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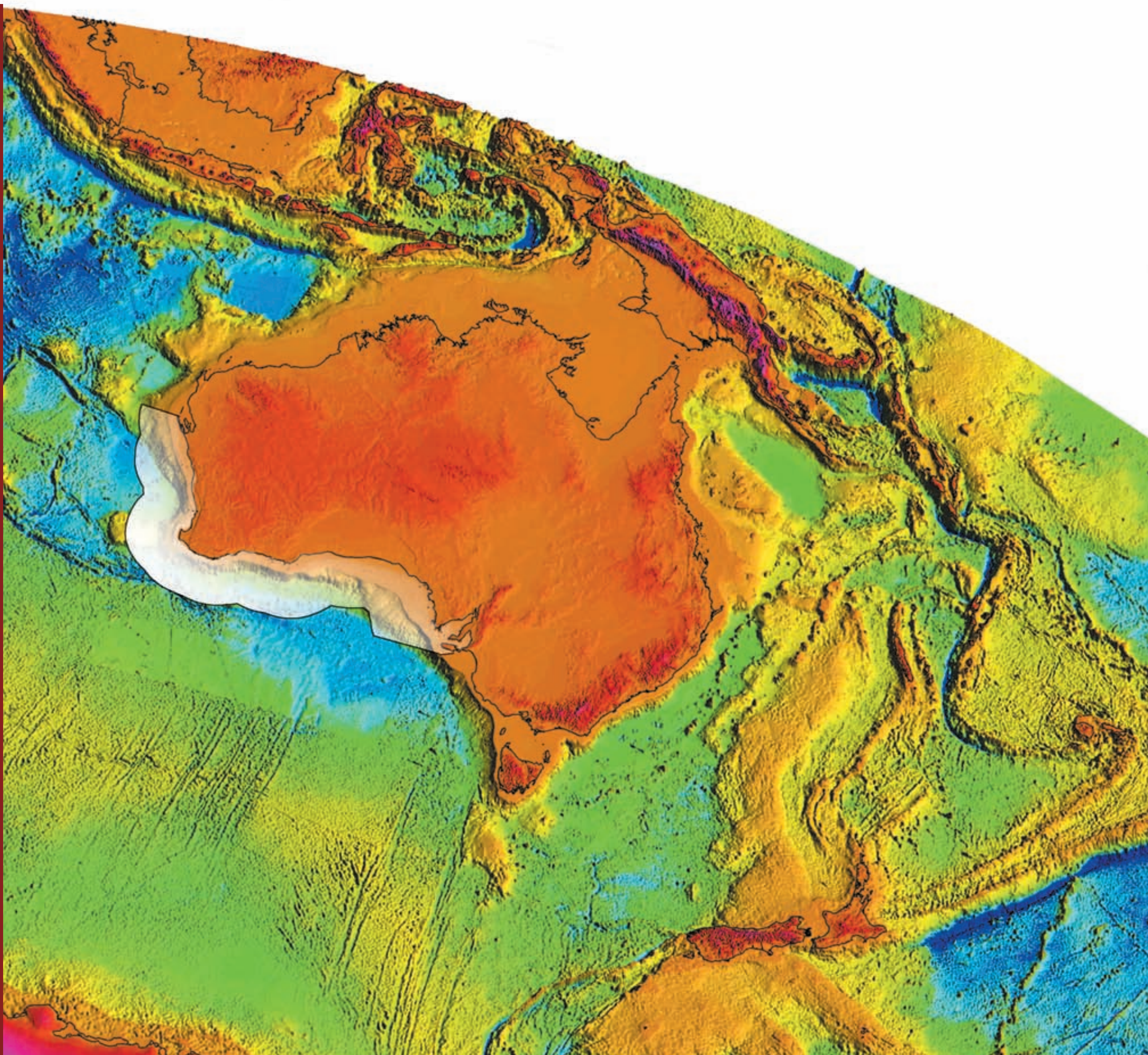
Geomorphology and Sedimentology of the South Western Planning Area of Australia

Review and synthesis of relevant literature in support of Regional Marine Planning

Laura Richardson, Emma Mathews & Andrew Heap

Record
2005/17



SPATIAL INFORMATION FOR THE NATION

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Laura Richardson, Emma Mathews and Andrew Heap

Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia

Australian Government

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Correspondence for feedback:
Andrew Heap
Geoscience Australia
GPO Box 378
Canberra
ACT 2601

Andrew.Heap@ga.gov.au

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Executive Summary

This record is a review and synthesis of geological research undertaken along the southwestern margin of Australia. The record has been written in support of regional marine planning to provide baseline scientific information for the South Western Planning Area. The South Western Planning Area (as defined by the National Oceans Office) extends from the tip of Dirk Hartog Island and Cape Inscription in the northwest, to Kangaroo Island and the southern tip of the Fleurieu Peninsula in the southeast. The area includes the ocean and seabed from the coast to the outer limit of the Exclusive Economic Zone. The information synthesised in this record can be used to define and characterise benthic (seabed) habitats for the purposes of contributing to a measure or description of habitat diversity.

The South Western Planning Area can be divided into four major physiographic provinces: (1) Rottnest; (2) South West (SW); (3) Great Australian Bight (GAB); and (4) Spencer and St. Vincent Gulfs, all of which contain a diverse range of geomorphic features extending from nearshore environments to the deep abyssal plain. The region includes a major cool-water carbonate province that extends along Australia's southern and southwestern margins. Shelf environments have been influenced by changing sea levels through time; however deep water environments have been relatively stable throughout the Cenozoic due to the South Western Planning Area's passive margin setting.

The Rottnest region is characterised by:

- A narrow, incipiently-rimmed shelf with submerged ridges and tropical carbonate platforms, an extensive continental slope dissected by numerous submarine canyons, a well developed continental rise and an extensive area of deep abyssal plain. The region includes the Perth Canyon which is the largest canyon on the Australian margin and a major biogeographical boundary;
- Oceanographic processes, dominated by southwesterly swells and storms that create moderate wave energy and mobilise sediments across the shelf.

A southward-flowing western boundary current, the Leeuwin Current, brings warm tropical water and biota into higher latitudes, allowing the development of high-latitude coral reefs and reducing the upwelling of nutrient-rich waters onto the shelf;

- Surface sediments that are predominantly cool-water carbonates, with shelf-parallel cool-water carbonate facies on the shelf and warm-water tropical carbonate facies on reef platforms. Shelf sediments are typical cool-water bryozoans, molluscs and coralline algae components and generally occur as thin, discontinuous sheets over rocky or algal substrates. On the platforms, zooxanthellate coral fragments reflect warm-water sediment types; and
- A Late Quaternary history that has created a complex bathymetry on the shelf, with barrier dune systems, shore parallel ridges and reefs which are remnants of previous shorelines. Sea level and oceanographic processes have controlled coral reef growth through time.

The Rottnest region contains a distinct latitudinal transition from tropical biota to temperate biota due to the influence of the southward-flowing Leeuwin Current.

The South West (SW) region is characterised by:

- A narrow continental shelf with nearshore reefs and islands, a slope incised by numerous, well-developed submarine canyons, mid-slope terraces, an extensive continental rise and the deepest marginal plateau on the Australian margin, the Naturaliste Plateau. This plateau forms a biogeographical 'island' separate from the shelf and slope. The SW has the largest area of abyssal plain in the planning area, plus a broad area of unique and complex topography comprising abyssal hills, ridges and troughs;
- Oceanographic processes dominated by southwesterly swells and storms from the Southern Ocean, forming a high energy environment. Sediments are mobilised down to ~100 m water depth and are generally transported off the shelf;

- Surficial sediments dominated by cool-water carbonate shell and coral fragments, with local concentrations of bryozoans, foraminifera and algae. A thin sediment blanket of bioclastic carbonate sands occur on areas of exposed shelf, and form sediment wedges in protected shelf areas. Deep water regions and canyons contain a thin veneer of calcareous ooze; and
- A Late Quaternary sea level history resulting in a very narrow and shallow shelf during lowstands, with active canyon cutting and increased sediment transport to the deep ocean.

The range of geomorphic features in the SW points to relatively diverse habitats in this region.

The Great Australian Bight (GAB) region is characterised by:

- A broad, seaward-sloping shelf, with a shallow inshore terrace, an extensive middle shelf and a narrow outer shelf. The largest terraces in the planning area occur on the mid-slope, dissected by several broad and shallow submarine canyons;
- Oceanographic processes that are dominated by southwesterly swells and storms, forming a high energy environment and a 'shaved shelf' (James et al., 1994), where sediment erosion is greater than sediment accumulation. Seasonal upwelling brings nutrients onto the shelf, supporting prolific carbonate production on the outer shelf and upper slope;
- Surface sediments dominated by cool water carbonates, with bioclastic fragments of bryozoans, molluscs, sponges, coralline algae, foraminifera and echinoids. A thin sediment veneer of locally rippled carbonate sand patches is interspersed with outcropping hard substrate. The outer shelf and slope is covered by a thin layer of pelagic calcareous ooze and mixed terrigenous-carbonate sand, silt and mud; and
- A Late Quaternary history dominated by a large accumulation of sediment on the outer shelf and upper slope, which is a result of prolific carbonate production. Bryozoan mounds, essentially 'cool-water reefs', grew on the outer shelf due to higher levels of oceanic upwelling.

The GAB is the world's largest cool-water carbonate province and is thus iconic. The province is due to the little to no terrigenous input and seasonal oceanic upwelling occurring on a temperate, latitude-parallel shelf.

The Spencer and St. Vincent Gulfs region is characterised by:

- Two shallow embayments that extend into continental Australia, which are very shallow in northern areas and contain carbonate banks, gently sloping margins and areas of sandwaves. Spencer Gulf is the largest non-tropical marine incursion into continental Australia;
- Oceanographic processes that are dominated by a high tidal range, forming extensive intertidal areas. Shallow depths, no terrigenous input and high amounts of evaporation result in high salinity levels at the heads of each gulf. Outflow of highly saline water occurs during Austral autumn, flowing out of Spencer Gulf and reducing carbonate production on the shelf;
- Inner shelf sediments of mixed terrigenous-carbonate sand, dominated by biogenic carbonate. Surficial sediments are directly related to water depth and display a clear zonation from subtidal to supratidal areas. Sediments consist of shell, gastropod, bivalve, foraminifera, coralline algae and quartz grains. Subtidal sediments support seagrass meadows and megaripple fields contain shell-rich sands. The intertidal zone contains muddy gastropod-rich sediments, inhabited by cyanobacterial mats and mangroves; and
- A Late Quaternary history dominated by multiple transitions between exposed shelf, lacustrine and marginal marine conditions, associated with eustatic sea level cycles. It is likely that the gulfs were covered in shallow, brackish water during sea level lowstands.

Shallow water depths and a high tidal range have resulted in extensive subtidal and supratidal areas that support some of the largest areas of temperate seagrasses, mangroves and saltmarshes in Australia.

1. Introduction

1.1. BACKGROUND

This report is a review and synthesis of geological research undertaken along the southwestern margin of Australia. The report has been compiled in support of regional marine planning to provide background scientific information for the development and implementation of a Regional Marine Plan for the southwestern Australian region. The information will contribute to the Department of Environment and Heritage (National Oceans Office) national work program and will also assist in the selection of candidate marine protected areas for this region. The region considered in this review coincides with the South Western Planning Area, as defined by the National Oceans Office (NOO) (Fig. 1.1). It extends from the tip of Dirk Hartog Island and Cape Inscription in the northwest to Kangaroo Island and the southern tip of the Fleurieu Peninsula in the southeast. The planning area includes the ocean and seabed from the coast to the outer limit of the Australian Exclusive Economic Zone (EEZ).

