow at rates of about 1.5 mm per year.

REFERENCES

Aurousseau, M., and Budge, E.A., 1921, The terraces of the Swan and Helena Rivers and their bearing on Recent displacements of the strand line: Royal Soc. West. Australia Jour., v. 7, p. 24-43.

Black, R., and Johnson, M.S., 1983, Marine biological studies on Rottnest Island: Royal Soc. West. Australia Jour., v. 66, p. 24-28.

Bradshaw, S.D. (ed.), 1983, Research on Rottnest Island: Royal Soc. West. Australia Jour., v. 66, 61 p.

Bunn, S.E., and Edward, D.H.D., 1984, Seasonal meromixis in three hypersaline lakes on Rottnest Island, Western Australia: Aust. Jour. Marine and Freshwater Research, v. 35, p. 261-265.

Carrigy, M.A., and Fairbridge, R.W., 1954, Recent sedimentation, physiography, and structure of the continental shelves of Western Australia: Royal Soc. West. Australia Jour., v. 38, p. 65-95.

Chappell, J., and Shackleton, N.J., 1986, Oxygen isotopes and sea level: Nature, v. 324, p. 137-140.

Churchill, D.M., 1959, Late Quaternary eustatic changes in the Swan River district: Royal Soc. West. Australia Jour., v. 42, p. 53-55.

Clarke, E. de C., 1926, The geology and physiography of the neighbourhood of Perth, Western Australia: Austral. Assoc. Adv. Sci., Handbook 18th meeting, Perth, p. 23-30.

Cope, R.N., 1975, Tertiary epeirogeny in the southern part of Western Australia: West. Australia Geol. Survey Ann. Rept for 1974, p. 40-46.

Deevey, E.S, Gralenski, L.J., and Hoffren, V., 1959, Yale natural radiocarbon measurements IV: Radiocarbon, v. 1, p. 144-172.

Edward, D.H.D., 1983, Inland waters of Rottnest Island: Royal Soc. West. Australia Jour., v. 66, p. 41-47.

Fairbridge, R.W., 1952, Marine erosion: Seventh Pacific Science Congress, Wellington New Zealand, v. III, p. 1-11.

_____________ 1953, Australian stratigraphy: Univ. West. Australia Text Books Board, Nedlands.

_____________ 1958, Dating the latest movements of the Quaternary sea level: New York Acad. Sci. Trans., Ser. 2, p. 471-482.

_____________ 1961, Eustatic changes in sea level, in Physics and chemistry of the earth, v. 4: Pergamon, London, p. 99-185.

Glenister, B.F., Hassell, C.W., and Kneebone, E.W.S., 1959, Geology of Rottnest Island: Royal Soc. West. Australia Jour., v. 42, p. 69-70.

Gordon, F.R., and Lewis, J.D., 1980, The Meckering and Calingiri Earthquakes, October 1968 and March 1970: West. Australia Geol. Survey, Bull. 126, 229 p.

Grant-Taylor, T.L., and Rafter, T.A., 1963, New Zealand natural radiocarbon measurements I-V: Radiocarbon, v. 5, p. 118-162.

Hassell, C.W., and Kneebone, E.W.S., 1960, The geology of Rottnest Island: Univ. West. Australia Dept Geology, B.Sc. Honours thesis (unpublished).

Heeres, J.E., 1899, The part borne by the Dutch in the discovery of Australia, 1606-1765: Luzac and Co., London.

Hodgkin, E.P., 1959, The salt lakes of Rottnest Island: Royal Soc. West. Australia Jour., v. 42, p. 84-85.

_____________ 1964, Rate of erosion of intertidal limestone: Zeitschr. Geomorphologie, N.F., v. 8, p. 385-392.

_____________1970, Geomorphology and biological erosion of limestone coasts in Malaysia: Geol. Soc. Malaysia, Bull. 3, p. 27-51.

_____________ Marsh, L., and Smith, G.G., 1959, The littoral environment of Rottnest Island: Royal Soc. West. Australia Jour., v. 42, p. 85-88.

