GUIDEBOOK

FOR

MID-CONFERENCE EXCURSION: ROTTNEST ISLAND

6 FEBRUARY 2002

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Preface

On this excursion our aim is to highlight some of the geological and biological features in southwestern Western Australia that may be of interest to foraminiferal workers. We hope that you can contribute to our understanding of these features by joining the discussions and bringing with you knowledge and experience of other places. You will have an opportunity to collect foraminiferal material from various sites (some of which require collecting permits). Although these may seem remote localities and "virgin" territory, much local work is under way on the foraminiferal faunas - both modern and fossil. We welcome collaboration in our efforts to understand these microfaunas better. If you collect material and prepare this for study and publication, please contact Western Australian workers to make sure you are not duplicating local work.

Field Safety

YOU TAKE PART IN THE EXCURSION AT YOUR OWN RISK

We will endeavour to make the excursion a pleasant and safe experience. Care will be taken by the UWA staff to ensure your safety and well being. We will provide you with safety instructions at each site and ask that you follow this advice.

The following general safety precautions should be followed.

1. Keep within sight of other excursion participants at all times while we are at field sites. Do not wander off on your own.
2. Wear a broad-brim hat, dark glasses, and full-length loose-fitting light clothes to guard against the effects of the intense sun. In particular make sure your feet, legs and arms are adequately protected from sunburn.
3. On a regular basis apply sun protection lotion (preferably 30+ rating) to exposed parts of your body.
4. Keep drinking water (at least 2 litres per day). There will be large amounts available on the bus and you should sip water throughout the day. Dehydration and heat stroke are real dangers and can simply be avoided by drinking water.
5. When walking over dunes or in the bush, look out for snakes. Do not approach snakes. Make noise as you walk - this usually frightens these reptiles.
6. When wading in water wear protective footwear.
7. You swim at your own risk. When swimming you should be particularly careful in protecting yourself against sunburn. You should remain close to other participants.
8. The horse flies are harmless, although a nuisance while outside. You may wish to apply insect repellent.
9. If you smoke, do not discard cigarette butts in the bush. These are major fire hazards.

Acknowledgments

The following people are thanked for their assistance during compilation of the Guidebook: Diana Walker and Gary Kendrick lent literature on seagrass and algae; Mathew Kuo and Christopher New provided technical assistance.

Introduction

INTRODUCTION

Introductory note

This guide should be read in conjunction with Phillip Playford's (1988) Guidebook to the Geology of Rottnest Island which has been given to each participant.

Itinerary

The excursion starts with a cruise down the Swan Estuary from the Perth Ferry Terminal at Barrack Square to North Port (Rous Head Harbour, North Fremantle) at the mouth of the Swan River (Figure 1). The ferry trip then goes across the continental shelf (the Rottnest Shelf) to Rottnest Island and lands at Thompson Bay, the main settlement on the Island. A cruise on the Underwater Explorer will show some of the shallow-water environments around Thompson Bay. For this, the party will be divided into two groups; while one group goes on the cruise the other group visits the local settlement (hiring snorkelling gear if needed) and museum. Lunch will be at Rottnest Lodge and after lunch the "wet" and "dry" tours of the island will be run.

Geological Setting

The Geological Survey of Western Australia recognizes sedimentary basins based on "their earliest structural configuration, the boundaries being carried upwards through the sedimentary sequence" (Trendall & Cockbain, 1990). Rottnest Island is situated in the Perth Basin (Hocking *et al.*, 1994), one of the main Phanerozoic basins on the western margin of Australia (see inside cover of this guide). Figure 2 shows the extent

Itinery

8.00: Bus pickup
(at back of St George's College)

8.30 - 10.00: Swan River Cruise

10.00 - 10.30: "Rottnest Shelf"

10.45 - 12.15:
Underwater Explorer Cruises

12.30 - 2.30: Lunch
(Rottnest Lodge)

2.30 - 4.30: Dry Tour — Page
- Parker Point........................17
- Little Salmon Bay...............17
- Fairbridge Bluff..................18
- Green Island.......................18
- Rocky Bay 18
- Cape Vlaming.....................19
- Lighthouse 19
- Salt Lake 19

2.30 - 4.30: Wet Tour
- Little Salmon Bay...............17
- Green Island.......................17
- Rocky Bay 18

5.15: Board Ferry for return

6.00: Depart Ferry at Rous Head

6.15: Bus to St George's College

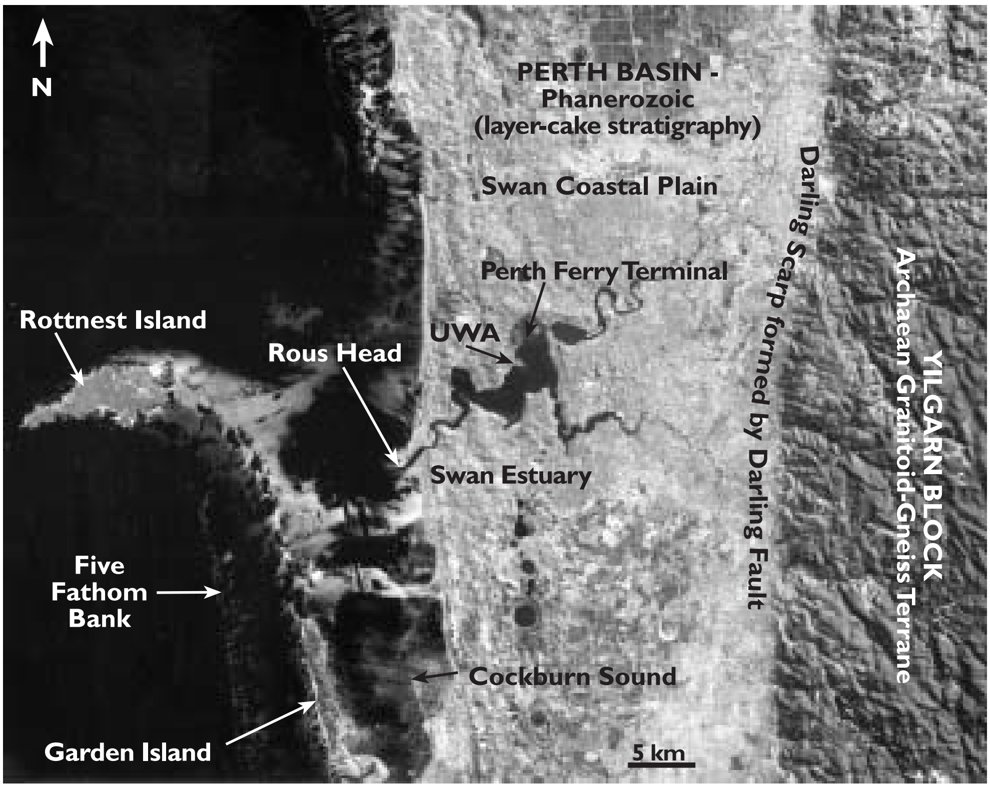


Figure 1. Satellite image of the Perth region (reproduced by permission of the Department of Land Administration)

of the basin and also shows an alternate view of superimposed basins in this region.

The broad Phanerozoic history of the region is best illustrated by the superimposed basins distinguished on Figure 2. A succession from a Permian interior rift basin followed by Triassic and Jurassic interior rift basins, to a Cretaceous (post-Valanginian) to Cenozoic continental margin basin is recognized. The interior basins of the Paleozoic and early Mesozoic were located at great distances from the continent-ocean crust boundary (Li & Powell, 2001) and were the sites of mainly fluvial deposition. After the Valanginian, the sea flooded the continental shelf repeatedly and a mainly shallow-marine succession with many hiatuses developed. The Rottnest region moved from high southern latitudes during the late Paleozoic and earliest Mesozoic to its present position at 32°S (Li & Powell, 2001).

Stratigraphic units known from the region are charted on Table 1. The Permian through lowermost Cretaceous interior-basin deposits represent mainly fluvial facies and are not exposed near Perth. Post-continental breakup deposits are Valanginian to Holocene neritic and shoreline units of the passive continental shelf facing the Indian Ocean. The Cretaceous units are poorly exposed on the Dandaragan Plateau to the north of Perth; whereas Pleistocene and Holocene units entirely cover the Swan Coastal Plain and the adjacent submerged Rottnest Shelf. Large aeolian dunes of Pleistocene age (Tamala Limestone) form most of Rottnest Island. These were deposited during a period of low sea level when the Swan River flowed north of the island and the coastline was to the west. Playford (1988) described the geology and geomorphology of the island (see p. 3-46 of his guidebook). A geological map of Rottnest is included at the back of Playford's guidebook.

Marine setting

The present continental shelf of the Perth Basin is a very low gradient submerged plain which is about 40 km wide in the Perth region but broadens to the north and south. The geomorphology of the inner shelf is complex with submerged dune ridges paralleling the coast (Searle & Semeniuk, 1985). Unlike most west-facing continental shelves, the marine waters are warm. This reflects the influence of the south-flowing

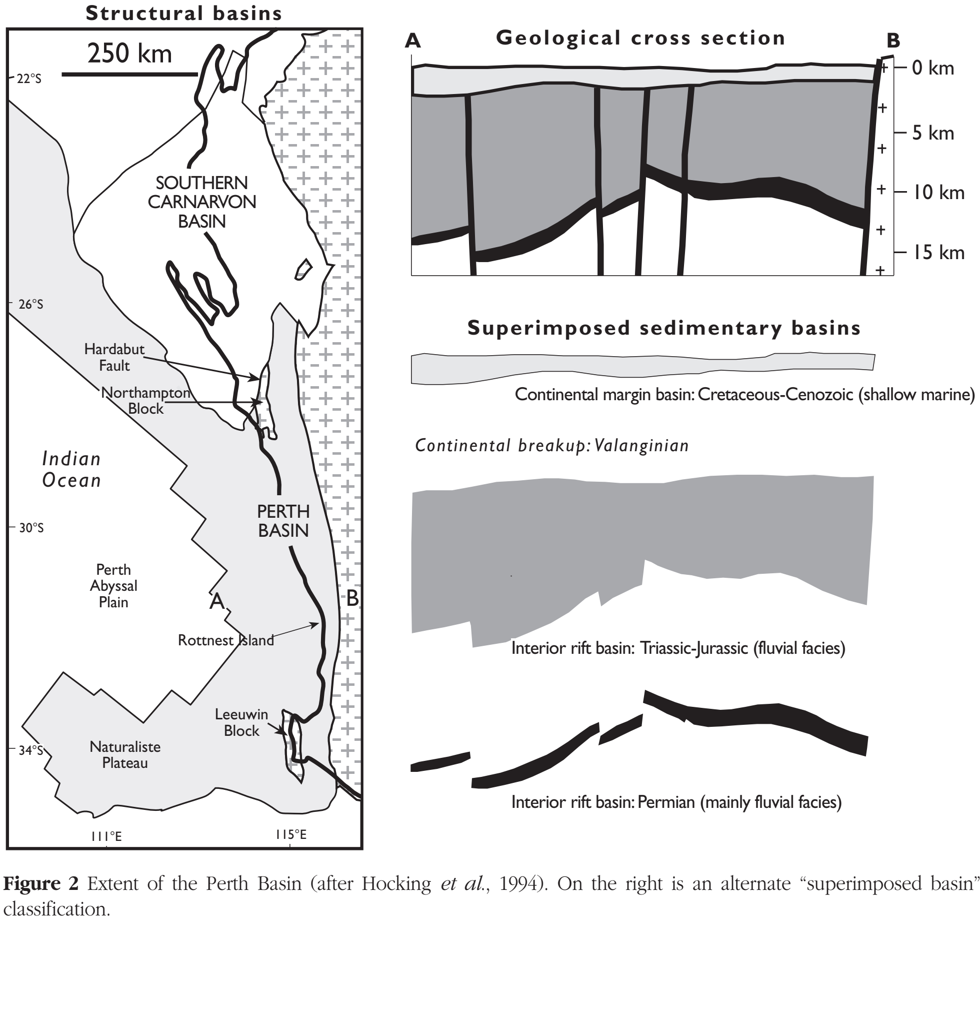


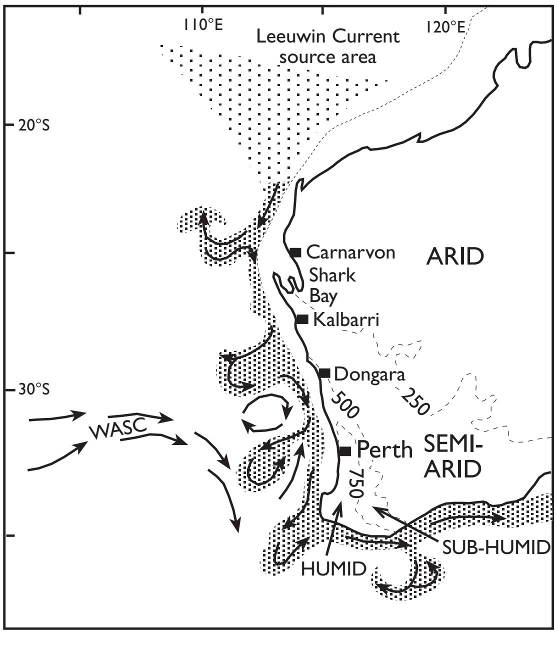
Figure 2 Extent of the Perth Basin (after Hocking *et al.*, 1994). On the right is an alternate "superimposed basin" classification.