1.1.1. Oceans Policy and Regional Marine Planning

Australia's Oceans Policy was introduced in 1998 to establish an integrated ecosystem-based approach for the planning and management of Australia's ocean resources. At the core of Oceans Policy is the protection and maintenance of biodiversity via regional marine planning (National Oceans Office, 2003). Regional marine planning allows for ecosystem-based management of Australia's ocean resources through the development of regional marine plans by the NOO.

1.1.2. Scope and Relevance

The scope of this report is the synthesis of geomorphic, sedimentary, tectonic and oceanographic information and knowledge published in scientific literature on the South Western Planning Area (Fig. 1.1). Additional information on the distribution of benthic communities such as hermatypic corals, seagrass and kelp are also reviewed where appropriate. Geomorphic and sedimentary information has already been used to develop a bioregionalisation for the South Western Planning Area (Heap et al., in press) and a geomorphic features map of the entire continental margin of Australia (Harris et al., 2005).

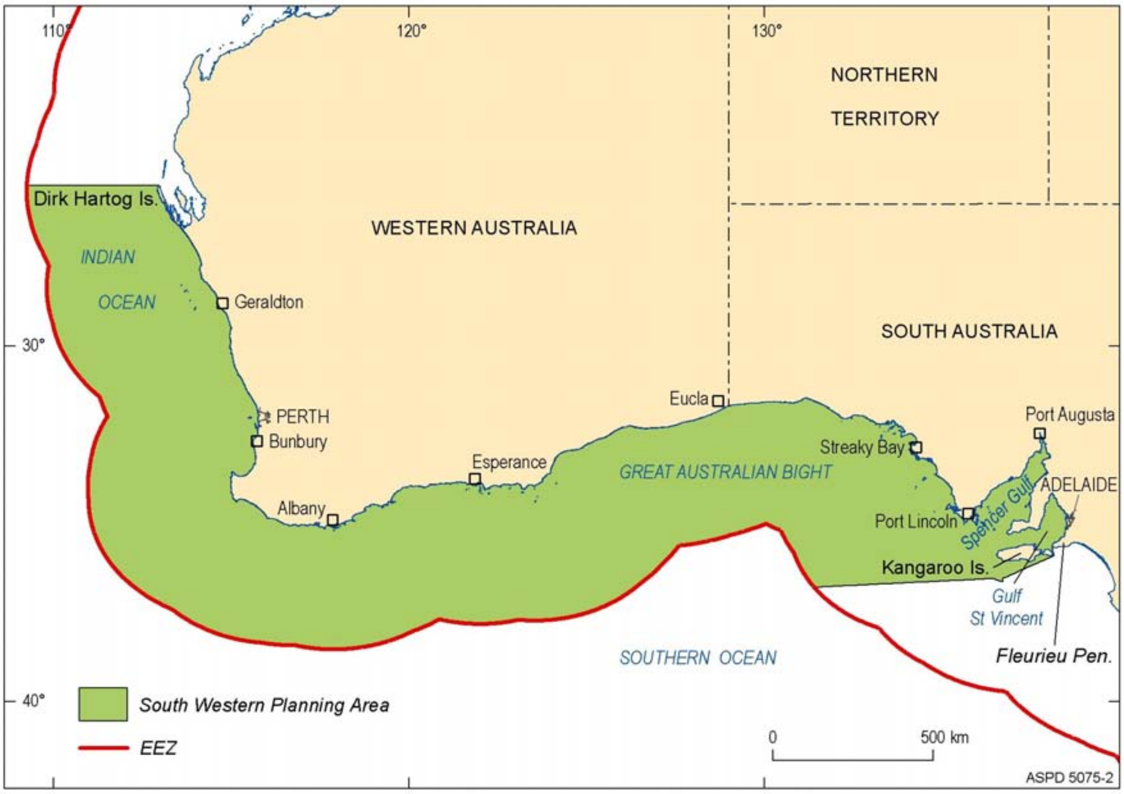

Figure 1.1. Map showing the boundaries of the South Western Planning Area, as defined by the Department of Environment and Heritage (National Oceans Office). The boundaries extend from Dirk Hartog Island at the tip of Cape Inscription in the northwest, to Kangaroo Island and the southern tip of Fleurieu Peninsula in the southeast, and the region encompasses the ocean and seabed from the coast out to the limits of the Exclusive Economic Zone (EEZ).

The physical characteristics of the seabed can assist in determining the dynamics and diversity of biological marine communities. This is important for ocean management and can be applied to better define and characterise seabed (benthic) habitats. This report emphasises geological information and also includes a discussion of the implications of this information for regional marine planning in the South Western Planning Area. This discussion provides examples of the relationship between sediment/substrate types and biota. Major differences in the abundance, distribution and nature of benthic habitats and the effects of hydrodynamic and sedimentary processes are emphasised. Habitat diversity, the protection of unique and endemic communities and the effects of climate change on seabed environments are some of the most significant environmental issues in the South Western Planning Area.

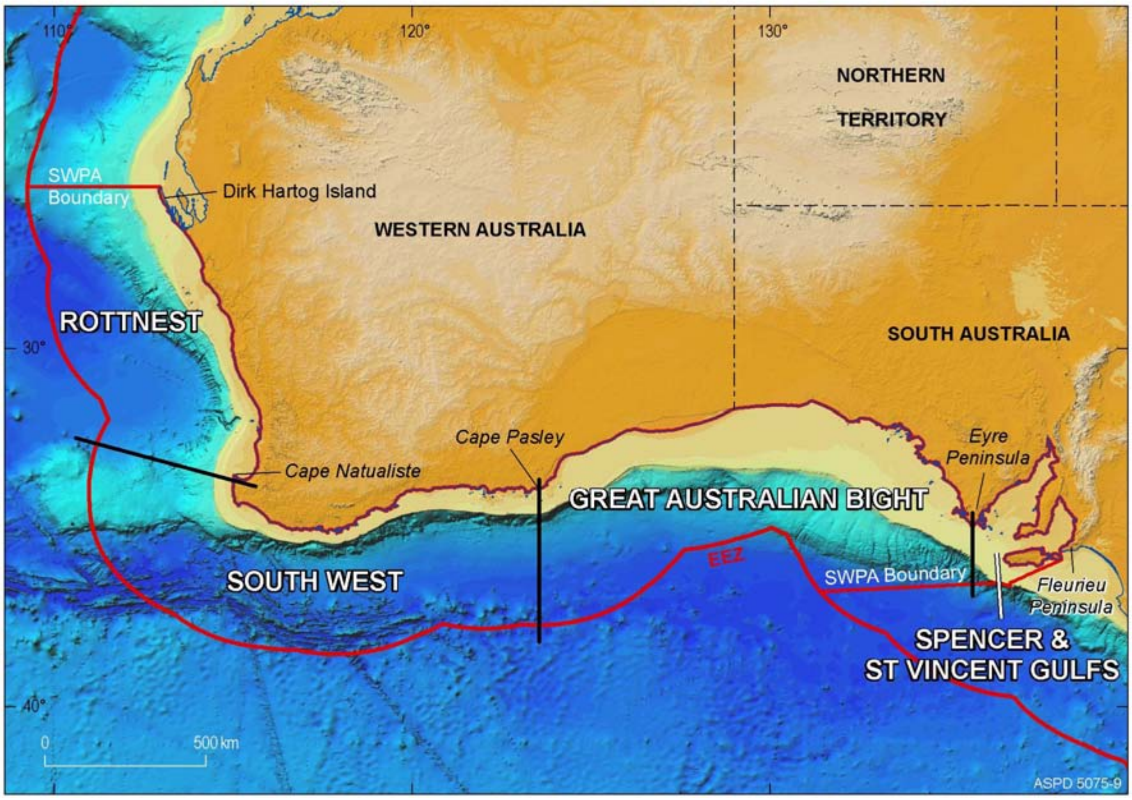

Figure 1.2. False-colour image showing the gross geomorphology and bathymetry of the southwestern margin of Australia. The region has been divided into four main physiographic provinces: 1) Rottnest; 2) South West (SW); 3) Great Australian Bight (GAB); and 4) Spencer and St. Vincent Gulfs. The boundary of the South Western Planning Area is also shown.

1.2. SOUTH WESTERN PLANNING AREA

The South Western Planning Area (SWPA) can be divided into four major physiographic provinces: 1) Rottnest; 2) South West (SW); 3) Great Australian Bight (GAB); and 4) Spencer and St. Vincent Gulfs (Fig. 1.2). This division is based on major geomorphic and sedimentary provinces in the region: e.g., the longitude-parallel continental shelf, slope and rise in the Rottnest; diverse slope and deep-water features in the SW; the broad shelf and carbonate province in the GAB; and shallow, restricted embayments in the Spencer and St. Vincent Gulfs. Features mentioned in the text are shown in Figure 1.3. Geomorphic features are mapped in Figure 1.4 and include shallow continental shelf, platform reefs, canyons, terraces, ridges and troughs, and the deep abyssal plain. Three main water masses influence all sections of the SWPA. These are the Western Australian Current, the Leeuwin Current and the Southern Ocean, which are shown for reference in Figure 1.5. Surface sediments reflect the area's physical oceanography and are dominated by cool-water carbonates. Australia's southern continental margin has been the site of cool-water carbonate deposition since the Cenozoic, resulting in a large cool-water carbonate province that extends from the Recherché Shelf to Tasmania (James et al., 1997; Feary et al., 2004).

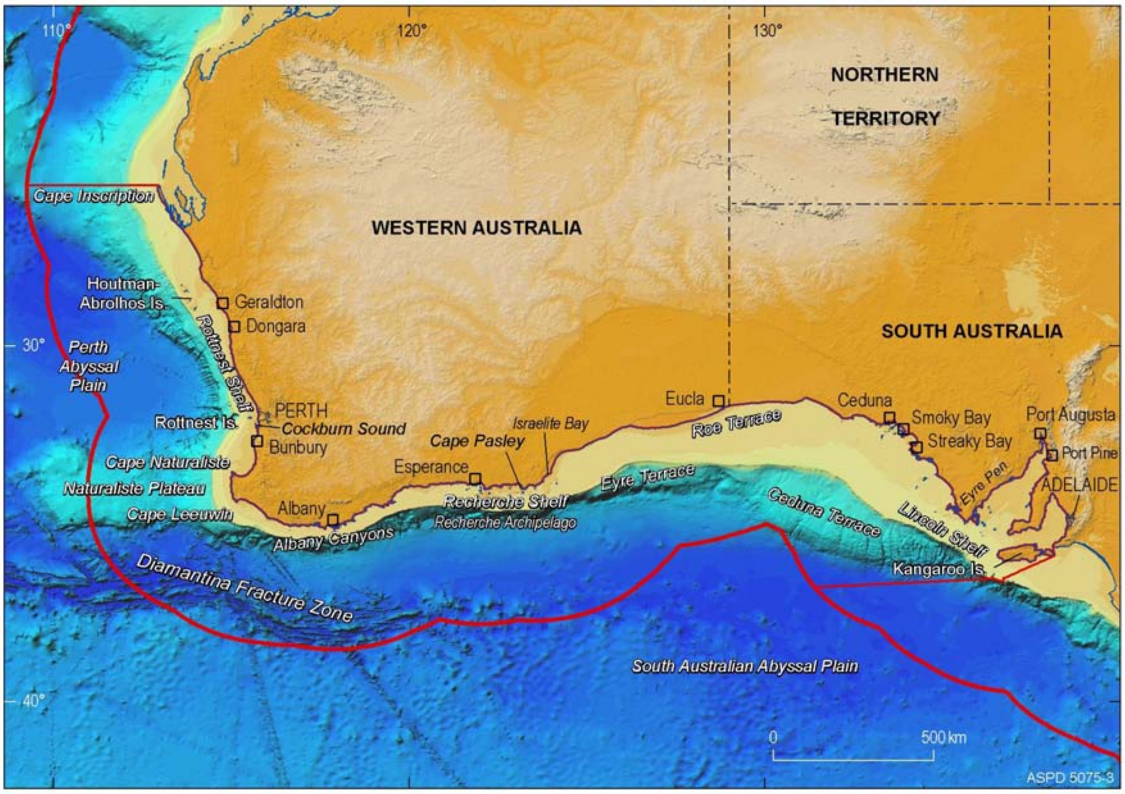

Figure 1.3. False-colour image showing the gross geomorphology and bathymetry of the southwestern margin of Australia, with the location of features mentioned in the text.