_____________ and Di Lollo, V., 1958, The tides of south-western Australia: Royal Soc. West. Australia Jour., v. 41, p. 42-54.

_____________ and Sheard, K., 1959, Rottnest Island: The Rottnest biological station and recent scientific research: Royal Soc. West. Australia Jour., v. 42, p. 65-95.

Hughes, P.J., Sullivan, M.E., and Branagan, D.F., 1978, Are there prehistoric shell middens on Rottnest Island?: Australian Archaeology, no. 8, p. 158-161.

Kendrick, G.W, 1977a, Fossils from the Herschell Limestone: West. Australia Geol. Survey, Rept 6, p. 87-98.

_____________ 1977b, Middle Holocene marine molluscs from near Guildford, Western Australia, and evidence for climatic change: Royal Soc. West Australia Jour., v. 59, p. 97-104.

Lambeck, K., 1987, The Perth Basin: A possible framework for its formation and evolution: Exploration Geophysics, v. 18, p. 124-128.

Leech, R.E.J., 1977, Hydrology, *in* Geology and hydrology of Rottnest Island: West. Australia Geol. Survey, Rept 6, Part 2, p. 54-98.

Lewis, J.D., Daetwyler, N.A., Bunting, J.A., and Moncrieff, J.S., 1981, The Cadoux Earthquake, 2 June 1979: West. Australia Geol. Survey, Rept 11, 133 p.

Mörner, N.A., 1976, Eustatic changes during the last 8 000 years in view of radiocarbon calibration and new information from the Kattegatt region and other northwestern European coastal areas: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 19, p. 63-85.

Pearce, A., 1987, The Leeuwin Current and Rottnest Island: Rottnest Island Board environmental education pamphlet.

__________ and Cresswell, G., 1985, Ocean circulation off Western Australia and the Leeuwin Current: CSIRO Div. of Oceanography, Information Service Sheet no. 16-3.

Pen, L.J., and Green, J.W., 1983, Botanical exploration and vegetational changes on Rottnest Island: Royal Soc. West. Australia Jour., v. 66, p. 20- 24.

Playford, P.E., 1976, Rottnest Island: geology and groundwater potential: West. Australia Geol. Survey Record 1976/7.

____________ 1977, Geology and groundwater potential, *in* Geology and hydrology of Rottnest Island: West. Australia Geol. Survey, Rept 6, Part 1, p. 1-53.

____________ 1983, Geological research on Rottnest Island: Royal Soc. West. Australia Jour., v. 66, p. 10-15.

____________ Cockbain, A.E., and Low, G.H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey, Bull. 124, 311 p.

____________ and Leech, R.E.J., 1977, Geology and hydrology of Rottnest Island: West. Australia Geol. Survey, Rept 6, 98 p.

Purdy, E.G., 1974, Reef configurations: cause and effect, *in* Reefs in time and space, L.F. Laporte (ed.): Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 18, p. 9-76.

Revelle, R., and Fairbridge, R.W., 1957, Carbonates and carbon dioxide, *in* Treatise on marine ecology and paleoecology, J.W. Hedgpeth (ed.): Geol. Soc. America Mem. 67, p. 239-296.

Searle, D.J., and Woods, P.J., 1986, Detailed documentation of a Holocene sea-level record in the Perth region, southern Western Australia: Quaternary Research, v. 26, p. 299-308.

Semeniuk, V., 1986, Holocene climate history of coastal Southwestern Australia using calcrete as an indicator: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 53, p. 289-308.

____________ and Johnson, D.P., 1985, Modern and Pleistocene rocky shore sequences along carbonate coastlines, southwestern Australia: Sedimentary Geology, v. 44, p. 225-261.

__________ and Searle, D.J., 1986, Variability of Holocene sealevel history along the southwestern coast of Australia - evidence for the effect of significant local tectonism: Marine Geology, v. 72, p. 47-58.

Somerville, J.L., 1921, Evidence of uplift in the neighbourhood of Perth: Royal Soc. West. Australia Jour., v. 6, p. 5-20.