Table 1. Generalised stratigraphy of the Perth-Rottnest region (adapted from Playford et al., 1976; Mory, 1995; Davidson, 1995), showing the succession of lithostratigraphic units (with outcropping units in bold print), facies and basin setting. Numbers after particular lithostratigraphic units refer to the following published records of foraminifera: 1, Yassini & Kendrick (1988); 2, Parr (1950); 3, Mallett (1982); 4, Quilty (1974); 5, Quilty (1978), 6, Parr (1938); 7, Coleman (1952); 8, McGowran (1964); 9, Haig *et al.* (1993); 10, Edgell (1964); 11, McNamara *et al.* (1988); 12, Howchin (1907); 13, Glauert (1910); 14, Chapman (1917); 15, Cushman (1936); 16, Edgell (1957); 17, Belford (1958); 18, Belford (1960); 19, Playford *et al.* (1976, citing unpublished work by Crespin and Rao).

Quaternary	*Holocene*	**Safety Bay Sand** (Quindalup Dunes)	coastal sand dunes with associated shore-line deposits (including coral-algal reefs)	PASSIVE CONTINENTAL MARGIN BASIN FACING INDIAN OCEAN
	Pleistocene	**Tamala Limestone** (Spearwood Dunes); **Bassendean Sand** (Bassendean Dunes)		
Neogene	*Pliocene*	(5) Ascot Formation (3)	inner neritic mixed siliciclastic-carbonate sand	
	Miocene	Stark Bay Formation (4, 5)	neritic bioclastic limestone	
Paleogene	*Oligocene*		neritic mixed siliciclastic shale and chalk	
	Eocene	un-named formations (5)		
	Paleocene	Kings Park Shale (4-9)	neritic siliciclastic mud confined to channel fill in Perth area	
Cretaceous	*Maastrichtian*	(5) Lancelin Fmn. (10,11); **Poison Hill Greensand**, **Gingin Chalk** (12-18) — Coolyena Group	inner neritic siliciclastic mud and sand (Albian-Cenomanian) overlain by mid to outer neritic glauconitic and chalk facies (Turonian-Maastrichtian)	
	Campanian			
	Santonian			
	Coniacian	**Molecap Greensand** — Coolyena Group		
	Turonian			
	Cenomanian	Osborne Formation — Coolyena Group		
	Albian			
	Aptian			
	Barremian	Leederville Formation — Warnbro Group	paralic to inner neritic siliciclastic facies	
	Hauterivian	South Perth Shale (7, 19) — Warnbro Group		
	Valanginian		*continental breakup*	
	Berriasian	Parmelia Formation		RIFT BASIN IN INTERIOR OF CONTINENT (POSSIBLY >1000 KM FROM OPEN CONTINENTAL SHELF)
Jurassic	*Tithonian*	**Yarragadee Formation**	fluvial facies	
	Kimmeridgian			
	Oxfordian			
	Callovian			
	Bathonian	Cadda Formation	inner neritic facies	
	Bajocian			
	Aalenian	Cattamarra Coal Measures	fluvial - swamp facies	
	Toarcian			
	Pliensbachian	Eneabba Formation	fluvial facies	
	Sinemurian			
	Hettangian			
Triassic	*Rhaetian*	Lesueur Sandstone	fluvial facies	
	Norian			
	Carnian			
	Ladinian			
	Anisian	Woodada Formation	fluvial facies	
	Scythian	Kockatea Shale	inner neritic to marginal marine facies	
Permian	*Tatarian*			
	Kazanian			
	Ufimian			
	Kungurian			
	Artinskian	Undifferentiated Lower Permian	inner neritic to paralic facies	
	Sakmarian			
	Asselian			
PRECAMBRIAN BASEMENT				

warm Leeuwin current (Pearce & Walker, 1991). A large along-shore pressure gradient exists between the warm (low-density) equatorial waters and the cool (high-density) Southern Ocean. These oceanographic conditions activate a net eastwards geostrophic flow that is deflected south along the pressure gradient down the Australia margin (Pearce, 1991). The current is accentuated by a flow of warm Pacific Ocean water through the Indonesian Archipelago into the north-eastern Indian Ocean (the Leeuwin Current source area, Figure 3). Despite upwelling-favourable winds, there is no significant upwelling of deep oceanic water along the west Australian margin (Pearce, 1991).

Figure 3 Map of Western Australia showing terrestrial humid, sub-humid, semi-arid, and arid climatic zones, separated by 750 mm, 500 mm, and 250 mm isohyets respectively (taken from Glassford & Semeniuk, 1995); and the Leeuwin and Western Australian Summer Currents (after Pearce, 1991)



Off the Perth stretch of coast, the Leeuwin Current runs just beyond the outer edge of the continental shelf at speeds that can exceed 1 knot, as a narrow water mass (100 km wide and more than 100 m deep). Its warm low-salinity waters can spread half way across the shelf toward the coast, except in summer when a wind-driven high-salinity northward flow occupies most of the shelf (Cresswell, 1991). Out to sea, the current often meanders in both cyclonic and anticyclonic eddies (Figure 3).

The Leeuwin Current greatly influences the marine biogeography of the region. In terms of zoogeographic provinces, the Northern Australian Tropical Province (Figure 4) has a biota that is typical for the Indo-West Pacific. Significant elements of this tropical fauna continue to the south along the outer continental shelf around the offshore islands (such as the Houtmann Abrolhos and Rottnest). The inner continental shelf from 20°S to 30°S forms a "Western Coast Overlap Zone" between the tropical province and the Southern Australian Warm Temperate Province. Morgan & Wells (1991) in their review of the zoogeography point out that there is a small proportion of marine species endemic to Western Australia, most having at least part of their range in the overlap zone. The endemism varies with taxonomic group (e.g. 20% among shallow-water asteroids; < 10% among prosobranch molluscs).

Overview of modern near-shore foraminifera along the west coast of Australia

Table 2 charts the distribution of species found by Haig in the innermost neritic zone (< 20 m water depth) along the Western Australian coast from 25°S to 34° S. The species are illustrated in an on-line digital catalogue accessible in the "Biostrat Gallery" from web site: www.geol.uwa.edu.au/biostrat. This preliminary compilation includes the innermost zone on the Houtmann Abrolhos Islands (where foraminiferal assemblages were initially studied by M. Corkeron in a 1994 unpublished UWA Honours thesis) and on Rottnest Island (where foraminiferal assemblages were initially studied by P. Miklavs in a 1998 unpublished UWA Honours thesis). The Houtmann

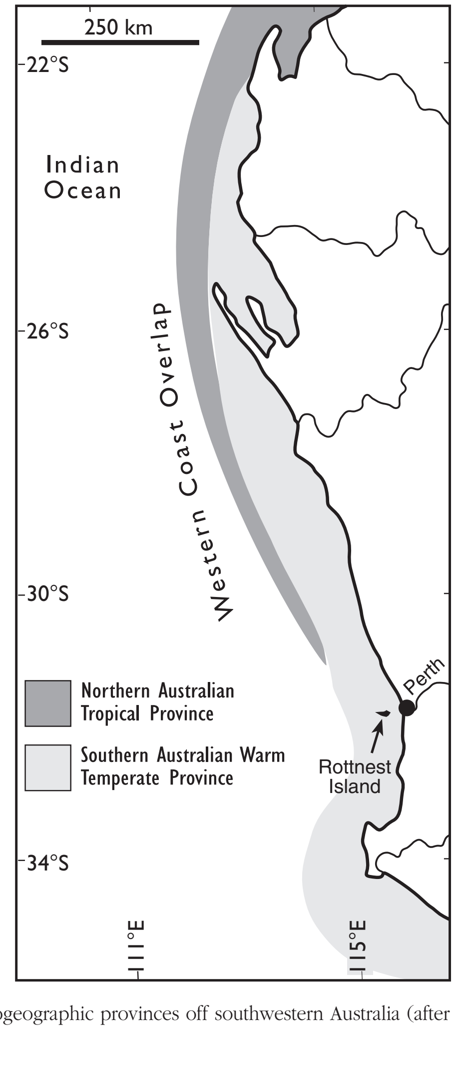


Figure 4. Marine zoogeographic provinces off southwestern Australia (after Morgan & Wells, 1991)

Table 2. Distribution of foraminifera identified by Haig from the inner neritic zone (< 20 m water depth) between 25°S and 34°S along the Western Australian coast. Those species that are known north of 25°S on the western and northern Australian margin are also indicated (see text).