There is a distinct lack of quantitative grain size and carbonate content data for the SWPA. Geoscience Australia's national marine samples database (MARS) currently holds 1,012 samples for the area (Fig. 1.6), however only 93 of these samples have been quantitatively analysed for grain size and carbonate content. The majority of samples analysed for grain size and carbonate content are located in the GAB marine park, with very little coverage elsewhere (Figs. 1.7, 1.8). No quantitative data is currently held in

MARS for the deep water of the southern margin or for any of the western margin. The majority of information in this report is based largely on data from other published sources. As a result, this information is not necessarily consistent with data held in MARS that has been used previously to support Regional Marine Planning in the South East and Northern Planning Areas (Butler et al., 2001; Heap et al., 2004) and in the construction of the National Benthic Marine Bioregionalisation (Heap et al., in press). Analysis of the 919 samples that have no quantitative data in MARS would provide key additional information which is currently missing on the texture and composition of the seabed, for deep water areas of the southern margin, and shelf, slope and deep water areas of the western margin in the SWPA, that is consistent with the rest of the Australian margin.

1.2.1. Rottnest

The Rottnest region (Fig 1.2) includes the Rottnest Shelf and the southern area of the Dirk Hartog Shelf, and deep water areas out to the Perth Abyssal Plain. The continental shelf is narrow and incipiently rimmed. It supports tropical reef growth at the Houtman Abrolhos Islands and cool-water carbonate production on the shelf and upper slope, with surface sediments displaying a shelf parallel distribution. Numerous canyons have cut into the continental slope. The largest of these is the Perth Canyon offshore of Rottnest Island, which forms a major biogeographical boundary. The canyon intersects the shelf and transports shelf detritus and sediment into deeper water. The Perth Abyssal Plain (Fig. 1.3) covers a large area of the region; it reaches depths of 5,600 m (Harris et al., 2005) and contains some of the deepest benthic habitats on the Australian margin. The southward-flowing Leeuwin Current (Fig. 1.5) is important for habitats on the outer shelf and upper slope, influencing sea surface temperature, the distribution of tropical and temperate biota, nutrient supply and the productivity of local fisheries (Pearce and Pattiaratchi, 1997).

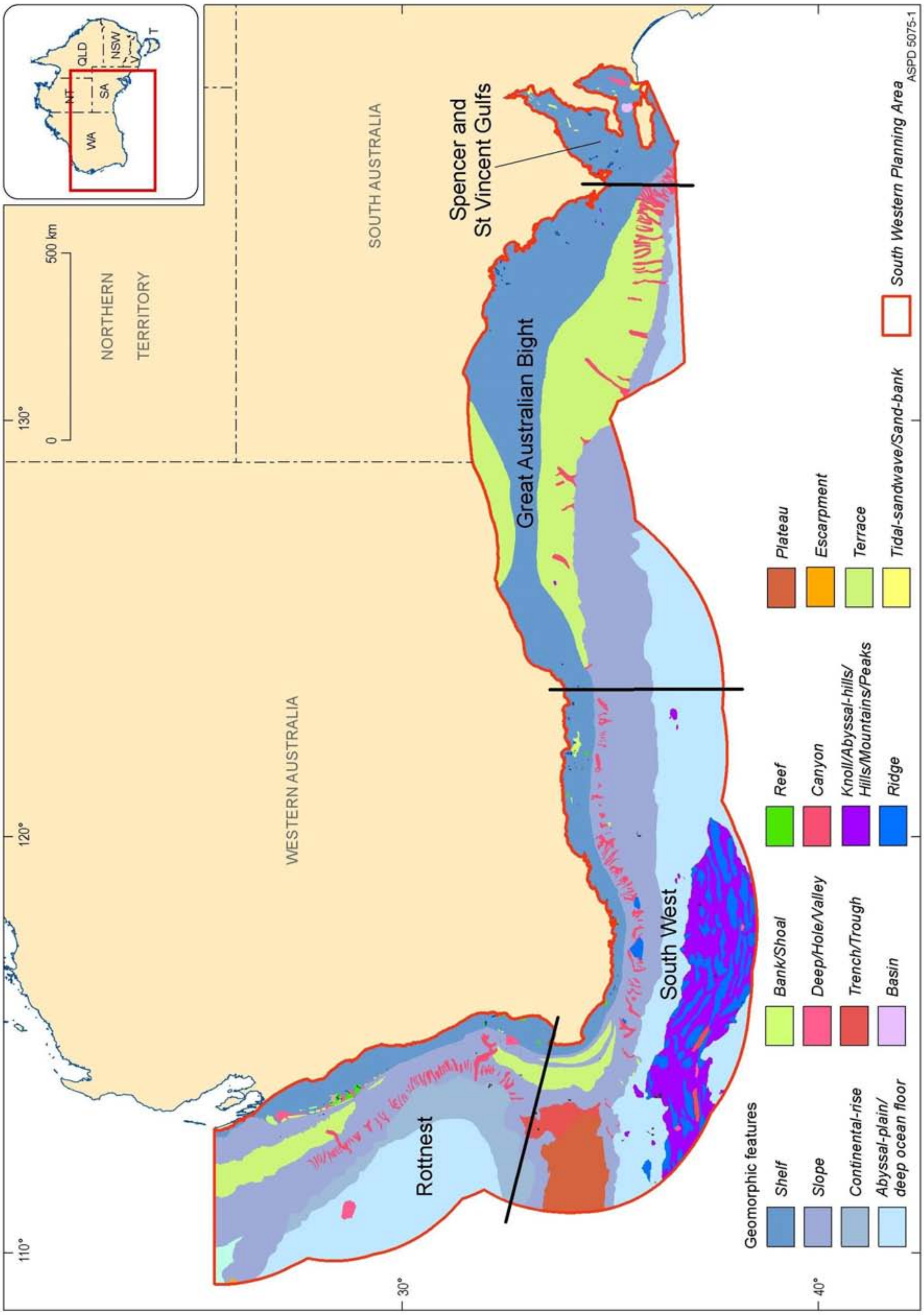
NORTHERN
TERRITORY
SOUTH AUSTRALIA
WESTERN AUSTRALIA
Spencer and
St Vincent Gulfs
Great Australian Bight
South West
Rottnest
0
500 km
110°
120°
130°
30°
40°
WA
NT
SA
QLD
NSW
T
Geomorphic features
Shelf
Slope
Continental-rise
Abyssal-plain/
deep ocean floor
Bank/Shoal
Deep/Hole/Valley
Trench/Trough
Basin
Reef
Canyon
Knoll/Abyssal-hills/
Hills/Mountains/Peaks
Ridge
Plateau
Escarpment
Terrace
Tidal-sandwave/Sand-bank
South Western Planning Area
ASPD 5075-1

Figure 1.4. Map showing the major geomorphic features in the South Western Planning Area (from Harris et al., 2005). The Rottnest region includes a longitude-parallel continental shelf with ridges and reefs, a slope incised by submarine canyons and a well-developed continental rise that grades into abyssal plain. The South West region has distinct deep-water features such as the offshore Naturaliste Plateau, continental slope canyons, an extensive area of abyssal plain and a series of abyssal hills, ridges and troughs on the deep ocean floor. The Great Australian Bight is dominated by a broad continental shelf and two extensive mid-slope submarine terraces that are dissected by several large canyons. The seabed on the shelf is influenced by Southern Ocean swell and storm waves that erode and transport sediment off the shelf. The Spencer and St. Vincent Gulfs region is characterised by two confined shallow shelf embayments with seabed covered in sandwaves/megaripples and carbonate banks.

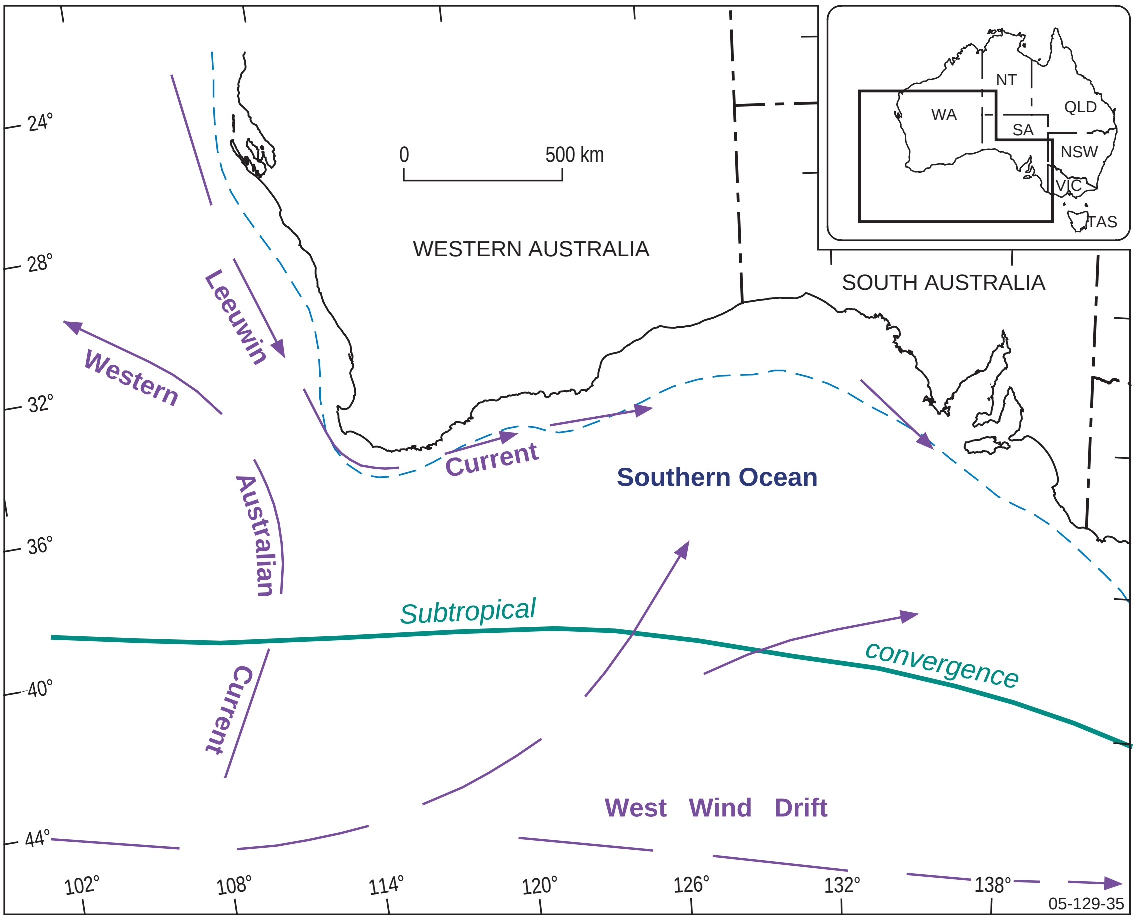

Figure 1.5. Physical oceanography of the South Western Planning Area, showing the three main water masses influencing the region: the Leeuwin Current, the Western Australian Current, and the Southern Ocean (modified from Li and McGowran, 1998). Also shown for reference is the west wind drift and the subtropical convergence. The west wind drift is the surface current that circulates around Antarctica, flowing from east to west. It influences the southwesterly direction of ocean swells affecting the SW Planning Area. The subtropical convergence is the zone in the Southern Ocean where two water masses meet and sharp changes in sea surface temperature are observed. The subtropical convergence shifts latitude through time, moving northwards closer to southern Australia during glacial periods (McGowran et al., 1997).