Somerville, W., 1949, Rottnest Island: Rottnest Island Board of Control, special publication.

Storr, G.M., 1963, Some factors inducing change in the vegetation of Rottnest Island: West. Australian Naturalist, v. 9, p. 15-22.

Szabo, B.J., 1979, Uranium-series age of coral reef growth on Rottnest Island, Western Australia: Marine Geology, v. 29, p. M11-M15.

Tamers, M.A., Pearson, F.J., and Davis, E.M., 1964, University of Texas radiocarbon dates II: Radiocarbon, v. 6, p. 138-159.

Teichert, C., 1950, Late Quaternary changes of sea level at Rottnest Island, Western Australia: Royal Soc. Victoria Proc., v. 59, p. 63-79.

__________ and Serventy, D.L., 1947, Deposits of shells transported by birds: Amer. Jour. Sci., v. 245, p. 322-328.

Thom, B.G., and Chappell, J., 1975, Holocene sea levels relative to Australia: Search, v. 6, p. 90-93.

Veeh, H.H., 1966, Th^{230}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea level stand: Jour. Geophysical Research, v. 71, p. 3379-3386.

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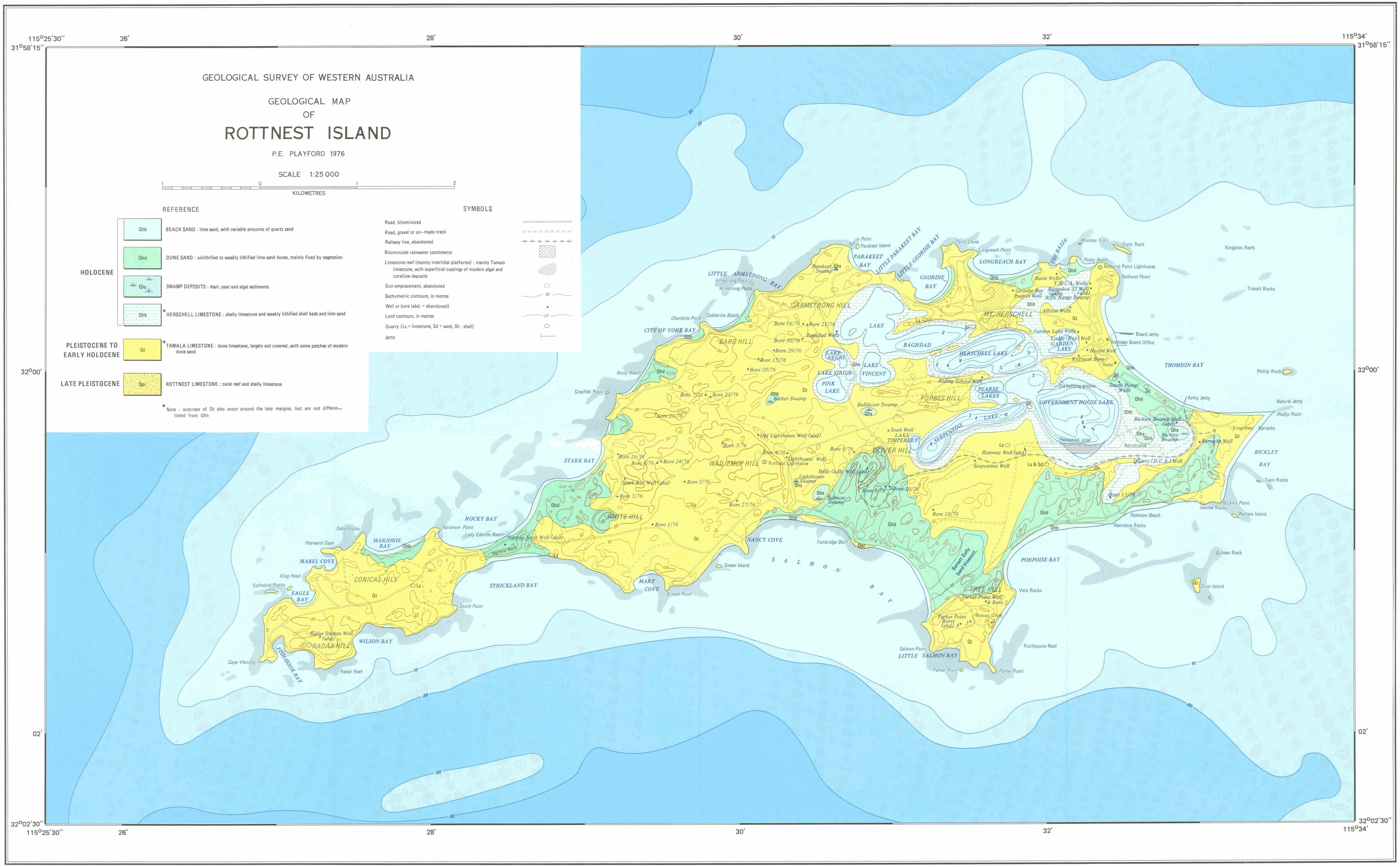
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP OF
ROTTNEST ISLAND
P.E. PLAYFORD 1976
SCALE 1:25 000
KILOMETRES
REFERENCE
HOLOCENE
Qhb BEACH SAND : lime sand, with variable amounts of quartz sand
Qhd DUNE SAND : unlithified to weakly lithified lime sand dunes, mainly fixed by vegetation
Qhs SWAMP DEPOSITS : marl, peat and algal sediments
Qhh *HERSCHELL LIMESTONE : shelly limestone and weakly lithified shell beds and lime sand
PLEISTOCENE TO EARLY HOLOCENE