	33_34°S (INSHORE)	32-33°S (INSHORE)	ROTTNEST (~ 32°S)	31-32°S (INSHORE)	30-31°S (INSHORE)	29_30°S (INSHORE)	ABROLHOS (~ 28-29°S)	27-29°S (INSHORE)	SHARK BAY (25-27°S)	NORTH
Agglutinated Species										
Ammotium australiensis (Collins)									X	X
Clavulina difformis Brady	X	X	X		X	X	X	X		
Clavulina multicamerata Chapman	X	X	X	X	X	X	X	X	X	X
Clavulina pacifica Cushman		X	X		X	X	X	X	X	X
Cribrobulimina mixta (Parker & Jones)		X	X		X					
Eggerelloides australis (Collins)			X							X
Paratrochammina sp. 1			X							
Placopsilina sp. 1							X			
Placopsilina sp. 2			X							
Pseudogaudryina sp. [? Gaudryina convexa (Karrer)]	X	X	X		X				X	X
Reophax sp.								X		
Rotaliammina chitinosa (Collins)		X	X						X	X
Rudigaudryina sp. 1			X				X			X
Sahulia sp. 1	X		X		X		X	X	X	X
Scherochorella sp. 1			X							
Septotrochammina sp. 1			X							
Siphoniferoides siphoniferus (Brady)			X				X		X	X
Siphotextularia? sp. 1		X								
Textularia agglutinans d'Orbigny		X						X	X	X
Textularia candeiana d'Orbigny		X							X	
Textularia cushmani Said		X	X			X	X		X	X
Textularia foliacea Heron-Allen & Earland			X							X
Textularia kerimbaensis Said	?		X				X			X
Textularia pseudogramen Chapman & Parr							X			X
Textularia sp. 1	X	X	X	X	X			X	X	X
Trochammina inflata (Montagu)		X				X			X	
Spicule-secreting (Carterinida) Species										
Carterina spiculotesta (Carter)									X	
Porcellaneous (Miliolida) Species										
Alveolinella quoyi (d'Orbigny)									X	X
Amphisorus hemprichii Ehrenberg	X	X	X		X	X	X	X	X	X
Articulina alticostata Cushman	X	X	X						X	X
Articulina sp. 1			X							
Articulina sp. 2 [? Articulina mucronata (d'Orbigny)]			X							
Biloculinella depressa (d'Orbigny)	X			X	X					X
Biloculinella labiata (Schlumberger)	X	X	X					X		X
Borelis schlumbergeri (Reichel)							X			X
Cornuspira planorbis Schultze	X	X	X				X	X	X	X
Coscinospira hemprichii Ehrenberg		X			X	X	X		X	X
Coscinospira okinawaensis (Ujiié & Hatta)									X	X
Cribromiliolinella milletti (Cushman)									X	X
Euthymonacha polita (Chapman)	X	X	X				X		X	X
Fischerinella diversa McCulloch			X							X
Hauerina diversa Cushman	X		X				X			
Inaequalina disparilis (Terquem)	X	X	X							X
Massilina sp. 1			X							
Massilina sp. 2			X							
Miliolinella baragwanathi (Parr)	X	X	X	X	X	X	X		X	X
Miliolinella pilasensis McCulloch	X	X	X	X	X	X	X	X	X	X
Miliolinella suborbicularis (d'Orbigny)		X					X		X	X
Miliolinella sp. of Haig 1997	X	X	X		X		X	X	X	X
Miliolinella sp. 2	X	X	X	X	X	X		X		
Miliolinella sp. 4	X	X	X		X				X	X
Monalysidium acicularis (Batsch)						X			X	X
Monalysidium? sp. 1	X								X	
Nevillina coronata (Millett)								X		
Nubecularia lucifuga Defrance	X	X	X		X	X	X	X	X	X
Nubeculina advena Cushman		X					X		X	X
Nubeculinita ramosa Loeblich & Tappan	X	X	X		X			X	X	X
Nummulopyrgo globulus (Hofker)	X	X	X		X	X	X	X		X
Parahauerinoides fragilissimus (Brady)									X	X
Parrina bradyi (Millett)	X	X	X	X	X	X	X	X	X	X
Peneroplis planatus (Fichtel & Moll)		X	X	X	X	X	X	X	X	X
Planispirinella exigua (Brady)	X	X	X						X	X
Pseudomassilina australis (Cushman)	X	X							X	X
Pseudomassilina macilenta (Brady)									X	X
Pseudomassilina sp. cf. P. robusta Lacroix		X	X						X	X
Pseudopyrgo milletti (Cushman)									X	X
Pyrgo compressioblonga Zheng							X	X	X	X
Pyrgo pisum Schlumberger			X		X				X	X
Pyrgo striolata (Brady)		X	X	X	X		X	X	X	X
Quinqueloculina agglutinans d'Orbigny			X							X
Quinqueloculina arenata Said	X	X							X	
Quinqueloculina sp. cf. Q. arenata Said		X	X				X		X	
Quinqueloculina barnardi Rasheed	X	X		X	X			X	X	X
Quinqueloculina bradyana Cushman	X	X	X	X	X	X	X	X		
Quinqueloculina crassicarinata Collins									X	X
Quinqueloculina sp. cf. Q. cuvieriana d'Orbigny	X	X	X	X	X	X	X	X	X	X
Quinqueloculina distorqueata Cushman	X	X	X						X	X
Quinqueloculina eburnea (d'Orbigny)	X	X	X						X	X
Quinqueloculina sp. cf. Q. eburnea (d'Orbigny)	X	X	X					X	X	X
Quinqueloculina exsculpta (Heron-Allen & Earland)		X	X				X		X	X
Quinqueloculina funafutiensis (Chapman)	X	X	X			X			X	X
Quinqueloculina sp. cf. Q. funafutiensis (Chapman)	X	X							X	
Quinqueloculina granulocostata Germeraad	X	X	X			X	X	X	X	X
Quinqueloculina sp. 1 cf. Q. granulocostata Germeraad		X								
Quinqueloculina sp. 2 cf. Q. granulocostata Germeraad		X							X	
Quinqueloculina sp. cf. Q. intricata Terquem		X								
Quinqueloculina neostriatula Thalmann		X	X		?		X		X	X
Quinqueloculina parkeri (Brady)		X	X		X	X	X	X	X	X
Quinqueloculina parvaggluta Vella	X	X							X	X
Quinqueloculina patagonica d'Orbigny		X	X		X	X	X	X	X	X
Quinqueloculina philippinensis Cushman		X						X		X
Quinqueloculina poeyana d'Orbigny	X	X	X		X			X	X	X
Quinqueloculina polygona d'Orbigny	X	X	X			X			X	X
Quinqueloculina quinquecarinata Collins		X	X	X		X	X	X	X	X
Quinqueloculina seminula (Linné)	X	X	X	X	X			X	X	X
Quinqueloculina subgranulata (Cushman)	X	X	X		X	X		X	X	X
Quinqueloculina subpolygona Parr	X	X	X	X	X	X	X	X	X	X
Quinqueloculina sulcata d'Orbigny	X	X	X		X		X	X	X	X
Quinqueloculina tropicalis Cushman		X	X						X	X
Quinqueloculina vandiemeniensis Loeblich & Tappan	X	X	X		X	X	X	X		X
Quinqueloculina wiesneri Parr									X	X
Quinqueloculina sp. 3		X	X		X	X			X	
Quinqueloculina sp. 4	X	X	X			X		X	X	X
Quinqueloculina sp. 5		X			X		X			
Quinqueloculina sp. 6	X	X	X			X		X	X	X
Quinqueloculina sp. 7		X	X	X		X	X	X	X	X
Quinqueloculina sp. 8		X	X	X						
Quinqueloculina sp. 9		X	X							
Quinqueloculina sp. 10			X			X	X		X	
Quinqueloculina sp. 11							X	X	X	
Quinqueloculina sp. 12		X	X		X		X		X	
Quinqueloculina sp. 13	X	X							X	
Quinqueloculina sp. 14							X			
Quinqueloculina sp. 15		X							X	
Quinqueloculina sp. 16	X	X								
Quinqueloculina sp. 17	X								X	
Rupertianella rupertiana (Brady)	X	X							X	X
Sigmamiliolinella australis (Parr)	X	X	X	X	X		X	X	X	X
Sigmoihauerina involuta (Cushman)	X								X	X
Sigmoilinella tortuosa Zheng		X	X	X	X		X			X
Sorites marginalis (Lamarck)									X	X
Sorites orbiculus (Forskal)		X	X		X	X	X	X	X	X
Spiroloculina angulata Cushman	X	X	X	X		X	X		X	X
Spiroloculina corrugata Cushman & Todd	X	X	X		X	X	X	X	X	X
Spiroloculina foveolata Egger			X				X			X
Spiroloculina hadai Thalmann	X	X	X				X		X	X
Spiroloculina nummiformis Said		X								
Spiroloculina parvula Chapman			X							X
Spiroloculina subimpressa Parr	X	X	X	X	X	X	X	X	X	X
Spiroloculina sp. 1				X						
Spiroloculina sp. 2									X	
Spiroloculina sp. 3										
Spiropthalmidium prolixum Loeblich & Tappan			?				X			X
Spirosigmoilina bradyi Collins							X			
Triloculina barnardi Rasheed			X				X		X	X
Triloculina bertheliniana (Brady)		X								X
Triloculina earlandi Cushman							X		X	X
Triloculina littoralis Collins									X	X
Triloculina marshallana Todd	X	X	X	X	X	X	X	X	X	X
Triloculina striatotrigonula Parr	X	X	X		X	X		X	X	
Triloculina tricarinata d'Orbigny	X	X	X		X	X	X	X	X	X
Triloculina trigonula (Lamarck)	X	X	X	X	X	X		X	X	X
Triloculina vespertilio Zheng			X	X			X		X	X
Vertebralina striata d'Orbigny	X	X	X		X	X	X	X	X	X
Wiesnerella auriculata (Egger)	X	X	X			X	X		X	X
Wiesnerella sp. 1	X	X								

Table 2. continued...

Species	33_34°S (INSHORE)	32-33°S (INSHORE)	ROTTNEST (~ 32°S)	31-32°S (INSHORE)	30-31°S (INSHORE)	29_30°S (INSHORE)	ABROLHOS (~ 28-29°S)	27-29°S (INSHORE)	SHARK BAY (25-27°S)	NORTH
Hyaline (Spirillinida) Species										
Heteropatellina sp. cf. H. frustratiformis McCulloch	X	X	X	X	X		X			
Mychostomina peripora Zheng		X	X			X	X		X	X
Mychostomina revertens (Rhumbler)	X	X	X		X				X	X
Patellina corrugata Williams		X	X	X	X	X	X	X		X
Patellina sp. 1	?		X						X	
Spirillina denticulata Brady	X	X	X	X	X		X	X	X	X
Spirillina inaequalis Brady		X	X	X	X	X	X		X	X
Spirillina planoconcava Zheng	X	X	X	X	X		X			
Spirillina runiana Heron-Allen & Earland	X	X	X		X				X	
Spirillina tuberculatolimbata Chapman	X	X	X	X			X			X
Spirillina vivipara Ehrenberg	X	X	X				X		X	X
spirillinid genus and species uncertain 1	X	X	X				X		X	
Turrispirillina sp. 1		X	X							
Hyaline (Lagenida) Species										
Astacolus sp. 1		X								
Behillia sp. cf. B. frailensis McCulloch							X			
Cushmanina sp. 1							X			
Dentalina sp. 2			X				X			
Entolingulina pilasensis (McCulloch)			X							
Fissurina bisulca (McCulloch)			X				X			
Fissurina sp. cf. F. bradyiformata (McCulloch)	X	X	X	X			X			
Fissurina contusa Parr	X	X	X	X	X		X			X
Fissurina favosiformis (McCulloch)		X	X							
Fissurina lacunata (Burrows & Holland)	X	X	X				X		X	X
Fissurina sp. F. lacunata (Burrows & Holland)	X	X	X	X		X	X			
Fissurina lucida (Williamson)	X	X	X			X	X		X	X
Fissurina omniperforata McCulloch	X	X	X			?				
Fissurina radiatomarginata (Parker & Jones)					X		X			X
Fissurina soulei (McCulloch)			X							X
Fissurina sp. 1		X	X			X	X		?	
Fissurina sp. 2	?	X	X		X					
Fissurina sp. 3		X								
Fissurina sp. 4			X							
Fissurina sp. 5			X							
Fissurina sp. 6			X							
Guttulina bartschi Cushman & Ozawa	X	X	X						X	X
Guttulina regina (Brady, Parker & Jones)			X							X
Laevidentalina sp. cf. L. bradyensis (Dervieux)		X			X					
Laevidentalina sp. 2		X	?							
Laevidentalina sp. 3			X							
Lagena flatulenta Loeblich & Tappan		X	X					X	X	
Lagena flexa Cushman & Gray	X	X								X
Lagena oceanica Albani		X	X						X	X
Lagena pustulostriatula Albani & Yassini		X	X							
Lagena sp. cf. L. semistriata Williamson		X				X				
Lagena sp. 2		X								
Lenticulina domantayi (McCulloch)	X	X	X				X		X	X
Lenticulina sp.						X				
Oolina sp. cf. O. ampulladistoma (Rymer-Jones)	X	X	X							
Oolina sp. 1	X	X				X				
Oolina sp. 2	X		X							
Polymorphina? sp.		X								
Procerolagena gracillima (Seguenza)	X	X	X							X
Procerolagena sp. 1	?	X	X							
Psilocitharella sp. 1			X							
Pyramidulina catesbyi (d'Orbigny)		X								X
Sigmoidella sp. cf. S. elegantissima (Parker & Jones)	X	X	X						X	X
Sigmoidella sp. 1							X			
Hyaline (Buliminida) Species										
Abditodendrix rhomboidalis (Millett)	X	X	X	X	X	X	X		X	X
Angulogerina sp. 1			X	X			X			X
Angulogerina sp. 2	X	X								
Bolivina pseudoplicata Heron-Allen & Earland		X								
Bolivina striatula Cushman	X	X	X			X		X	X	X
Bolivina vadescens Cushman		X				X			X	X
Bolivina variabilis (Williamson)		X	X	X	X	X	X	?	X	X
Bolivina sp. 1 of Haig 1997	X		X	X						X
Bolivina sp. 4			X							
Bolivina sp. 5			X							
Bulimina marginata d'Orbigny		X							X	X
Bulimina elongata d'Orbigny		X				?				
Buliminella elegantissima (d'Orbigny)		X	X							X
Cheilochanus fimbriatus (Collins)							X			X
Chrysalidinella dimorpha (Brady)		X		X			X			X
Elongobulla gracilis (Collins)	X	X							X	
Elongobulla sp. cf. E. gracilis (Collins)			X	X						
Elongobula hebetata (Cushman & Parker)	X	X	X	X			X		X	X
Elongobula sp. cf. E. spicata (Cushman & Parker)	X	X			X		X		X	X
Fursenkoina schreibersiana (Czjzek)		X	X						X	X
Globocassidulina minuta (Cushman)		X	X				X		X	X
Hopkinsinella glabra (Millett)		X								X
Loxostomina costatapertusa Loeblich & Tappan		X					X		X	X
Loxostomina costulata (Cushman)		X								X
Loxostomina limbata (Brady)	X	X	X	X			X	X	X	X
Loxostomina sp. 1		X	X				X		X	
Loxostomina sp. 3		X								
Millettia limbata (Brady)							X			X
Neocassidulina abbreviata (Heron-Allen & Earland)	X	X	X	X	X	X	X	X	X	X
Pavonina flabelliformis d'Orbigny	X	X	X	X			X			X
Radiatobolivina okinawaensis Hatta	X	X	X	X		X	X			X
Reussella? armata Parr	X	X	X	X	X		X			
Reussella neopolitana Hofker							X			X
Reussella? sp. 1	X	X	X	X	X		X		X	X
Rugobolivinella elegans (Parr)	X	X	X	X			X		X	X
Sagrina sp. cf. S. zanzibarica (Cushman)							X		X	X
Sigmavirgulina tortuosa (Brady)	X	X	X		X	X	X		X	X
Sigmavirgulina sp. 1	X	X	X	X	X	X	X			X
Sigmavirgulina? sp. 2			X			X				
Siphogenerina raphana (Parker & Jones)	X	X	X	X	X	X	X	X	X	X
Siphogenerina sp. 1	X	X	X	X	X	X	X		X	
Siphouvigerina sp. cf. S. porrecta (Brady)		X								X
Trimosina sp.									X	

Abrolhos and Rottnest Islands are located near the outer edge of the continental shelf and come under the direct influence of the south-flowing warm Leeuwin Current (see above). Also indicated on the Table, are those species that have been recorded to the north of 25°S (in unpublished records from J. Parker, J. Blakeway, and D. Haig from Ningaloo Reef; Haig, 1997, and Orpin *et al.*, 1999, from Exmouth Gulf; Loeblich & Tappan, 1994, from the Sahul Shelf; and unpublished 2001 UWA Honours work by D. Collins on Ashmore Reef). For some of the rare species, records from the northern (New Guinea) margin of the Australian continent by Haig (1988, 1993) are also noted in the "N" column, if no northern Western Australian record is available.