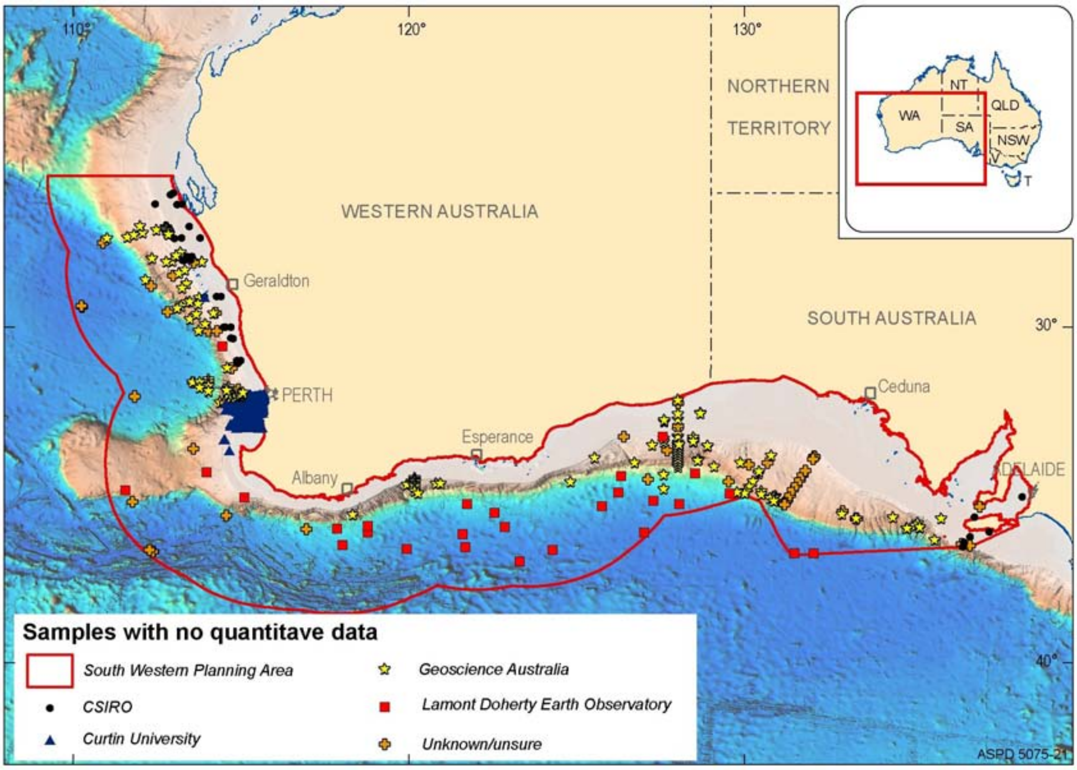

Figure 1.6. False-colour image showing the location of samples from the SWPA currently held in MARS that have no quantitative grain size or carbonate content data.

1.2.2. South West

The South West (SW) region (Fig 1.2) comprises a narrow continental shelf, a slope dissected by numerous, well-developed submarine canyons, the large deepwater Naturaliste Plateau and a rugged area of abyssal hills and ridges that make up the Diamantina Zone. The region marks a transition from tropical to temperate foraminifera and contains hermatypic corals, extensive nearshore seagrass habitats and kelp (macrophyte) communities (Li and McGowran, 1998). Numerous islands of the Recherché Archipelago offshore from Esperance form a protected setting with sediment accumulation on the leeward (northeastern) side of islands. This sheltered environment is important for commercial fisheries such as Abalone, Pilchard, Shark and the Southern Rock Lobster (Baxter, 2003).

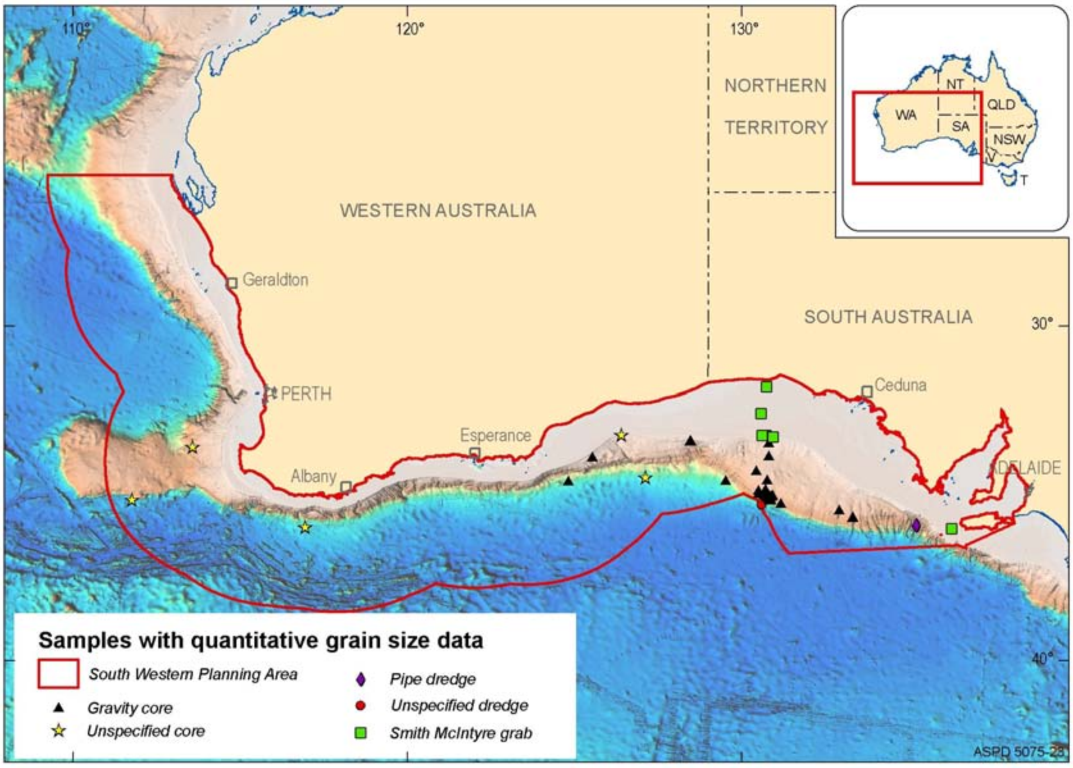

Figure 1.7. False-colour image showing the location and distribution of samples from the SWPA currently held in MARS that have quantitative grain size data.

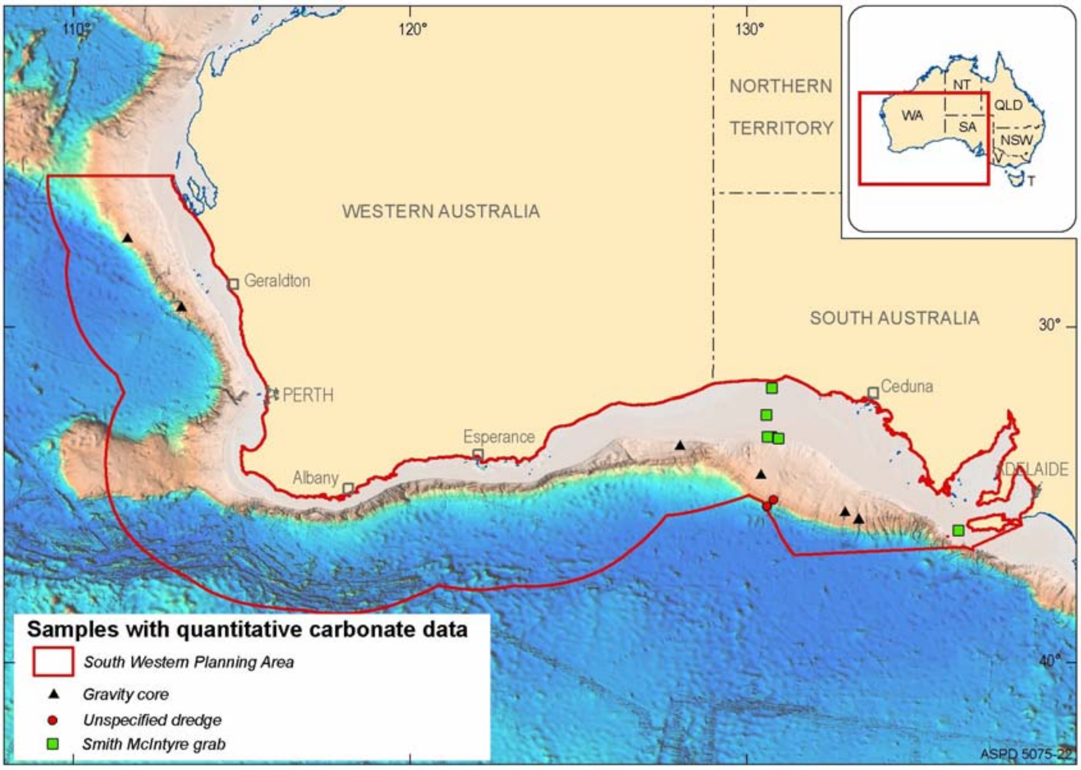

Figure 1.8. False-colour image showing the location and distribution of samples from the SWPA currently held in MARS that have quantitative carbonate content data.

1.2.3. Great Australian Bight

The Great Australian Bight region (Fig 1.2) includes a broad, latitude-parallel continental shelf that contains the world's largest modern cool-water carbonate province. It features warm-temperate carbonates and abundant seagrass and kelp beds on the inner shelf and cool-temperate carbonates, sponges and benthic foraminifera on the middle and outer shelf. This is an ideal site for cool-water carbonate production due to low terrigenous input, oceanographic upwelling, suitable water depth and temperature (James, 1997). Upwelling brings cold, nutrient-rich water onto the shelf, and is highest during summer when the Leeuwin Current is weakest (James et al., 2001). Additionally, the two largest mid-slope terraces on the Australian margin occur on the continental slope, and the abyssal plain occurs in water depths of >5,500 m (Fig. 1.4).

1.2.4. Spencer and St. Vincent Gulfs

The Spencer and St. Vincent Gulfs region (Fig 1.2) contains several busy industrial ports and the city of Adelaide. The gulfs are restricted and highly saline marine embayments that together cover an area of ~14,300 km^2 (Bye, 1976; Fuller et al., 1994). A high tidal range has produced broad intertidal and supratidal zones in the shallow northern areas of each gulf. The shallow gulfs contain seagrass habitats and other benthic communities that support algae, bryozoans and foraminifera. Pollutants from industrial activity are not efficiently distributed or diluted due to restricted circulation in the gulfs, and as a result have long residence times in gulf waters. During the Late Quaternary the gulfs fluctuated between dry terrestrial, lacustrine, lagoonal and ephemeral shallow marine environments due to changing sea levels.