Qt *TAMALA LIMESTONE : dune limestone, largely soil covered, with some patches of modern dune sand
LATE PLEISTOCENE
Qpr ROTTNEST LIMESTONE : coral reef and shelly limestone
*Note : outcrops of Qt also occur around the lake margins, but are not differentiated from Qhh
SYMBOLS
Road, bituminized
Road, gravel or un-made track
Railway line, abandoned
Bituminized rainwater catchments
Limestone reef (mainly intertidal platforms) : mainly Tamala limestone, with superficial coatings of modern algal and coralline deposits
Gun emplacement, abandoned
Bathymetric contours, in metres
Well or bore (abd. = abandoned)
Land contours, in metres
Quarry (Ls = limestone, Sd = sand, Sh - shell)
Jetty
115°25'30"
31°58'15"
26'
28'
30'
32'
115°34'
32°00'
02'
32°02'30"
LITTLE ARMSTRONG BAY
PARAKEET BAY
LITTLE PARAKEET BAY
LITTLE GEORDIE BAY
GEORDIE BAY
LONGREACH BAY
THE BASIN
CITY OF YORK BAY
ARMSTRONG HILL
BARE HILL
LAKE BAGHDAD
HERSCHELL LAKE
MT. HERSCHELL
LAKE NEGRI
LAKE SIRIUS
LAKE VINCENT
PINK LAKE
PEARSE LAKES
GOVERNMENT HOUSE LAKE
FORBES HILL
SERPENTINE LAKE
LAKE TIMPERLEY
OLIVER HILL
WADJEMUP HILL
THOMSON BAY
BICKLEY BAY
STARK BAY
WHITE HILL
ROCKY BAY
MARJORIE BAY
MABEL COVE
CONICAL HILL
EAGLE BAY
STRICKLAND BAY
MARY COVE
NANCY COVE
SALMON BAY
PORPOISE BAY
TREE HILL
WILSON BAY
RADAR HILL
FISH HOOK BAY
LITTLE SALMON BAY
Kingston Reefs
Transit Rocks
Phillip Rock
Duck Rock
Crayfish Rock
Green Island
Dyer Island
Cathedral Rocks
Cape Vlamingh
Radar Reef
Parker Point
Pocillopora Reef
Vera Rocks
Henrietta Rocks
Jubilee Rocks
Wallace Island
Twin Rocks