The compilation of the distributions of about 350 near-shore species suggests that many range through the 25-34°S region. Species, common in the south, whose distributions may extend no further north than 25°S (northern part of Shark Bay) include: *Triloculina striatotrigonula* (> 25°S), *Siphogenerina* sp. 1 (> 25°S), *Annulopatellina annularis* (> 25°S), *Planoglabratella opercularis* (> 25°S), *Clavulina*

Table 2. continued...

Hyaline (Rotaliida) Species	33_34°S (INSHORE)	32-33°S (INSHORE)	ROTTNEST (~ 32°S)	31-32°S (INSHORE)	30-31°S (INSHORE)	29_30°S (INSHORE)	ABROLHOS (~ 28-29°S)	27-29°S (INSHORE)	SHARK BAY (25-27°S)	NORTH
Acervulina mahabeti (Said)	X	X	X	X	X	X	X	X	X	X
Ammonia convexa (Collins)					?			X	X	X
Ammonia parkinsoniana (d'Orbigny)		X	X						X	X
Ammonia tepida (Cushman)	X	X	X			X	X	X	X	X
Ammonia sp. of Haig (1998)									X	X
Amphistegina lessonii d'Orbigny	X	X	X	X	X	X	X	X	X	X
Amphistegina lobifera Larsen									X	X
Angulodiscorbis corrugata (Millett)		X	X	X		X	X		X	X
Annulopatellina annularis (Parker & Jones)	X	X	X	X	X	X	X		X	
Anomalinulla glabrata (Cushman)	X	X	X	X		X	X		X	X
Anomalinulla sp. 1	X	X	X	X	X	X			X	X
Asanonella tubulifera (Heron-Allen & Earland)	X		X	X			X			X
Asterigerina sp.	X									
Bronnimannia haliotis (Heron-Allen & Earland)		X	X				X			X
Buccella? rara (Yassini & Jones)		X	X							
Buliminoides williamsonianus (Brady)		X		X	X	X	X		X	X
buliminoid? genus & species uncertain			X				X			
Cancris auriculus (Fichtel & Moll)	X	X	X			X			?	X
Cibicides mayori (Cushman)	X	X	X				X		X	X
Cibicides sp. cf. C. refulgens Montfort	X	X	X	X	X	X	X	X	X	X
Cibicidoides basilanensis McCulloch		X	X		X		X			X
Cibicidoides sp. of Haig 1997	X	X	X		X				X	
Colonimilesia obscura McCulloch	X									X
Conorbella pulvinata (Brady)	X	X	X	X	X		X		X	X
Cribrobaggina socorroensis McCulloch			X				X			
Cymbaloporetta bermudezi (Sellier de Civrieux)	X	X	X			X		X	X	
Cymbaloporetta bradyi (Cushman)							X	X	X	X
Discorbinella sp. 1		X								
Discorbinella sp. 2	X									
Discorbinoides minogasaformis Ujiié			?		X		X	X	X	X
Dyocibicides biserialis Cushman & Valentine	X	X	X	X	X	X	X	X	X	X
Elphidium advenum (Cushman)	X	X				X		X	X	X
Elphidium botaniense Albani	X	X	X		X	X	X		X	X
Elphidium craticulatum (Fichtel & Moll)		X							X	X
Elphidium crispum (Linné)	X	X	X	X	X	X	X	X	X	X
Elphidium spp. aff. E. excavatum (Terquem)	X	X	X	X	X	X	X		X	X
Elphidium mortonbayensis Albani & Yassini									X	X
Elphidium novozealandicum Cushman	X	X	X	X	X	X	X	X	X	X
Elphidium reticulosum Cushman		X	X			X	X		X	X
Elphidium silvestrii Hayward		X	X						X	
Elphidium sp. cf. E. striatopunctatus (Fichtel & Moll)									X	X
Elphidium sp. 5			X				X		X	
Elphidium sp. of Haig 1997	X	X			X		X	X	X	X
Elphidium sp. 7		X								
Elphidium sp. 10		X								
Elphidium sp. 11									X	
Elphidium sp.								X		
Epistomarioides polystomelloides (Parker & Jones)	X		X		X		X			X
Eponides repandus (Fichtel and Moll)		X	X				X	X	X	X
Eupatellinella fastidiosa (McCulloch)							X			X
Fijinonion sp. 1		X	X							
Glabratella? sp. 1		X							X	
Glabratellina australensis (Heron-Allen & Earland)	X	X	X	X	X	X	X	X	X	X
Glabratellina patelliformis (Brady)	X	X	X						X	
Glabratellina sp. 3			X							
Glabratellina sp. 4			X							
Glabratellina sp. 5		X		X	X	X	X		X	
Glabratellina sp. 6	X		X				X			
Glabratellina sp. 7		X								
Heronallenia lingulata (Burrows & Holland)	X	X	X	X			X			
Heronallenia? sp.	X									
Heterostegina depressa d'Orbigny					X		X		X	X
Homotrema rubra (Lamarck)							X	X	X	X
Lamellodiscorbis dimidiatus (Jones & Parker)	X	X	X	X	X	X	X	X	X	X
Lamellodiscorbis melbyae Hansen & Revets	X	X	X	X	X	X	X	X	X	X
Lamellodiscorbis sp. 1	X	X	X		X	X				
Laminononion sp. 1		X								
Metarotiella? sp.									X	
Millettiana millettii (Heron-Allen & Earland)		X					X		X	X
Miniacina miniacea (Pallas)		X	X				X	X		X
Monspeliensina sp. 1 of Haig, 1997		X		X						X
Monspeliensina? sp. 2	X	X	X	X	X					
Murrayinella murrayi (Heron-Allen & Earland)		X					X		X	X
Neoconorbina cavalliensis Hayward et al.	X	X	X	X	X	X	X		X	X
Neoconorbina sp.									X	X
Neoeponides sp.							X			
Neorotalia calcar (d'Orbigny)			X	X	X	X	X	X	X	X
Neorotalia sp.	X	X	X		X					
Nonionoides grateloupi (d'Orbigny)		X				X			X	X
Orbitina carinata Sellier de Civrieux	X		X		X	X			X	X
Pannellaina earlandi (Collins)							X			X
Pararotalia nipponica (Asano)	X	X	X	X	X	X		X	X	X
Patellinella inconspicua (Brady)			X				X			
Pegidia lacunata McCulloch										
Planodiscorbis sp.	X	X	X							
Planoglabratella opercularis (d'Orbigny)	X	X	X	X	X		X		X	
Planoglabratella sp. aff. P. opercularis (d'Orbigny)	X	X	X	X	X		X			
Planogypsina acervalis (Brady)	X	X	X	X	X	X	X	X	X	X
Planogypsina squamiformis (Chapman)	X	X	X	X	X	X	X	X	X	X
Planulinoides biconcavus (Parker & Jones)	X	X	X	X	X	X		X	X	X
Planulinoides narcotti Hedley, Hurdle & Burdett	X	X	X	X	X	X	X			X
Poroeponides lateralis (Terquem)								X	X	X
Pseudoparrella? sp. 1				X						
Pyropiloides elongatus Zheng	X	X	X		X	X		X		X
Rosalina bradyi (Cushman)		X	X	X	X	X	X	X	X	X
Rosalina cosymbosella Loeblich & Tappan			X				X			X
Rosalina sp. 1	X	X	X	X				X	X	
Rosalina? sp. 2						X	X	X	X	
Rosalina sp. 3		X		X						
Rotorbis auberi (d'Orbigny)	X	X	X	X	X	X	X		X	X
Rotorboides granulosa (Heron-Allen & Earland)			X		X	X	X		X	X
Saintclairoides marlysae McCulloch	X	X	X				X			X
Siphonina tubulosa Cushman			X				X			X
Siphoninoides laevigatus (Howchin)		X	X	X			X		X	X
Siphoninoides echinatus (Brady)		X			X		X			X
Sphaerogypsina globulus (Reuss)	X	X	X		X		X		X	X
Stomatorbina concentrica (Parker & Jones)	X	X	X				X			X
Svratkina bubnanensis McCulloch	X				X					X
Tretomphalus bulloides (d'Orbigny)	X	X	X				X	X	X	X
indeterminant rotaliid	X									

difformis (> 27°S), *Miliolinella* sp. 2 (> 27°S), *Quinqueloculina bradyana* (> 27°S), *Reussella? armata* (> 28°S), *Planoglabratella* sp. aff. *P. opercularis* (> 28°S), *Cribrobulimina mixta* (> 30°S), *Monspeliensina?* sp. 2 (> 30°S), and *Neorotalia* sp. (> 30°S). Species that are well known to the north but come only part of the way south in this region include *Ammonia convexa* (< 31°S), *Monalysidium acicularis* (< 30°S), *Borelis schlumbergeri* (< 29°S), *Pyrgo compressioblonga* (< 29°S), *Triloculina earlandi* (< 29°S), *Poroeponides lateralis* (< 29°S), *Alveolinella quoyi* (< 27°S), *Coscinospira okinawaensis* (< 27°S), *Cribromiliolinella milletti* (< 27°S), *Parahauerinoides fragilissimus* (< 27°S), *Pseudomassilina macilenta* (< 27°S), *Pseudopyrgo milletti* (< 27°S), *Quinqueloculina crassicarinata* (< 27°S), *Triloculina littoralis* (< 27°S), *Ammonia* sp. (< 27°S), *Amphistegina lobifera* (< 27°S), and *Elphidium mortonbayensis* (< 27°S).

Betjeman (1969) reviewed the distribution of foraminifera in sediment samples taken mainly from mid to outer neritic water depths over a similar latitudinal range to that discussed here. His sample coverage was scattered and his characterisation of guide species for temperate and tropical-subtropical faunal regions is, in general, not supported by the present compilation.

The near-shore foraminiferal distributions along the south-west coast conform to the marine zoogeographic provinces recognized by Morgan & Wells (1991). Most of the region falls within the "Western Coast Overlap Zone" containing elements of both the Northern Australian Tropical Province (a typical Indo-West Pacific fauna) and the Southern Australian Warm Temperate Province. There seems to be a gradual north-south transition in foraminiferal distributions between these provinces.

Swan Estuary & Coastal Plain

RIVER CRUISE, PERTH TO NORTH PORT: SWAN ESTUARY AND COASTAL PLAIN

Overview of Swan Coastal Plain

In the Perth region, the Swan Coastal Plain is bordered to the east by the Darling Scarp (Figure 1), formed by the Darling Fault. Most of the coastal plain is covered by Pleistocene sand dunes that dominate the local landscape and greatly influence the vegetation. The dunes are the reason why Western Australians are called "sand-gropers" (named after a small arthropod, *Cylindracheta*, which burrows into the sand dunes). The dunes form ridges that parallel the coast, and are up to 100 m higher than the interdunal depressions that, in places, contain small permanent lakes and swamps. The soils developed on the dunes are composed almost entirely of quartz. Three dune systems are recognized: (1) the Quindalup Dunes that are forming along the present coast; (2) the Spearwood Dunes that are further inland and made up of mixed carbonate-quartz sand; and (3) the Bassendean Dunes which form the eastern-most dunes of the coastal plain and are characterised by yellow quartz sand (see Figure 5 for distribution of dune systems).