2. Rottnest

The Rottnest region of the South Western Planning Area (SWPA) extends from Dirk Hartog Island at the mouth of Shark Bay in the north to the tip of Cape Naturaliste in the south, an area of approximately 365,500 km^2 (Fig. 1.2). The continental shelf comprises the Dirk Hartog Shelf and the Rottnest Shelf. The Rottnest Shelf has been defined as the continental shelf from the Houtman Abrolhos Islands to Cape Leeuwin (Carrigy and Fairbridge, 1954), and in this report it has been divided into the northern shelf and southern shelf, with the boundary occurring at the Perth Canyon offshore of Perth (32°S) (Fig. 2.1). This division is used in the literature and is based on the Perth Canyon being a major biogeographic boundary. The region contains a latitudinal transition zone that occurs at the Houtman Abrolhos Islands, where tropical reef biota occur on the reef platforms with cool-water carbonate sediments dominating the surrounding shelf environment.

2.1. Tectonic Setting

The Rottnest region is dominated by the north-south trending Perth Basin, which extends for ~1,300 km along the southwestern continental margin from north of Shark Bay to south of Cape Leeuwin (Fig. 2.2.). It is a large complex onshore and offshore sedimentary basin consisting of a series of sub-basins, troughs and highs (Stagg et al., 1999). The Perth Basin is an intra-cratonic graben, and lies between the oceanic crust of the Perth Abyssal Plain in the west and the continental Yilgarn Craton in the east (Song and Cawood, 2000). In the north it is adjacent to the Wallaby Plateau and intersects the southern Carnarvon Basin. In the south, it extends over the continental shelf towards Cape Naturaliste (Fig. 2.2; Felton et al., 1993; Colwell et al., 1994; Sayers et al., 2002). The major border fault system is the Darling Fault which forms the eastern onshore Basin margin (Stagg et al., 1999). Sedimentary basins contain a Permian-Early Cretaceous sediment fill of up to 15,000 m thick and overlie older basement rocks (Bradshaw et al., 2003). The Perth Basin formed during Permian-Early Cretaceous rifting between Western Australia and Greater India (Harris, 1994a; Bradshaw et al., 2003). Overlying Cenozoic marine carbonates are evidence of subsequent passive margin conditions that continue to the present day (Bradshaw et al., 2003). Northwest of the Perth Basin, the Wallaby Saddle separates the Perth Basin from the Wallaby Plateau. The Wallaby Saddle has formed from a series of thick volcanic flows (Bradshaw et al., 2003).

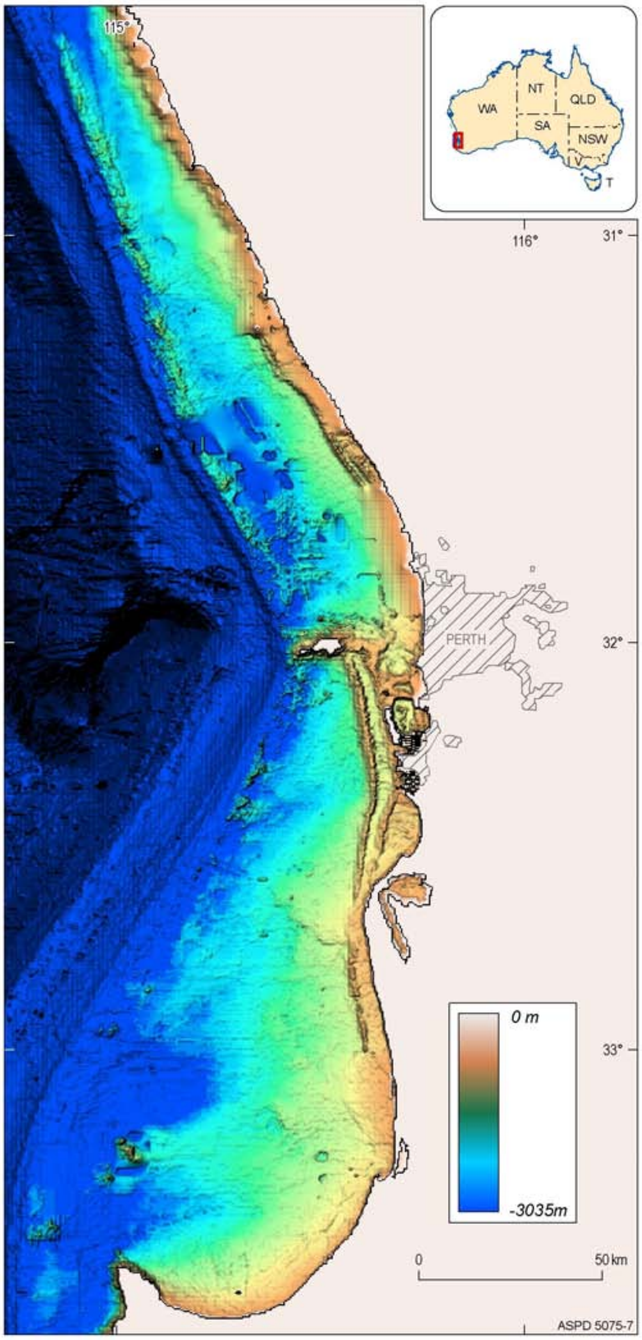

Figure 2.1. False-colour image showing the geomorphology and bathymetry of the Rottnest Shelf from 30.5°S to 33.5°S. In this report the 'southern Rottnest Shelf' refers to the area south of Perth.

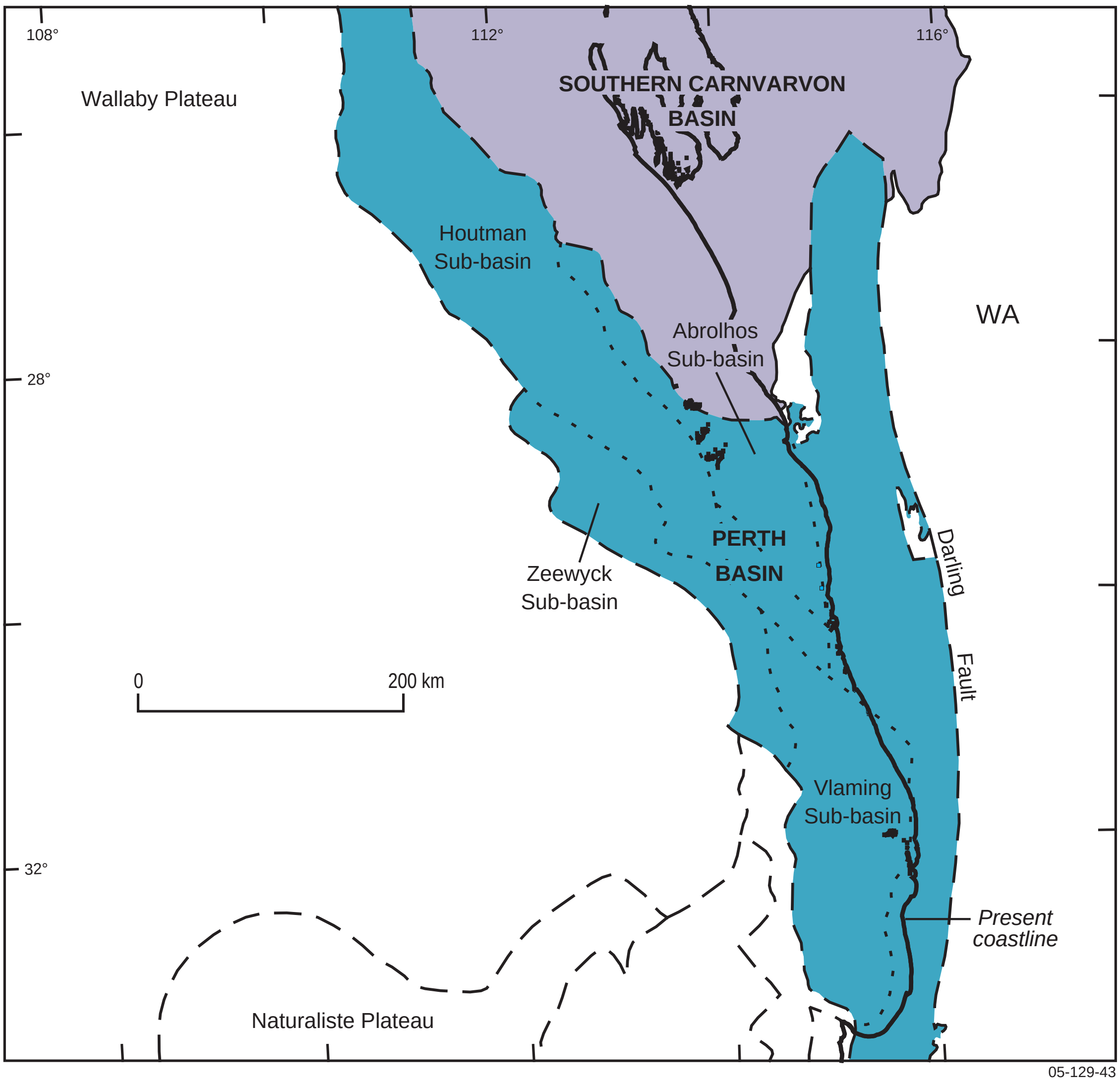

Figure 2.2. Map showing the geological setting of the Rottnest region (modified from Bradshaw et al., 2003). The Rottnest Region is underlain by the major Perth Basin which contains several troughs and highs and includes four sub-basins.

The Perth Basin can be sub-divided into four major sub-basins (Fig. 2.2; Bradshaw et al., 2003):

1. The Houtman Sub-basin is the largest tectonic element in the Perth Basin, extending over an area of 52,900 km^2. It is located on the continental shelf and slope, in water depths of 100-3,500 m, from the Wallaby Saddle in the north, to the Perth Abyssal plain in the south.
2. The Abrolhos Sub-basin extends across the continental shelf in water depths of 0-300 m, and comprises an area of 15,200 km^2. It is closely related to other areas

of the northern Perth Basin, and also southern parts of the Carnarvon Basin (Smith and Cowley, 1987).

3. The Zeewyck Sub-basin is a deep water rift basin that formed during the Early Cretaceous. It extends for an area of 15,400 km^2 across the continental slope in 1,000-5,000 m water depth.
4. The Vlaming Sub-basin is 19,200 km^2 in extent and stretches across continental shelf and slope in water depths of 0-3,000 m.

Tectonic structures in these basins may have implications for the formation of different seabed features and therefore habitats. For example, graben sediments, border faults, internal structures and other structural elements may influence the distribution of rock types, scarps and canyons on the seabed. In addition, the spatial distribution of seabed features may change due to tectonic activity (e.g. fault activation and seismicity). Such processes can potentially produce mass flows and other seabed changes, which will modify benthic habitats.

2.2. Geomorphology

The continental shelf in the Rottnest is 43,500 km^2 in area (Table 2.1) and comprises the Rottnest Shelf and the Dirk Hartog Shelf. The Dirk Hartog Shelf (also known as the Carnarvon Ramp; James et al., 1999) extends from North West Cape in the north (outside of the SWPA) to Shoal Point in the south and is ~70 km wide (Harris et al., 2005). The Rottnest Shelf extends from Geraldton in the north to Cape Leeuwin in the south and is 45-100 km wide (Carrigy and Fairbridge, 1954; Playford et al., 1976; Collins, 1988). It is a narrow, incipiently rimmed, flat-topped shelf that steepens away from the coast (Fig. 2.1; James et al., 1999). The southern Rottnest Shelf has been called a 'bathymetrically complex coast' by Semeniuk (1996) and can be divided into four main sections: 1) nearshore ridges, reefs, depressions and topographic highs between 0 and 20 m water depth; 2) a smooth inner shelf plain between 20 and 48 m; 3) a shore-parallel ridge complex between 48 and 60 m; and 4) a steep, narrow outer shelf from 60 m to the edge of the shelf-slope break, which ranges between 170 and 200 m (Fig. 2.3; Collins, 1988). Figure 2.4 shows a similar geomorphology of the northern Rottnest Shelf in cross-section, at the Houtman Abrolhos Islands (James et al., 1999).