During the Pliocene the predominantly siliciclastic Ascot Formation (Table 1) was deposited on the inner shelf of the Perth Region. The overlying carbonate coastal dunes reflect a change to high biogenic carbonate productivity in the coastal waters during the Middle Pleistocene. Kendrick *et al.* (1991) attributed this to an active Leeuwin Current flowing, as relatively warm low-salinity water, southward along the Western Australian continental shelf. During the Pliocene, the Leeuwin Current may have been inactive or, at least, not as active as during the Middle Pleistocene.

Just to the east of Perth City (and the start of our river cruise) lies the Bassendean Dune System, the oldest of the Pleistocene dunes, now represented through much of the area by a broad sand plain. The Bassendean Sand forming the dunes consists of yellow quartz sand. The colour of the sand results from a clay-size coating of goethite and kaolinite on the quartz grains. Considerable controversy exists about the origin of the yellow-sand deposits. One view claims that the quartz sand is a residue from weathering of calcarenites similar to the Tamala Limestone of the younger Spearwood Dune System (e.g. Playford *et al.*, 1976; Wyrwoll & King, 1984; Bastian, 1996). An alternate view is that the yellow quartz sand has an eastern desert origin and was blown to its present site during arid phases of the Pleistocene when winds may have been stronger than at present (e.g. Semeniuk & Glassford, 1988; Glassford & Semeniuk, 1990, 1995).

Most of the river cruise traverses the Spearwood Dune System. The Tamala Limestone (forming the Spearwood Dunes) consists of coarse to medium-grained calcarenite composed mainly of foraminifera, molluscs, and articulate coralline algae. Large-scale aeolian cross-bedding is characteristic of the dune deposits. Soil horizons and calcified root structures are common in the calcarenite sections. Whereas aeolian dune deposits dominate outcrops of the Tamala Limestone, some marine units are included in the formation. These include coral-algal reefs, seagrass meadow deposits, and shelly shore-face and estuary sand-gravel facies. In some of the older literature and in more recent papers by Semeniuk and others (e.g. Semeniuk & Johnson, 1982; Semeniuk & Glassford, 1988) the Tamala Limestone is called the Coastal Limestone.

Bastian (1996) mapped and named individual Pleistocene dune ridges in the Perth region (Figure 6), and showed that these were continuous dunes that parallel the present coast. Similar dune ridges also are present on the continental shelf west of the present coast; some occur as islands (e.g. Garden Island and Rottnest Island; Figure 1) and others are submerged (e.g. Five Fathom Bank; Figure 1). A systematic

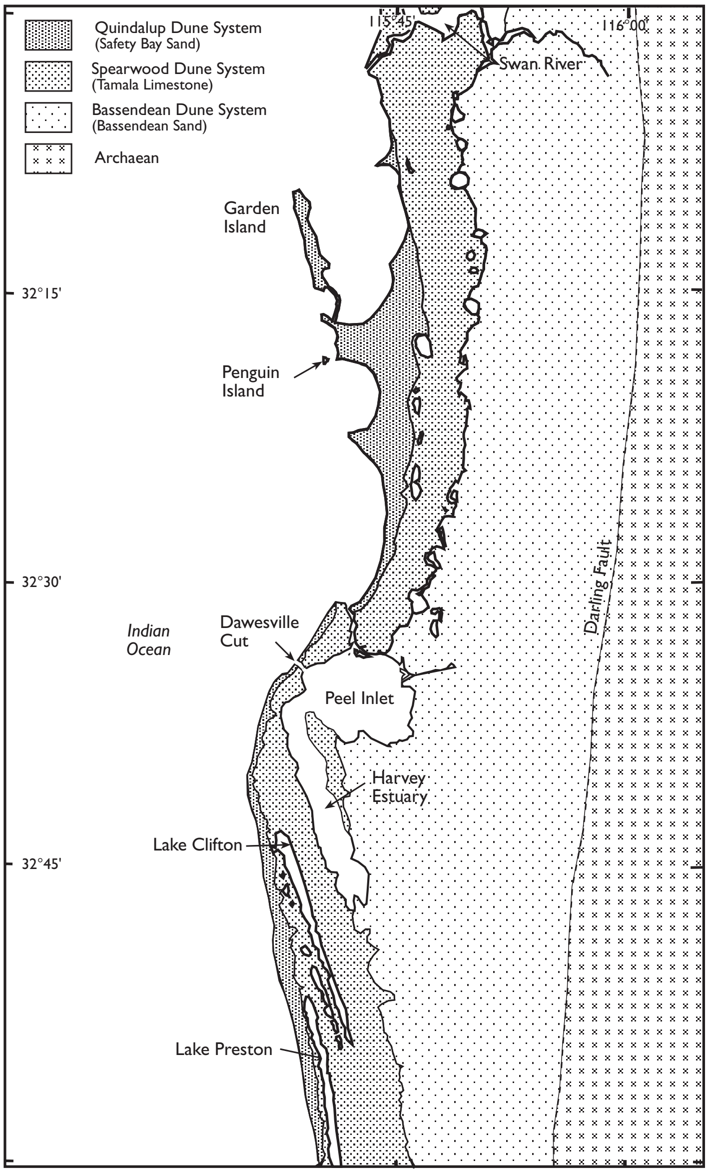


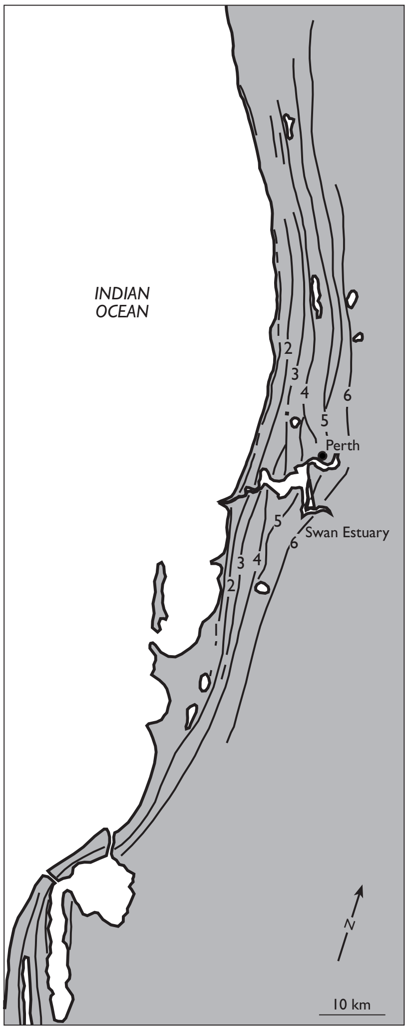
Figure 5. Geological map of region south of Perth, showing the location of the Holocene and Pleistocene dune systems (after Wilde & Low, 1980).

study has not been attempted to date each dune ridge. Some dates for units included in the Tamala Limestone are available. These have been mainly derived from the marine units in the formation, and include U-series ages (Szabo, 1979; Stirling *et al.*, 1995), electron spin resonance dates (Hewgill *et al.*, 1983) and amino acid-racemization dates (Murray-Wallace and Kimber, 1989). Together with broader stratigraphic evidence, these age determinations were taken by Kendrick *et al.* (1991) to indicate that the investigated shells beds in the Perth region belong to Oxygen Isotope Stage 7 (mid Pleistocene).

The Yokine Dunes, the oldest set in the Spearwood Dune System, are present within the central business area of Perth. As we cruise downstream from the ferry terminal and view the northern side of the river, we pass progressively younger dunes. The area between the Narrows Bridge and UWA, looking towards Kings Park (Figure 7), shows a cross-section of the Balcatta Dunes. Further along the river, prime real estate in the suburbs of Dalkeith and Claremont sits on the Gwelup Dunes. As the river channel swings around the Point Walter sand spit (on the south side) and then narrows, the Karrinyup Dunes form river cliffs on the north side in the suburbs of Peppermint Grove and Mosman Park. As Fremantle is approached, the Karrinyup Dunes give way to the Trigg Dunes, the youngest Pleistocene set.

The Safety Bay Sand, which forms the Holocene Quindalup Dunes bordering the present coastline, is made up of biogenic carbonate grains (mainly foraminifera,

Figure 6. Pleistocene dune trend lines in the Perth region. Dunes are numbered 1-6: 1, Trigg Dunes; 2, Karrinyup Dunes; 3, Gwelup Dunes; 4, Balcatta Dunes; 5, Yokine Dunes; 6, Gnangarra Dunes (after Bastian, 1996).



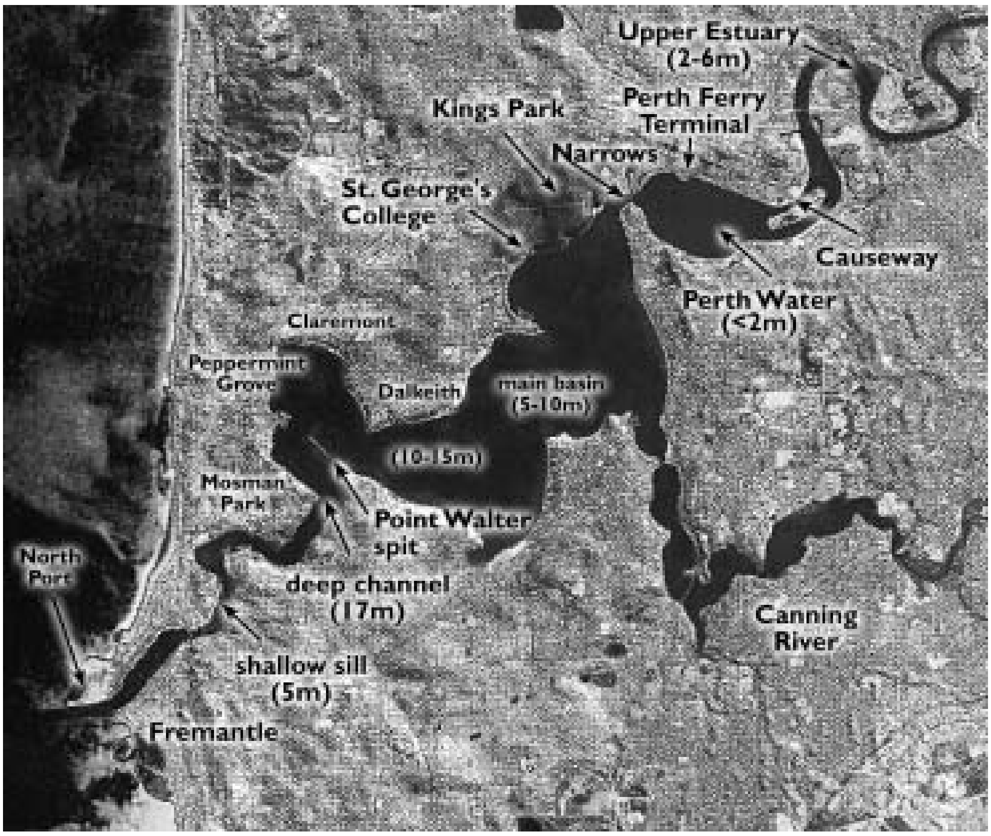


Figure 7. Satellite image of Perth Estuary (reproduced by permission of Department of Land Administration).

molluscs, articulate coralline algae) with varying amounts of quartz (Playford *et al.*, 1976). Semeniuk & Johnson (1982) established a stratigraphic model for dune deposition along the wave-dominated sandy coastline of south-west Western Australia. Various landforms in the Quindalup Dune System and its internal stratigraphy were described by Semeniuk *et al.* (1989). The Fremantle region belongs within the Cape Bouvard-Trigg Island Sector of the inner Rottnest Shelf (Searle & Semeniuk, 1985). This sector extends along the coast from about 80 km south of the Swan River mouth to about 20 km north of the river mouth. As described by Semeniuk *et al.* (1989), the Quindalup Dune System in this sector is characterised by a low cuspate beach-ridge plain that, in places, is up to 10 km wide. In the Fremantle area adjoining the river mouth, it is very narrow and is not present where sea cliffs of Tamala Limestone form along the coast. Within the Quindalup Dune System, there are parallel beach ridges that represent accretion stages of a prograding shoreline. The beach ridges are 1-3 m high and up to 50 m wide. In some places blow-outs have occurred and the associated parabolic dunes are up to 20-30 m high.

The dune deposits in the Perth area form a veneer on older Paleocene and Cretaceous units. For example, the upper Paleocene Kings Park Shale was encountered when pylons were dug for the Narrows Bridge; and the Cretaceous Leederville Formation is occasionally exposed under the Bassendean Sand in quarries on the eastern side of Perth.

The Swan Estuary

The Swan River drains a region that has a Mediterranean type climate (with a hot dry summer and a cool wet winter) and lies in the sub-humid belt of Western Australia (Figure 1). Water temperatures in this microtidal estuary change markedly with the season: 12-14°C during winter ; and 22-24°C during summer. In front of the Perth Ferry Terminal (Figure 7), between the Causeway (upstream) and the Narrows Bridge (downstream), is a very shallow part of the river (< 2 m deep) called Perth Water. It forms a sill within the river separating the upper estuary (east of the Causeway) from the lower estuary (downstream from the Narrows Bridge). In the upper estuary, water depths are generally 2-3 m but some areas reach 6 m. In the lower estuary, the section of river between Fremantle and Mosman Park (Figure 7) forms another sill. This part of the river is about 5 deep and separates an upstream narrow channel (up to 17 m deep) leading into the main basin of the upper estuary, from a downstream channel (10-15 m deep) open to the ocean (Figure 7).

The two sills greatly affect the exchange of river and ocean waters. During summer (December-February) there is little freshwater inflow into the estuary, and only weak vertical stratification in the water column of the main basin and the upper estuary. In the lower estuary, saline water flows across the Mosman Park sill into the main basin forming a salt wedge that gradually advances upstream (Stephens & Imberger, 1996). The saline waters extend to about 42 km up the river. In summer the estuary basin is well oxygenated with no vertical stratification. Most rain falls in winter (June-August) and, due to freshwater inflow, a low-salinity surface layer develops above the saline estuarine water and advances downstream. Because of this and because of the smaller amplitudes of neap tides in winter, very little oxygenated saline oceanic water flows over the sill near Mosman Park, and the bottom waters of the main basin become stagnant and de-oxygenated (Stephens & Imberger, 1996; Kurup *et al.*, 1998).

There is no detailed published account of the sediment distribution in the Swan Estuary. In general below 1 m water depth the sediment is muddy. In her 1998 unpublished Honours Thesis from The University of Western Australia, Sandra Corr described the sediment distribution in the upper estuary (upstream of the Causeway; Figure 7). In areas shallower than 1 m, fine to medium sand forms the substrate. Mud forms the deeper water substrate and varies from fluid-mud ooze in the main river channel below 2 m water depth to a cohesive black mud and a shelly organic-rich mud in other areas. Published studies of relevance to the sedimentology of the estuary, include Griffin (2000) on the production and settling rates of faecal pellets produced by copepods as a means of incorporating organic matter in the sediment, and Douglas and Adeney (2000) on diagenetic cycling of trace elements in the sediment.

The main benthic plant living in the lower estuary in water depths less than 2 m is *Halophila ovalis* which covers about 20% of the area of the main estuary basin (Hillman *et al.*, 1995). Because of its small size, fragile leaves, and high leaf turnover, this plant has a low epiphyte load. The lower estuary also has a variety of mainly red and brown macroalgae which show seasonal changes in diversity (John, 1988). John (1983, 1988) described the diatom flora of the Swan Estuary, including the epiphytic species.

Foraminifera of the Swan River

In the upper estuary, Sandra Corr (unpublished Honours Thesis, The University of Western Australia) found that *Ammonia tepida* dominates the foraminiferal assemblage with the highest numbers of tests found in the mud deposits of the channel. Tests of *Elphidium advenum, Elphidium* spp. cf. *E. excavatum*, and a few organic-cemented agglutinated species (*Haplophragmoides* sp. and *Morulaeplecta* sp.) are also present in the mud.

Muds of the more saline lower estuary contain a more diverse foraminiferal assemblage which has not been documented. Patrick Quilty is undertaking a study of this fauna. A sample of mud from the river channel near the Fremantle bridges yielded the assemblage recorded on Table 3. This assemblage is dominated by *Elphidium advenum.* Shallow-water mud-facies assemblages are uncommon along the south-west coast of Western Australia where sand dominates the soft-bottom marine substrates, and are only found in the deeper parts of estuaries or in restricted embayments (such as Cockburn and Warnbro Sounds to the south of Fremantle).

Table 3. List of species identified by Haig from a mud sample collected from the lower Swan Estuary near the Fremantle traffic bridges.

Agglutinated Species
Textularia agglutinans d'Orbigny
Textularia cushmani Said
Textularia sp. 1

Porcellaneous (Miliolida) Species
Articulina alticostata Cushman
Biloculinella labiata (Schlumberger)
Miliolinella baragwanathi (Parr)
Miliolinella sp. 2
Nummulopyrgo globulus (Hofker)
Parrina bradyi (Millett)
Peneroplis planatus (Fichtel & Moll)
Quinqueloculina bradyana Cushman
Quinqueloculina sp. cf. Q. cuvieriana d'Orbigny
Quinqueloculina granulocostata Germeraad
Quinqueloculina sp. cf. Q. intricata Terquem
Quinqueloculina neostriatula Thalmann
Quinqueloculina poeyana d'Orbigny
Quinqueloculina polygona d'Orbigny
Quinqueloculina quinquecarinata Collins
Quinqueloculina seminula (Linné)
Quinqueloculina subgranulata (Cushman)
Quinqueloculina subpolygona Parr
Quinqueloculina transversestriata (Brady)
Quinqueloculina vandiemeniensis Loeblich & Tappan
Quinqueloculina sp. 3
Quinqueloculina sp. 4
Quinqueloculina sp. 15
Sigmamiliolinella australis (Parr)
Spiroloculina angulata Cushman
Spiroloculina corrugata Cushman & Todd
Spiroloculina foveolata Egger
Triloculina barnardi Rasheed
Triloculina marshallana Todd sensu Hatta & Ujiie 1992
Triloculina striatotrigonula Parr
Triloculina tricarinata d'Orbigny
Triloculina trigonula (Lamarck)
Vertebralina striata d'Orbigny

Hyaline (Lagenida) Species
Fissurina sp. cf. F. bradyiformata (McCulloch)
Fissurina contusa Parr
Fissurina sp. F. lacunata (Burrows & Holland)
Fissurina lucida (Williamson)
Lagena sp.
Lenticulina domantayi (McCulloch)
Procerolagena gracillima (Seguenza)
Procerolagena sp. 1

Hyaline (Buliminida) Species
Abditodendrix rhomboidalis (Millett)
Angulogerina sp. 2
Bolivina striatula Cushman
Bolivina variabilis (Williamson)
Bulimina marginata d'Orbigny
Bulimina elongata d'Orbigny
Fursenkoina schreibersiana (Czjzek)
Pavonina flabelliformis d'Orbigny
Reussella? sp. 1
Sigmavirgulina tortuosa (Brady)

Hyaline (Rotaliida) Species
Ammonia tepida (Cushman)
Cibicides sp. cf. C. refulgens Montfort
Conorbella pulvinata (Brady)
Dyocibicides biserialis Cushman & Valentine
Elphidium advenum (Cushman)
Elphidium botaniense Albani
Elphidium spp. aff. E. excavatum (Terquem)
Elphidium novozealandicum Cushman
Elphidium reticulosum Cushman
Elphidium sp. cf. E. striatopunctatus (Fichtel & Moll)
Lamellodiscorbis dimidiatus (Jones & Parker)
Lamellodiscorbis melbyae Hansen & Revets
Millettiana millettii (Heron-Allen & Earland)
Monspeliensina? sp. 2
Murrayinella murrayi (Heron-Allen & Earland)
Planogypsina acervalis (Brady)
Rosalina ?bradyi (Cushman)

Rottnest Shelf

ROTTNEST SHELF FROM ROUS HEAD TO ROTTNEST ISLAND

Regional setting

The Rottnest Shelf extends from about 29°S to just below 33°S (Clarke, 1926; Carrigy & Fairbridge, 1954; Fairbridge, 1955). The Rottnest Shelf (to the 170 m bathymetric contour) is about 30 km wide at 32°S in the Perth-Rottnest Island vicinity. It has a very low east-west gradient with most of the shelf in the vicinity of Perth being submerged by < 50 m of water (Figure 8). Masselink (1996) summarized various oceanographic parameters that affect the metropolitan coastline. These include one of the most energetic sea-breeze systems in the world (locally known as the "Fremantle Doctor"). A persistent south to south-west swell impacts the coast, and superimposed on this are northwesterly to westerly storm waves during winter, and waves generated by the strong south to southwesterly summer sea breezes (which blow on about 60 % of summer days, frequently exceeding 10 mS^{-1}). The tides along the coast have a mean spring tidal range of 0.4 m (microtidal).

Collins (1988) outlined the sediment distribution on the Rottnest Shelf to the south of Rottnest Island. James *et al.* (1999) described the sediment distribution pattern on the middle and outer shelf in the region north of the island. According to Collins (1988), the thin Holocene veneer on the inner shelf between Fremantle and Rottnest is a mixed quartz-carbonate sand. In grab-samples studied by Collins, the quartz content varied from 50% to 98% of the sand, and the dominant biogenic grains recorded by him were bryozoans, molluscs, coralline algae and benthic foraminifera. West of Rottnest Island the mixed quartz-carbonate sand grades into foraminiferal-rich algal-bryozoan sand and in deeper water on the outermost shelf the sand passes into skeletal mud. According to James et al. (1999), the middle part of the northern Rottnest Shelf has coralline algae-encrusted hardgrounds and carbonate sand with abundant coralline algae, "larger" (symbiont-bearing) foraminifera, together with abundant "cool-water" elements such as bryozoans, molluscs, and "smaller" foraminifera. This part of the shelf has dense stands of seagrass and macroalgae. The deep outer shelf and upper slope in this region (below the photic zone) has sediment dominated by bryozoa with abundant smaller foraminifera and sponge spicules.

Seagrasses are a major component of the ecosystem on the inner and middle Rottnest Shelf, and have a major influence on the production of carbonate sediment here (through habitat provision for calcareous epiphytes). As summarized by Walker (1991), seagrasses occupy about 20 000 km^2 on the Western Australian coast; their water depth range is from intertidal to 45 m; and their diversity (including 10 genera and 25 species) is higher than elsewhere in the world. As Walker (1991) pointed out, the presence of abundant seagrass meadows on the Western Australian shelf contrasts with a lack of similar seagrass stands on the western African and the western South American continental shelves. Extensive subtidal large-kelp forests such as are present in South Africa and South America are lacking in Western Australia. However, over 340 species of macroalgae (including 54 species of green algae, 71 species of brown algae, and 222 species of red algae) were recorded by Huisman & Walker (1990) from rock platforms around Rottnest Island. Walker (1991) suggested that the total number of macroalgal species from Western Australia may be about 700 through a water-depth range of 0-50 m.

According to Huisman & Walker (1990), seagrasses that have a distributional range encompassing the Rottnest region, include *Amphibolis antarctica, A. griffithii, Posidonia australis, P. sinuosa, Heterozostera tasmanica, Syringodium isoetifolium, Thalassodendron pachyrhizum*, and *Halophila ovalis*. All of the species, except the cosmopolitan *S. isoetifolium* and *H. ovalis*, are endemic to warm temperate parts of southern Australia. Calcified green algae recorded at Rottnest Island by Huisman & Walker (1990) include species of *Halimeda, Penicillus,* and *Acetabularia* . Calcified red algae that they recorded from around Rottnest include species of the encrusting *Peyssonnelia* and many unnamed encrusting coralline types; "articulate" species of *Amphiroa, Cheilosporum, Corallina, Galaxaura, Haliptilon, Jania, Metagoniolithon, Rhodopeltis,* and *Tricleocarpa*; and non-articulate species of *Dotyophycus, Galaxaura, Liagora,* and *Metamastophora.* James et al. (1990) noted that Halimeda is weakly calcified on the mid Rottnest Shelf and does not contribute to the sediment.

Other seagrass studies on Rottnest Shelf meadows that are of interest from a sedimentological point of view, include: (1) changes in sea-grass cover (viz. a 21% increase) on submerged sand banks over a 30 year period (Kendrick *et al.*, 2000) ; (2) loss of seagrass in embayments on Rottnest Island, and the consequent de-stabilisation of sand, due to boat moorings (Hastings *et al.*, 1995); effect on seagrass meadows of an increase input of anthropogenic nutrients (McMachon *et al.*, 1997); documentation of light incidence and energy flow in a seagrass canopy (Carruthers & Walker, 1997); and seagrass growth strategies (Cambridge, 1999). Various other papers on seagrasses around Rottnest Island and their faunal communities are presented in Walker & Wells (1999).