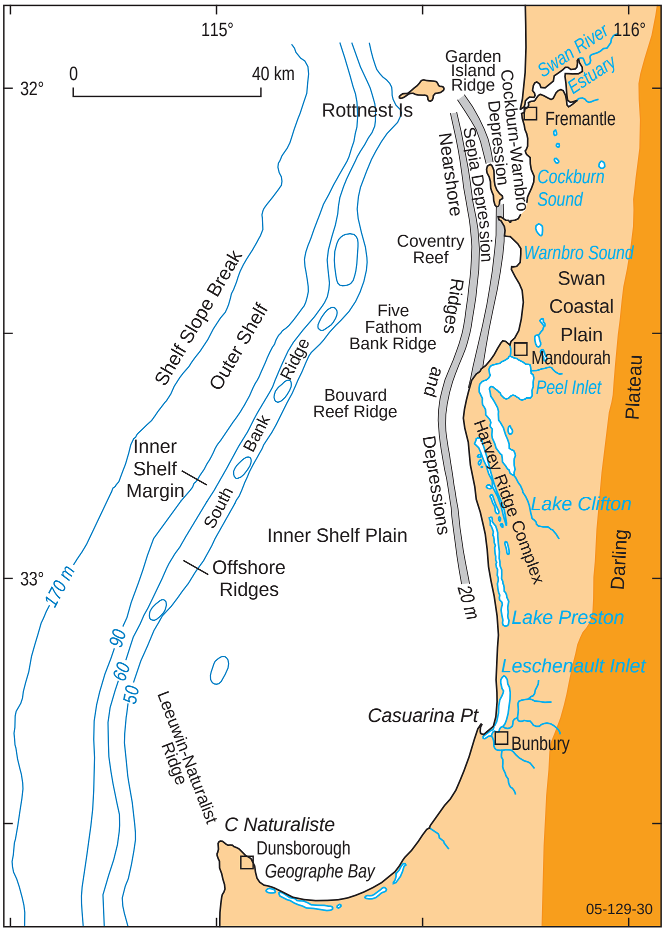

Figure 2.3. Schematic diagram showing the morphology of the southern Rottnest Shelf (area south of Rottnest Island) (redrawn from Collins, 1988). The four main geomorphic sections mentioned in the text are shown in the diagram: 1) near-shore ridges and depressions; 2) an inner shelf plain; 3) offshore ridges (shore-parallel ridges); and 4) a narrow outer shelf.

Irregular topography close to the coast consists of eroded limestone reefs and pinnacles that stand 10-20 m above the seafloor and reach within 5 m of the sea surface. These structures help to shelter the coast from wave energy, resulting in the occurrence of cuspate forelands, embayments and inlet beaches (Semeniuk, 1996; Sanderson et al., 2000). The inner shelf plain is smooth and gently sloping, with water depths of less than 48 m. Wave currents rework sediments by sorting and abrasion, forming symmetrical wave ripples and gravel lag deposits that are typically oriented north-south (Collins, 1988).

Marking the edge of the inner shelf plain at 48-60 m water depth is a series of discontinuous, north-trending offshore ridges ranging from 1-5 km in width. These ridges occur intermittently along the entire length of the Rottnest Shelf, and only in the north are they emergent, supporting tropical carbonate reef growth at the Houtman Abrolhos Islands. On the southern Rottnest Shelf, these ridges have jagged tops and steep sides (Collins, 1988; James et al., 1999). North of the Houtman Abrolhos, a transition zone occurs between the Rottnest Shelf and the Carnarvon Ramp; at this transition ridges gradually recede to form smoother seafloor topography (James et al., 1999).

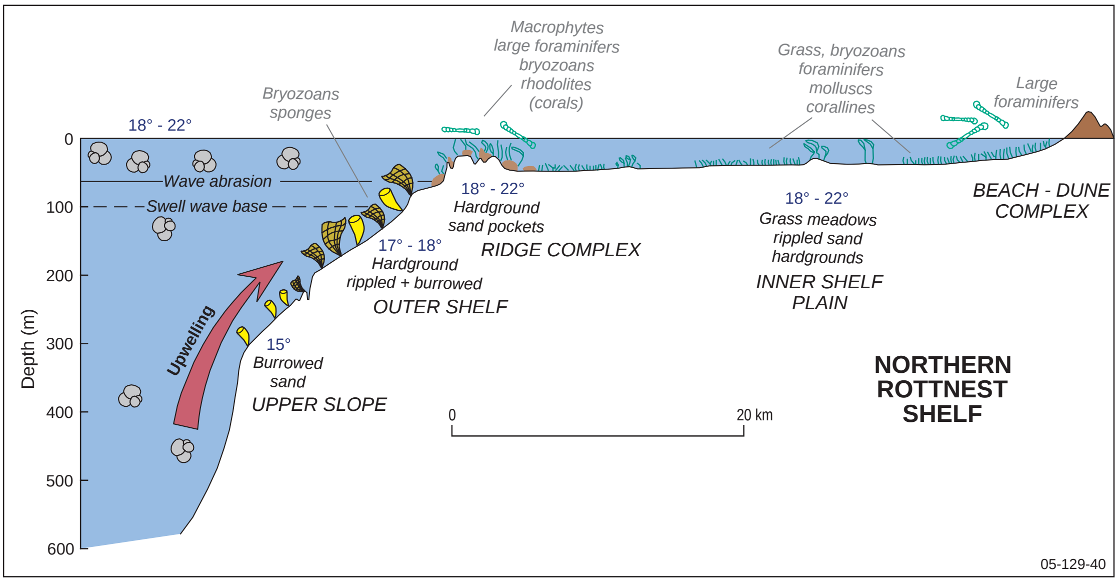

Figure 2.4. Schematic cross-section of the northern Rottnest Shelf, illustrating the smooth inner-shelf plain, ridge complex, outer shelf and upper slope (modified from James et al., 1999). Habitat associations and sea surface temperatures are also shown.

The Houtman Abrolhos complex is a series of over 100 islands situated approximately 70 km off the Western Australian coast at 28-29°S (Fig. 2.5). The islands occur in three main groups and cover an area of 1,120 km² (Table 2.1). The three reef complexes, Wallabi, Easter and Pelsaert, are separated by two 40 m deep, flat-floored channels (Fig. 2.6), have windward (western) and leeward (eastern) reefs and lagoons, and support the highest-latitude platform reef growth in the Indian Ocean (Veron and Marsh, 1988; James et al., 1999). Holocene reef growth occurs on the windward and leeward sides of each reef complex; however the central platforms are above current sea level. Each reef complex has gently sloping western margins and steep southeast and northern margins, with distinct 'blue-hole' terrains and reticulate reefs occurring on eastern margins. Blue-hole terrains consist of reef pinnacles separated by 'holes' generally 20 m deep (Fig. 2.7). Submerged banks are present to the north and south of the emergent reefs, situated on the north-south trending ridge system (Collins et al., 1993a,b; Collins et al., 1997).

Table 2.1. Geomorphic features in the Rottnest region (from Harris et al., 2005).

Geomorphic Feature	Area (km^2)	Percent
Shelf*	43,500	11.92
Slope*	122,670	33.61
Continental Rise*	47,700	13.07
Abyssal-plain/deep ocean floor*	103,910	28.47
Apron/Fan	240	0.07
Bank/Shoals	800	0.22
Canyon	8,740	2.40
Deep/hole/valley	3,180	0.87
Escarpment	240	0.07
Pinnacle	160	0.04
Reef	1,120	0.31
Saddle	3,630	1.00
Terrace	28,420	7.79
Trench/trough	650	0.18
Total	364,960	100.00

*These units are less the surface areas of superimposed features.

The outer shelf is an inclined surface that spans 10-20 km, extending from the edge of the reef or ridge complex to approximately 200 m water depth. The steep, narrow outer shelf west of the Houtman Abrolhos islands has several shore-parallel ridges within the 70-100 m depth interval (Fig. 2.8). These ridges have up to 20 m relief and can be traced for over 100 km along the outer shelf. They are up to 400 m wide and have variable morphology, from sharp and narrow to tabular in cross-section (Harris et al., 1991; Collins et al., 1997; Harris et al., 2005). On the outer shelf and upper continental slope, wave reworking is not as common as on the inner shelf, yet current ripples, linear ridges and scours occur locally (Collins, 1988).

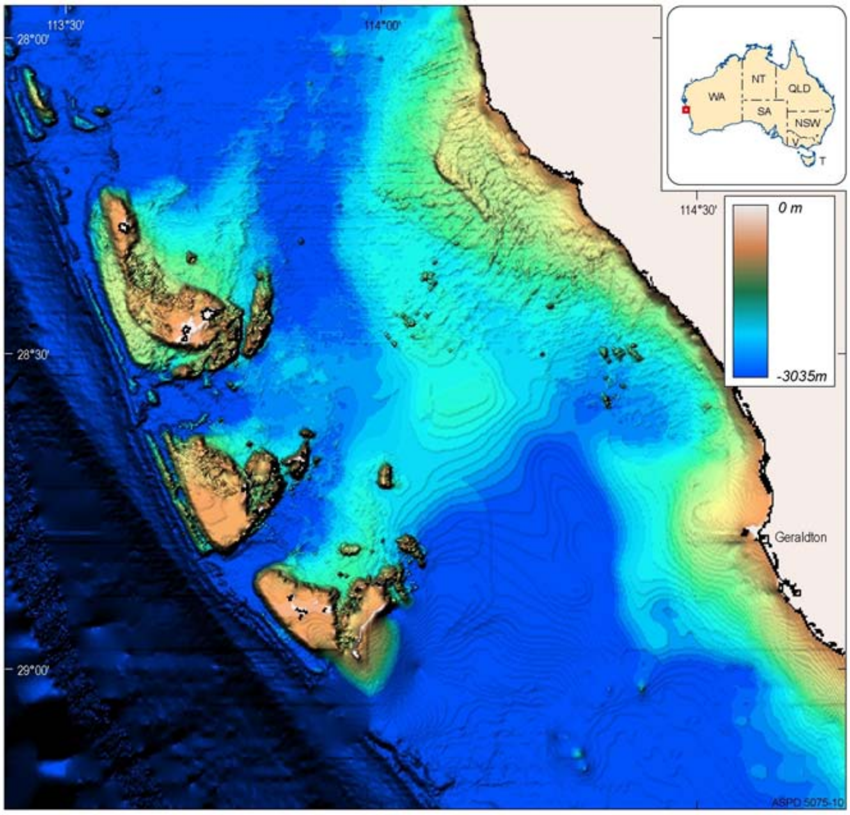

Figure 2.5. False-colour image showing the geomorphology and bathymetry of the Houtman Abrolhos Islands situated close to the shelf edge. The Houtman Abrolhos Islands comprise three groups of platforms and islands; from north to south these are Wallaby, Easter and Pelsaert.