Few studies of living foraminifera have been made on the Rottnest Shelf. Semeniuk (2000) studied spatial variability, at micro- to regional scales, in epiphytic populations in monospecific meadows of *Posidonia australis*. Her study sites on the Rottnest Shelf were inshore meadows near Dongara (at about 29°30'S) and in the Perth region. She also studied a seagrass meadow on the southern Western Australian coast. The foraminiferal distribution along individual seagrass leaf blades is typically heterogeneous, with foraminiferal density ranging from 0 to 3.7 tests/cm2. The highest densities are in areas where there is epiphytic algal growth on the leaves. The species composition of populations inhabiting different leaves at the same site also varies, especially for miliolids, buliminids, and spirillinids. Semeniuk found that on a typical leaf, *Lamellodiscorbis dimidiatus* and *Crithionina* sp. live on the basal 15 cm section of a leaf in detritus-rich areas; soritids and discorbids occupy the middle section of the leaf; and smaller miliolids, buliminids, glabratellids, spirillinids, cibicidids and encrusting rotaliids occupy the top 10 cm section of leaf that is often algal covered. Among other associations she often found *Rosalina* spp. living near serpulid tubes; and *Peneroplis* and *Quinqueloculina* in aggregations in algal growth on leaves. Most species are homogeneously distributed within each of the meadows Semeniuk studied, but a number of species show significant heterogeneity at a local scale. (e.g. *Peneroplis planatus, Triloculina trigonula* and *L. dimidiatus* in the Dongara meadow). Semeniuk (2001) found variations on a regional scale between the epiphytic foraminiferal populations at the three sites she studied. She suggested that *Peneroplis, Vertebralina, Amphisorus* and *Marginopora** characterise warmer water assemblages and *Lamellodiscorbis* and *Rosalina* characterise cooler water assemblages. [*The *Marginopora vertebralis* identified by Semeniuk is probably not this species, but may be similar to *M. kudakajimaensis* and may be closely related, perhaps con-specific, to *Amphisorus hemprichii*, based on the molecular phylogeny suggested by Holzmann *et al.*, 2001]

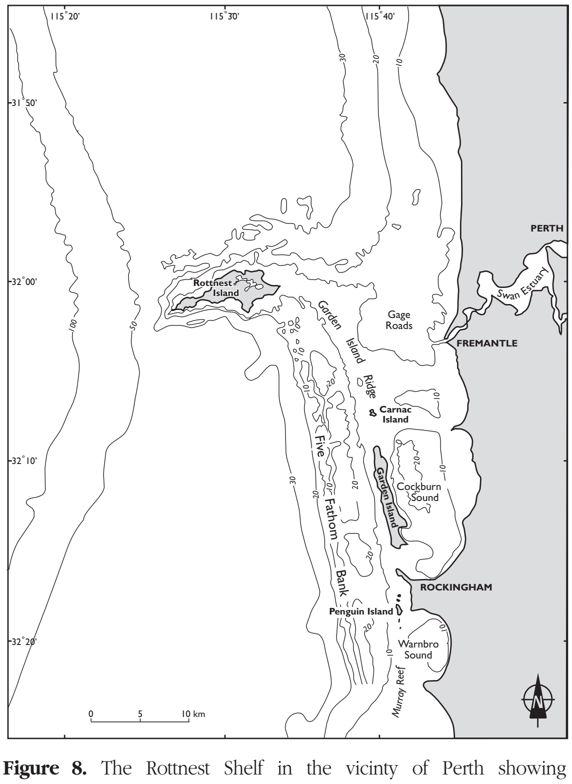
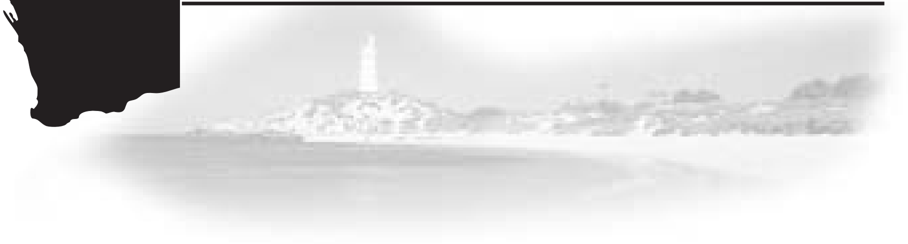


Figure 8. The Rottnest Shelf in the vicinty of Perth showing bathymetry (after Playford & Leech, 1977)

Rottnest Island



Underwater Explorer Cruise out of Thompson Bay (all participants).

The cruise will visit two submerged limestone platforms in Thompson Bay (Transit and Kingston Reefs) and go over seagrass meadows and sand flats in the bay. Two shipwrecks will be seen on Kingston Reef, the Denton Holme and the Macedon.

Parker Point (dry tour)

(see Stop 14 of Playford, 1988, p. 63, and Figures 22, 26).

This locality overlooks a wave-cut platform cut in Tamala Limestone (see Playford, 1988, p. 22-26). In places on the platform, the coral *Pocillopora damicornis* forms small reefs of about 3m maximum relief. The platform off Parker Point is the only place on the island where coral reefs (with skeletal framework) are present. Elsewhere around the island, isolated coral colonies encrust the rock platforms. The *Pocillopora* reefs at Rottnest Island are the most southern of the Western Australian coral reefs (Figure 9). The platform on which the reefs have developed faces into the ocean swell which comes mainly from the south-west. Sixteen coral genera and 25 species have been recognized in the Rottnest reefs (Hatcher, 1991) compared to 42 genera and 184 species in the Houtman Abrolhos reefs further north on the outer Rottnest Shelf (at 28-29°S). *Pocillopora* forms the Rottnest reefs, whereas *Acropora* forms most of the framework of the Houtman Abrolhos reefs. Hatcher (1991) noted that Rottnest was not as proximal to the main flow of the Leeuwin Current as was the Houtman Abrolhos, and this may account for the much lower coral diversity at Rottnest.

Little Salmon Bay (both tours)

An aerial photograph of this bay is shown in Figure 10. A very small *Pocillopora* reef (see above) is located in front of the submerged rock platform in the middle of the bay. The rock platforms are covered in algae, and stands of seagrass (including the ribbon grass *Posidonia*, and *Amphibolis* with leaf clusters) grow on sand around the rock platform.

Hutchins (1999) reported that this reef has grown in size over the last 25 years. According to him, 15 years ago only small to medium-size colonies were present. These have developed into a continuous reef structure about 20 m long.

The sediment in the bay is mainly biogenic carbonate grains, including mollusc fragments (16-49%) by weight of dry sediment), coralline algal fragments (18-32%), echinoderm debris (3-21%), and foraminifera (1-18%). Minor components include bryozoan, serpulid, ostracod, sponge-spicule, coral, and fish debris. Close to rock platforms, quartz and limestone clasts, reworked from the Tamala Limestone, are present forming up to 35 % of the sediment. The sand

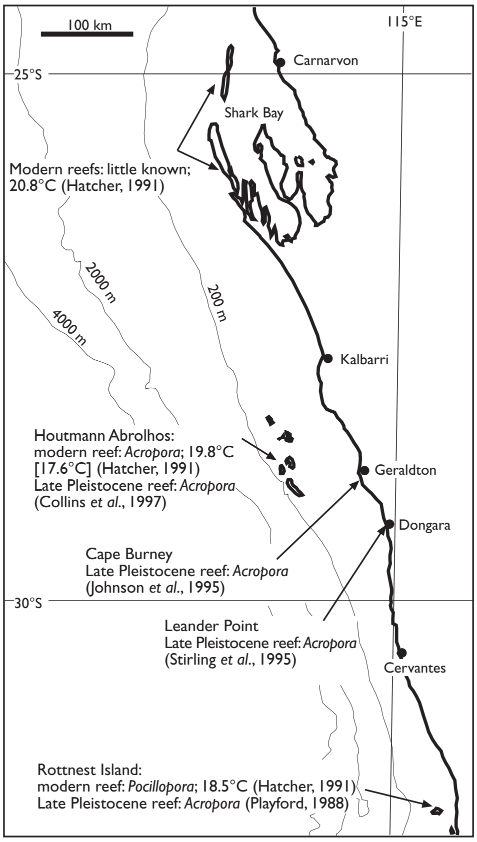


Figure 9. Location of main coral-algal reefs along the mid Western Australian coast, and the positions of known Late Pleistocene reefs.

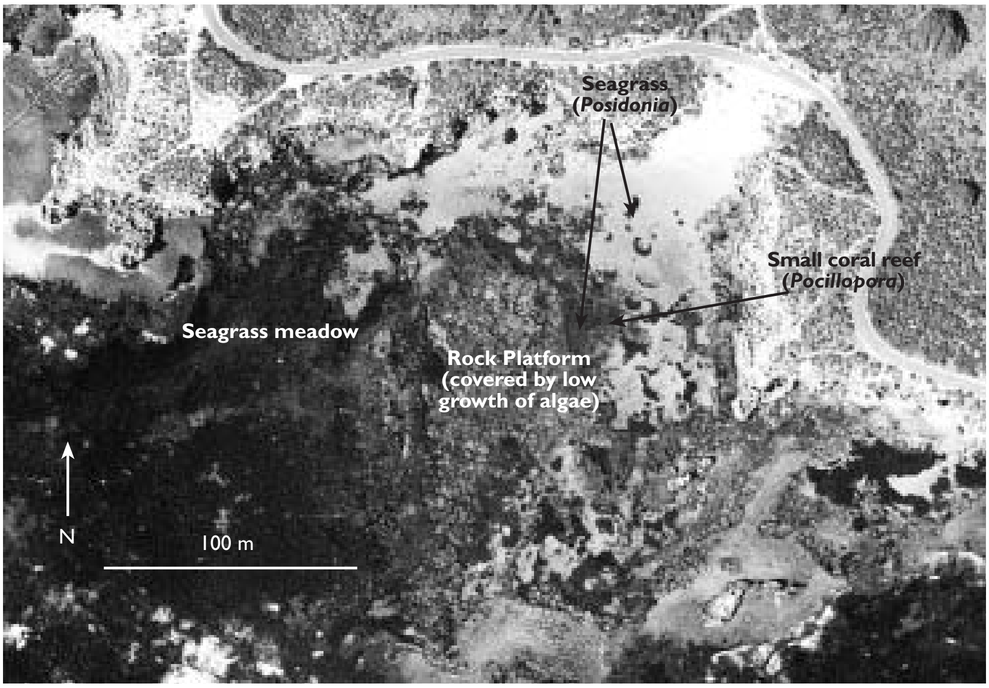


Figure 10. Little Salmon Bay (part of aerial photograph WA4173C Metro Regional Area, Run 41, no. 5144, scale 1:25 000, 07/01/99; reproduced by permission of Department of Land Administration)

sample from this site given to each excursion participant came from the seagrass stand in front of the central submerged rock platform near the *Pocillopora* reef. The sample has been washed (decanting with fresh water) but not sieved.

Algal turf on the rock platforms provides a habitat for many smaller foraminifera, and the seagrass stands host epiphytic types including abundant *Peneroplis* and *Neorotalia* and some *Amphisorus*. The sediment seems to contain few live foraminifera. The most common foraminiferal tests forming the sediment include *Peneroplis planatus* (44-68% of foraminiferal grains counted in 150µm to 2 mm sediment fraction) *Neorotalia calcar* (7-20%), *Elphidium crispum* (2-16%), *Epistomarioides polystomelloides* (< 10%), and *Lamellodiscorbis dimidiatus* (< 7%). The complete species list known from Rottnest Island is given on Table 1. Many of these species occur in Little Salmon Bay, most with low abundance.

Fairbridge Bluff (dry tour)

(see Stop 1 of Playford, 1988, p. 56-57, and Figures 36-39).

This is an *Acropora*-dominated raised reef similar to reefs exposed at Leander Point (on the mainland about 350 km north of Perth) and at Cape Burney (a further 40 km to the north; see Figure 8). Both bafflestone (formed by branching *Acropora*, Figure 36 of Playford, 1988) and bindstone (formed by palmate *Acropora* bound by coralline algae, Figure 37 of Playford, 1988) form the Fairbridge Bluff reef. Stirling *et al.* (1995) dated coral from the reef using the high-precision U-series method. They obtained ages ranging from about 122 Ka to 127 Ka, the same as they obtained for a similar reef at Leander Point. Using electron spin resonance, Johnson *et al.* (1995) dated corals from the Cape Burney reef at 120 Ka to 132 Ka.

The Rottnest Island, Leander Point, and Cape Burney Pleistocene reefs are exposed in sea cliffs at about the same height above present-sea level. These reefs suggest that, during the Last Interglacial, sea level in the region was at least 2 metres above the present level.