Irregular topography west of Rottnest Island is related to the Perth Canyon, (Fig. 2.9) which is the largest canyon on the west coast (von der Borch, 1968). The canyon head has two well defined tributaries that have cut into the continental shelf (Collins, 1988). Numerous, smaller canyons also occur along the continental slope, which is steep in the north (the Wallaby-Perth Scarp) and more gently dipping in the south (Harris et al., 2005). These canyons cover an area of 8,744 km^2 (Table 2.1) and have transported shelf sediment onto the Perth Abyssal Plain (Falvey and Veevers, 1974).

In deeper water, three terraces are present on the continental slope, together covering 28,431 km^2. Two terraces sit at 200-212 m and 236-242 m offshore of Cape Naturaliste and Cape Leeuwin, and the southern tip of the Carnarvon Terrace sits offshore of the Abrolhos reefs at 600 m water depth (Collins, 1988; James et al., 1999; Harris et al., 2005). At the northern boundary of the SWPA, the Carnarvon Terrace broadens into the Wallaby Plateau (Harris et al., 2005).

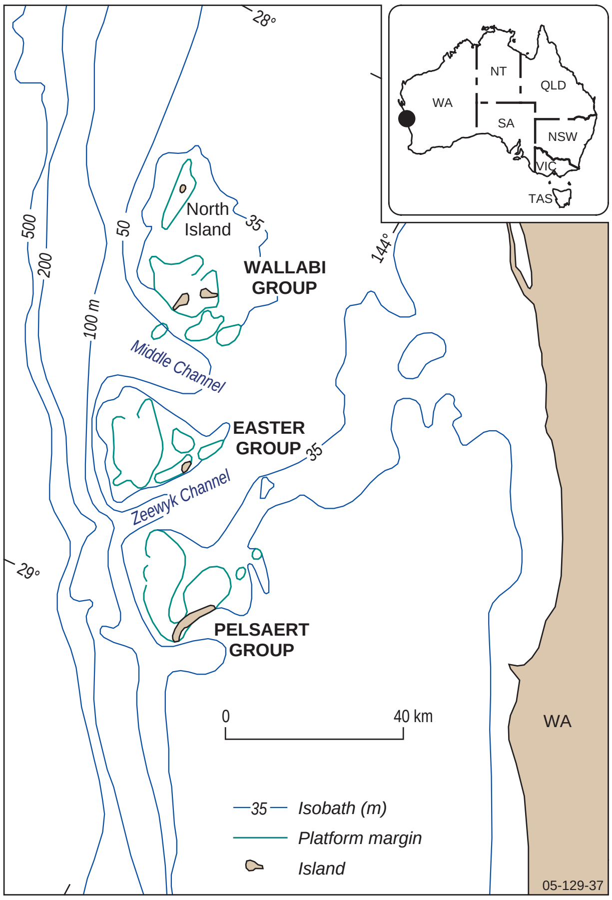

Figure 2.6. Bathymetry map showing the three Houtman Abrolhos platform groups (redrawn from Collins et al., 1997). Platforms are marked in green with outcropping islands shaded yellow.

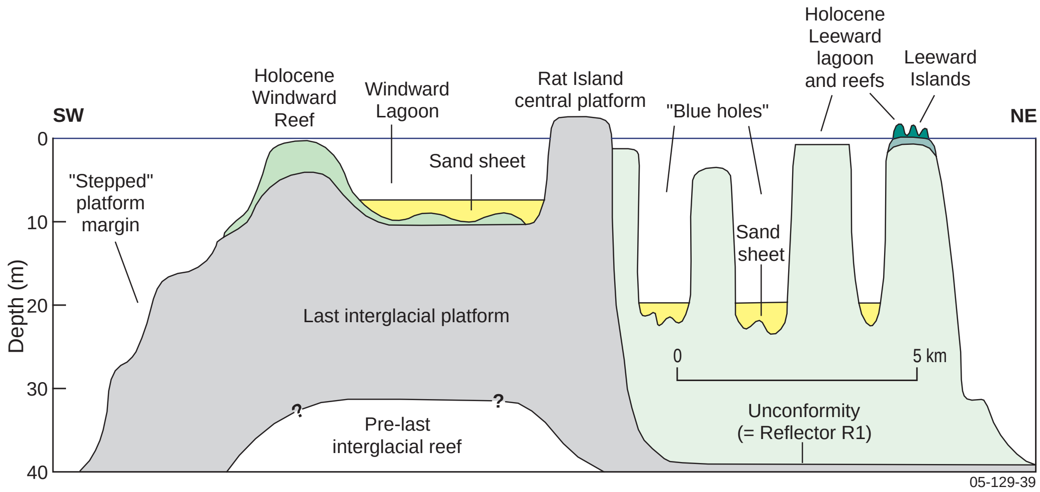

Figure 2.7. Schematic cross-section of the Easter Platform, showing platform structure and reef growth (modified from Collins et al., 1996). Holocene leeward reef growth is shown in light green and is more extensive than Holocene windward reef growth, shown in darker green. 'Blue-Hole' terrain is present on the leeward reef margin.

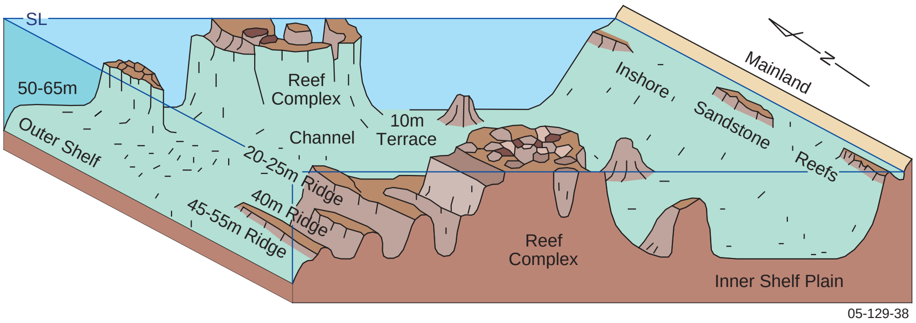

Figure 2.8. Idealised morphology of the inner Abrolhos Shelf (northern Rottnest Shelf), showing inshore reefs and ridges, an inner shelf plain, a reef complex and outer shelf ridges (redrawn from Collins et al., 1997; not to scale).

The continental rise in the region is the most extensive area of continental rise on the Australian margin. It is generally a smooth sediment apron and probably formed during rifting of Australia from India and Antarctica during the Cretaceous. The rise is widest in the south and is less extensive in the north offshore of the Carnarvon Terrace and the Perth-Wallaby Scarp. In the north it is located in water depths of 4,500 to 5,500 m (Marshall et al., 1989; Harris et al., 2005).

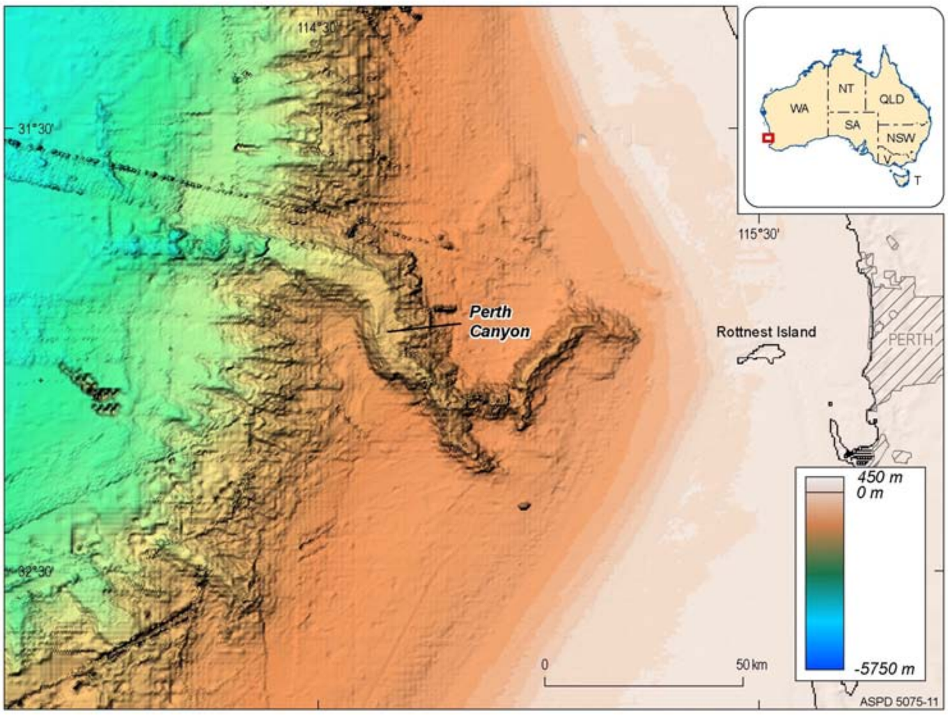

Figure 2.9. False-colour image showing the geomorphology and bathymetry of the Perth Canyon. The canyon head starts on the continental shelf and transports shelf material into the deep ocean. It is an important link between continental shelf habitats and deep-water habitats and forms a major biogeographical boundary.

The Perth Abyssal Plain is typically flat with water depths generally over 5,600 m. It covers 28.5% of the region, encompassing 103,911 km^2 (Table 2.1). Low abyssal hills occurring in the west are covered in sharp, NNE-NE trending ridges, which terminate abruptly along northwesterly lineations. Stagg and Exon (1981) have interpreted these lineations as possible fracture zones (Harris et al., 2005).

2.3. Oceanography

Two major water masses occur off the Western Australian coast (see Fig. 1.5). The volumetrically large, northward-flowing Western Australian Current brings cold water from high latitudes, and is part of the major anticlockwise Indian Ocean circulation (Cresswell and Golding, 1980; Pattiaratchi and Buchan, 1991; Li and McGowran, 1998). In contrast, the volumetrically small, southward-flowing Leeuwin Current (LC) brings relatively warm, low-salinity, nutrient-poor water from the tropics (Cresswell, 1991). The LC is a shallow (<300 m), narrow (<100 km wide) current that flows close to the coast, is strongest in autumn and winter, and has the greatest influence on shelf sediments and biota (Cresswell and Golding, 1980; Cresswell, 1991; Pattiaratchi and Buchan, 1991). It is the only west coast boundary current that flows towards the poles; currents on the west coasts of Africa and South America are cold, nutrient-rich, equatorward currents that promote upwelling and high biological productivity (Cresswell, 1991). In comparison, the LC impedes upwelling in the region, resulting in nutrient-poor waters and low productivity (Thompson, 1984; Godfrey and Ridgeway, 1985; James et al., 1999).

On the northern Rottnest Shelf sea surface temperatures range from 18°C in winter to 26°C in summer (Wilson and Marsh, 1979). Temperatures fall below 20°C for up to 30% of the year (France, 1985, cited in Collins et al., 1997) and conditions are often near the limits for reef-building coral growth (Collins et al., 1993a). On the southern Rottnest Shelf temperatures range from 15-20°C, with very little temperature change with depth (Hodgkin and Phillips, 1969; James et al., 1999).

A biogeographical transition zone is present on the northern Rottnest Shelf. The warm, tropical nature of the LC influences the distribution and type of marine biota in the region and allows tropical species to flourish at higher latitudes than normal. The

LC allows the tropical to subtropical transition to occur at 28-29.5°S, whereas on the east coast it occurs at 24°S (Collins et al., 1991). For example, the LC allows the Houtman Abrolhos Islands to support the highest-latitude coral reefs in the Indian Ocean. In addition to temperature, the LC also brings low-nutrient waters that inhibit macroalgae growth, allowing for more active coral reef development (Hatcher, 1991; Collins et al., 1997). The influence of the LC is also shown from the presence of coral communities around Rottnest Island and the occurrence of warm-water foraminifera and algae as far east as the Recherché Archipelago (Maxwell and Cresswell, 1981; Veron and Marsh, 1988; Bone et al., 1994; Pearce and Pattiaratchi, 1997; McGowran et al., 1997).