Green Island (wet and dry tours)

(see Stop 11 of Playford, 1988, p. 62, and his Figures 19-21)

An aerial view of the Green Island is shown in Figure 11. Green Island is connected to Rottnest by a submerged rock platform. The swell from the south-west pushes water over the platform and this flow exits via the bay. Rhodoliths (see Playford,

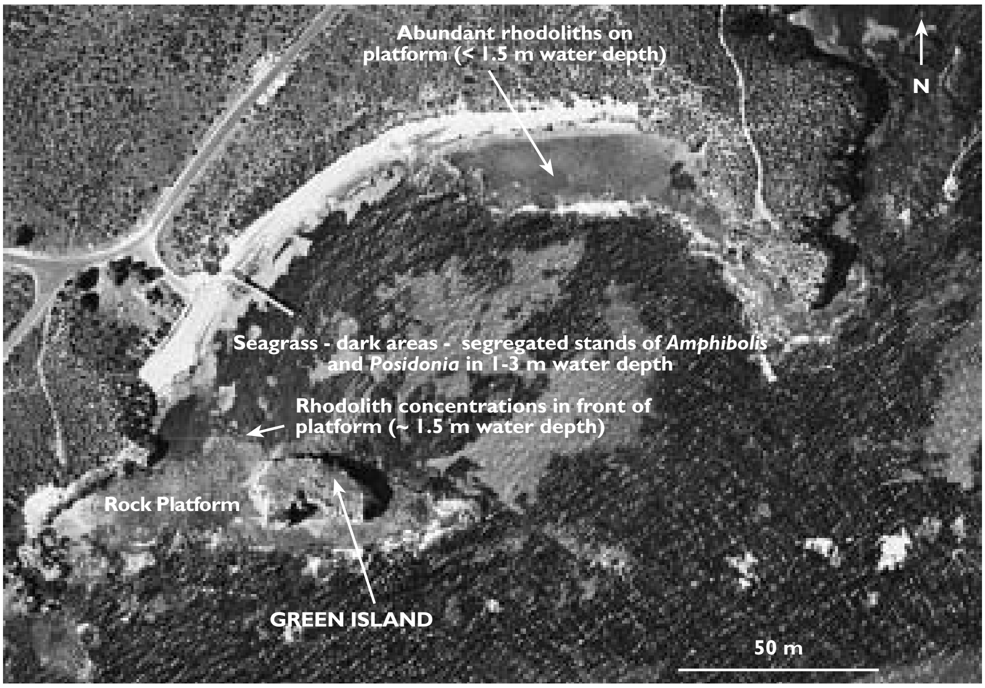


Figure 11. Green Island area (part of aerial photograph WA4173C Metro Regional Area, Run 41, no. 5144, scale 1:25 000, 07/01/99; reproduced by permission of Department of Land Administration)

1988, Figures 20-21) are forming on the bay side of the rock platform where there is continuous water movement, and also on the broad rock platform on the eastern side of the bay (Playford's Stop 11) where there is continuous wave action. The seagrass meadow in the bay consists of segregated stands of *Amphibolis* and *Posidonia.* The submerged rock platform is covered in places by macroalgae and crustose coralline algae (Sim & Townsend, 1999). Rare coral colonies are scattered on the platform.

The sediment in the bay between Green Island and the Rottnest mainland consists mainly of coarse to medium sand with mollusc debris (13-40 % dry weight of sand), coralline algal fragments (17-38 %), and foraminifera (11-26 %) the main biogenic

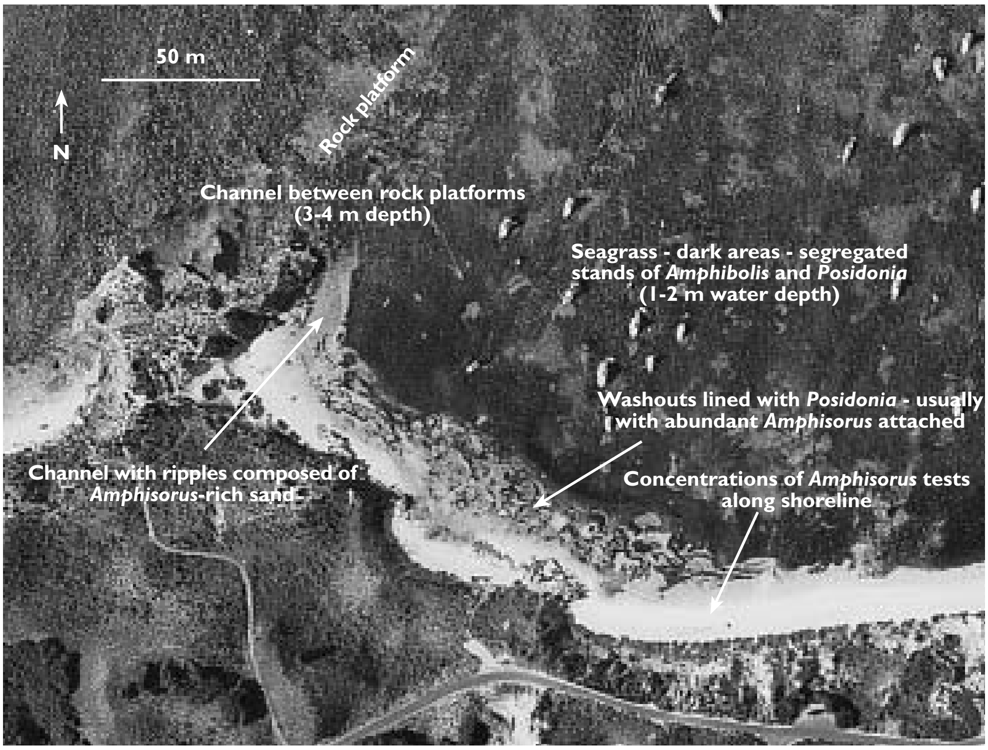


Figure 12. Western side of Rocky Bay (part of aerial photograph WA4173C Metro Regional Area, Run 41, no. 5144, scale 1:25 000, 07/01/99; reproduced by permission of Department of Land Administration)

components. Limestone clasts and quartz grains reworked from the Tamala Limestone form 4-39% of the sand. Most sediment grains are abraded, showing the effects of movement due to the currents and wave action. Coralline algae encrust many of the large gastropod shells concentrated in front of the rock platform.

A lower diversity of foraminiferal tests is found in the sediment here than at Little Salmon and Rocky Bays, and the assemblage is sorted by current action. The most common foraminifera are *Neorotalia calcar* (30-76 % of foraminiferal tests in 150 µm to 2 mm sediment fraction), *Lamellodiscorbis* spp. (3-39 %), *Amphisorus hemprichii* (test fragments and whole, 1-25 %), *Peneroplis planatus* (1-19 %), and *Epistomarioides polystomelloides* (2-18 %).

Rocky Bay (wet and dry tours)

Rocky Bay lies on the north side of the island and is protected from the ocean swell and the dominant south to south-west winds. Figure 12 shows an aerial view of the western part of the bay. A submerged rock platform runs from the western headland (Abraham Point) in a north-east direction and forms a barrier projecting the bay. Within the bay is a dense sea-grass meadow consisting of segregated stands of *Amphibolis* and *Posidonia*. On the western side of the bay adjacent to the western headland is a channel with a rippled coarse-sand substrate. Adjacent the shoreline is a zone of shallow washouts in the seagrass meadow, these are lined by *Posidonia*.

The sediment in the seagrass meadow is mainly medium to coarse sand; and in the channel is coarse to very coarse. The sand waves in the channel have concentrations of the disc-like soritid *Amphisorus* which lives on leaves in the seagrass meadow and among low algal turf on the submerged rock platforms. Concentrations of dead *Amphisorus* also are present along the strandline on the beach. The sediment sample prepared for excursion participants was collected in the seagrass about 50 m out from the southern and western shores in about 2 m of water; it is fine to medium sand. The sand in the western part of Rocky Bay is composed mainly of biogenic grains including abundant foraminifera (15-50 % of grains in 150 µm to 2 mm sediment fraction), mollusc fragments (8-25 %), coralline algal fragments (3-39 %), serpulid worm tubes (< 13%), echinoderm debris (< 10 %), and minor ostracod valves, sponge spicules, stony coral fragments, and fish debris. Bryozoan skeletons are very rare. Lithogenic grains (mainly limestone clasts including cement-infilled foraminiferal tests, and some quartz) form 3-27 % of the sand, and are reworked from the Pleistocene Tamala Limestone and unconsolidated younger dunes that form the sea-cliffs and rock platforms around the bay.

A diverse foraminiferal assemblage lives in the seagrass meadow and the tests are preserved in the sand. Most of the species known from shallow embayments on Rottnest Island (Table 1) are present in Rocky Bay. The most common foraminiferal species found here are *Lamellodiscorbis* spp. (8-62% of grains in 0.5-2 mm sediment fraction), *Neorotalia calcar* (12-38 %), *Peneroplis planatus* (11-38%), and *Amphisorus hemprichii* (5-30%). *Lamellodiscorbis* includes types such as *L. melbyae* with keeled periphery, *L dimidiatus* with rounded perforate periphery, and a rare high-trochospiral morphotype.

Cape Vlaming (dry tour)

(see Stop 13 of Playford, 1988, p. 63; and his Figures 10, 12)

Cape Vlaming forms the western-most part of Rottnest Island. A boardwalk , leading to various viewing platforms, protects the nests, dug in the ground, of the Wedgetailed Shearwater, *Puffinus pacificus*. Towards the west is the vast expanse of the Indian Ocean. The continental shelf-slope break (at about 170 m) is about 10 km to the west.

On the east side of Cape Vlaming is Fish-hook Bay. Note the large-scale aeolian cross-bedding in the Tamala Limestone here (see p. 22 of Playford, 1988), and the shoreline platform, shoreline notch, visor, and storm bench as figured by Playford (1988, p. 10, Figures 9, 10, 12).

Rottnest Lighthouse on Wadjemup Hill (dry tour)

At an elevation of 45 m above sea level, Wadjemup Hill is the highest point on Rottnest Island. The hill is a Pleistocene sand dune composed of Tamala Limestone. From this vantage point the Swan Coastal Plain can be seen to the east, backed by the Darling Scarp (see Figure 1 of this guide). The Darling Scarp, formed by the Darling Fault which has been active throughout the Phanerozoic, represents the eastern boundary of the Perth Basin (see Figure 2 of this guide). The scarp is developed in granitoids and gneisses of the Archaean Yilgarn Craton.

On Rottnest, just to the north-north-east of Wadjemup Hill is Barker Swamp. This is one of five interdunal freshwater swamps on the island. It contains an undisturbed Holocene succession that includes peat (about 1 m thick) with mollusc shells and abundant ostracods at the base, followed by a rhythmically bedded unit (about 1.27 m thick) composed of thin charcoal-rich layers alternating with slightly thicker carbonate-mud beds. This is followed by about 1.56 m of carbonate mud (rich in ostracods) overlain by a surface layer (13 cm thick) of peat (Backhouse, 1993). Backhouse recorded the pollen from the succession and noted significant changes in vegetation, including a decline in eucalypts during 7500 years of swamp history. Backhouse suggested that the vegetation was affected by fire events and by the flooding of the land connection between Rottnest and the mainland (at about 6500 ka) which created less population pressure on quokkas and increased their grazing.

European settlement over the last 170 years has affected the vegetation (Rippley & Rowland, 1995) and the only areas of "natural" low woodland left on the island are small clusters of Rottnest tea trees (*Melaleuca lanceolata*) at the eastern side of the island, in some places associated with Rottnest Island pines (*Callitris preissii*). Thickets of Acacia are present in a few areas. In some areas, reforestation is being attempted by the Rottnest Island Authority and fences around vegetation are being erected to prevent grazing by quokkas. The central hills of the island will remain bare of trees so that these will not affect the underground water reserves.

Government House Lake at old bathing groyne (dry tour)

(see Stop 15 of Playford, 1988, p. 64; and his Figure 48).

Western Australia is noted for its lakes and restricted embayments containing extensive microbial mats and stromatolites-thrombolites. In Western Australia, extensive microbial mats were first described by Clarke & Teichert (1946) from Lake Cowan about 600 km east of Perth. The best known sites for stromatolites are Hamelin Pool in Shark Bay (Logan et al., 1974); Lake Thetis near Cervantes, about 150 m north of Perth (Grey et al., 1990); Lake Clifton on the Swan Coastal Plain south of Perth (Moore et al., 1984; Burne & Moore, 1993; Moore & Burne, 1994); and Lake Richmond also on the Swan Coastal Plain south of Perth (McNamara, 1997).

Playford (1988, p. 5-8, 38) described the salt lakes on Rottnest Island. Active stromatolites (about 5-10 cm high) are present at water depths of 0.2 to 3 m immediately east of the old bathing groyne. Inactive and partly eroded stromatolites are present on the western edge of Serpentine Lake which lies to the west of Government House Lake.

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