While the LC impedes large-scale upwelling on the west coast, small-scale upwelling is locally important (Gersbach et al., 1999). During summer the LC is weak and situated further offshore, allowing upwelling to occur on the outer Rottnest Shelf and along seaward margins of the Houtman Abrolhos platforms (James et al., 1999). Holocene reef growth has not been symmetrical around the central reef platforms due to predominant swell-wave approach from the west and southwest. In addition, periodic upwelling of nutrient-rich waters results in competition between macroalgae and corals on the windward platforms (Hatcher, 1991). Seaward of the Houtman Abrolhos Islands, bryozoan growth is prolific, more so than elsewhere, suggesting that local upwelling provides good trophic resources to the outer shelf in this area (James et al., 1999).

On the southern Rottnest Shelf, a number of authors have observed and described a cold water mass called the Capes Current that is present on the inner continental shelf between Capes Leeuwin and Naturaliste during summer (Fig. 2.10; Cresswell and Peterson, 1993; Pearce and Pattiaratchi, 1999). This current flows northwards, and has been observed as far north as Geraldton (James et al., 1999). The nutrients brought to the surface by this upwelling result in large-scale phytoplankton blooms that are important for commercial fisheries (Webb and Morris, 1984). The Capes Current may also be important for the seasonal migration and spawning patterns of fish species such as salmon (Gersbach et al., 1999; Pearce and Pattiaratchi, 1999).

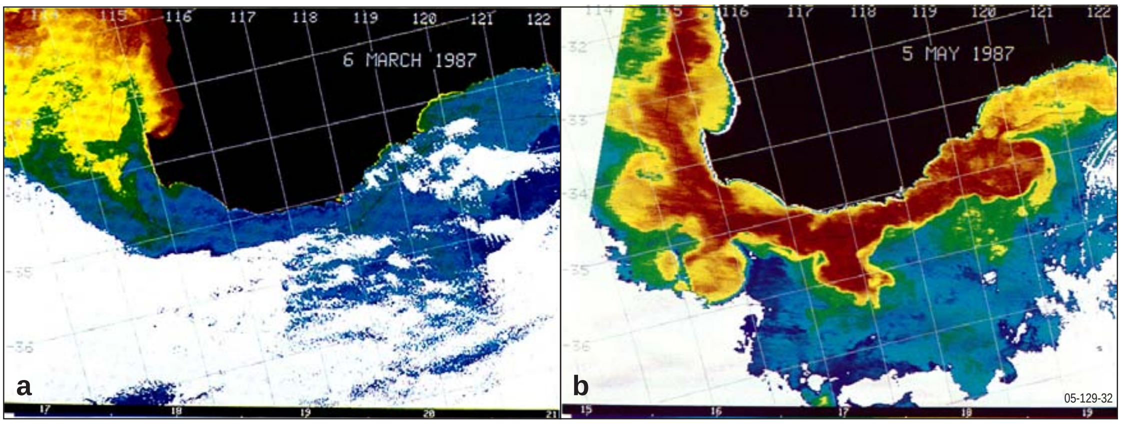

Figure 2.10. Satellite image of the Leeuwin Current in March 1987 and May 1987 (from Cresswell and Peterson, 1993). (a) shows a weaker Leeuwin Current with a tongue of cool water, the Capes Current, evident offshore of Cape's Leeuwin and Naturaliste. (b) shows a stronger Leeuwin Current flowing around Cape Leeuwin and across the Recherché Shelf. There is a sharp temperature gradient between the Leeuwin Current and Southern Ocean water of up to 5°C. White areas are cloud.

Periodic downwelling is also locally important for the distribution of sediments in the region. Hypersaline outflow from Shark Bay moves westward and southward onto the shelf (Fig. 2.11), dramatically reducing the diversity of carbonate biota in its path (James et al., 1999).

The dominant physical processes on the Rottnest Shelf are swell and storm waves from the Southern and Indian Oceans. As a result the shelf is a high-energy environment and wave abrasion and erosion is frequent, particularly on the inner shelf. Swell waves of 2 m high predominantly come from the west and southwest throughout the year (Fig. 2.12a). Storm waves of up to 10 m high generate significant seas on the southern Rottnest Shelf in winter and spring (Fig. 2.12b) (Collins, 1988; Semeniuk, 1996; Collins et al., 1997; James et al., 1999). Swell waves have wavelengths of up to 200 m and significantly affect bottom sediments on the inner and outer shelf. These wave currents frequently rework sediments down to 60 m and are able to rework sediments and form wave ripples down to 100 m. Figure 2.13 shows mean and maximum wave energy for the Rottnest region, illustrating the protection offered to the inner shelf by

Cape Naturaliste and the Houtman Abrolhos Islands (Fig. 2.13a), and the decrease in maximum wave energy from south to north (Fig. 2.13b). As over 90% of the inner shelf is shallower than 50 m, inner shelf sediments experience continual wave abrasion and reworking (Collins, 1988; James et al., 1999). Storm waves form long, straight ripples and lag deposits on the inner shelf, and tropical cyclones occur on average once every four years, creating extreme wave conditions that can rework sediments down to 200 m (Collins, 1988).

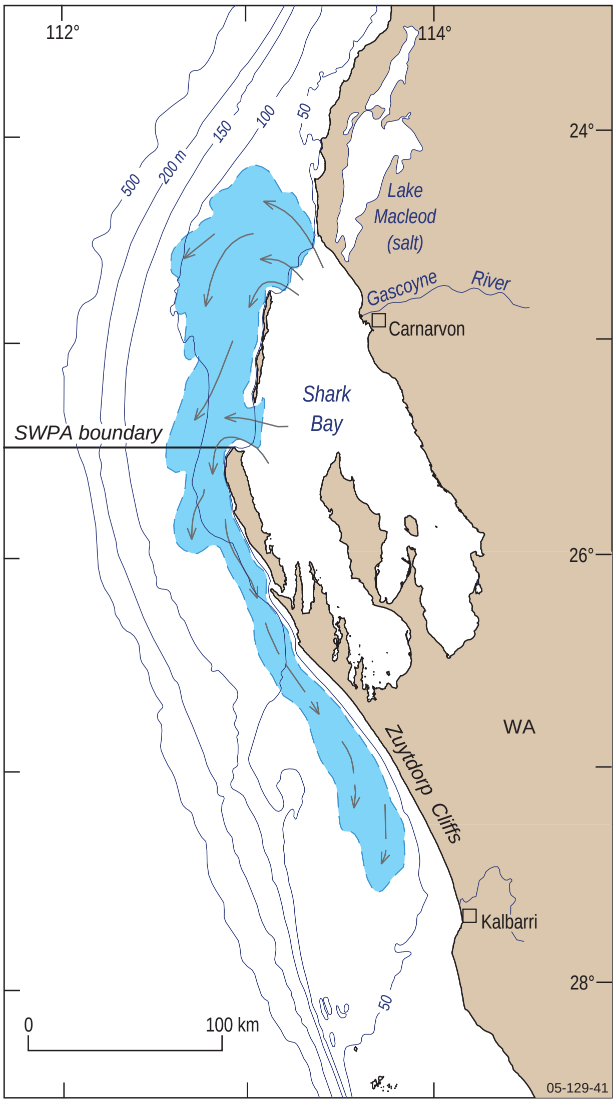

Figure 2.11. Interpreted flow of saline bottom waters out of Shark Bay based on observations and modelling (redrawn from James et al., 1999). The outflow would travel south due to local currents and the Coriolis effect. Diversity of carbonate biota is dramatically reduced in areas influenced by this outflow.

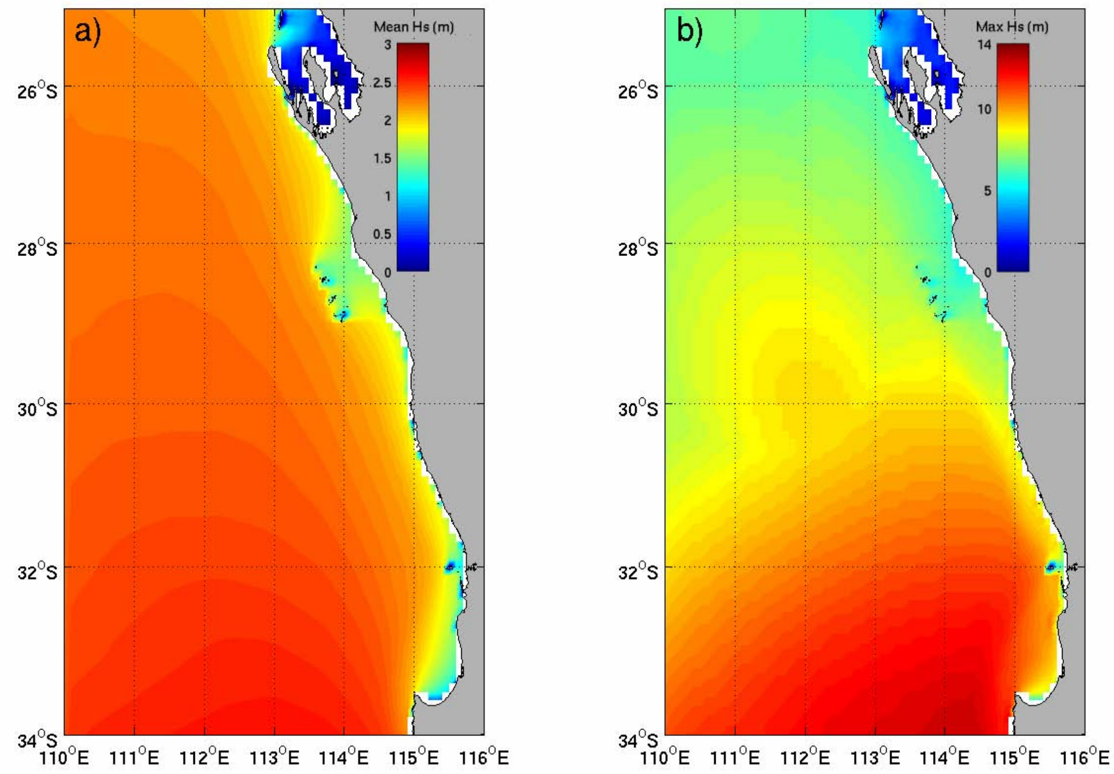

Figure 2.12. Map showing significant wave height for the Rottnest region. Mean wave height (a) is the height of the highest 1/3 if waves based on a seven year mean (Feb 1997 – Feb 2004), and (b) shows maximum wave height for the same period. Swells predominantly come from the southwest.

Tides on the Rottnest Shelf are microtidal, with a range of <0.5 m. As such, tides play a relatively minor role in sediment transport on the shelf (Searle and Semeniuk, 1985; Valesini et al., 2003). In contrast, non-tidal sea-level variations are significant. Provis and Radok (1979) found the greatest variability in non-tidal sea-level variations around Australia to be on the south and west coasts. For example, sea level along the west coast is higher when the LC is stronger (Pattiaratchi and Buchan, 1991), and tropical cyclones can induce 1-2 m high sea level peaks when they travel parallel to the coast (Cresswell et al., 1989).

Complex bathymetry results in a range of coastal habitats, depending on the amount of exposure to ocean swells. Offshore limestone reefs, ridges, islands and shallow banks prevent up to 60% of wave energy reaching the adjacent coast. Where these structures protect the coast, sheltered sandy beaches and estuarine lagoons occur (Valesini et al., 2003).

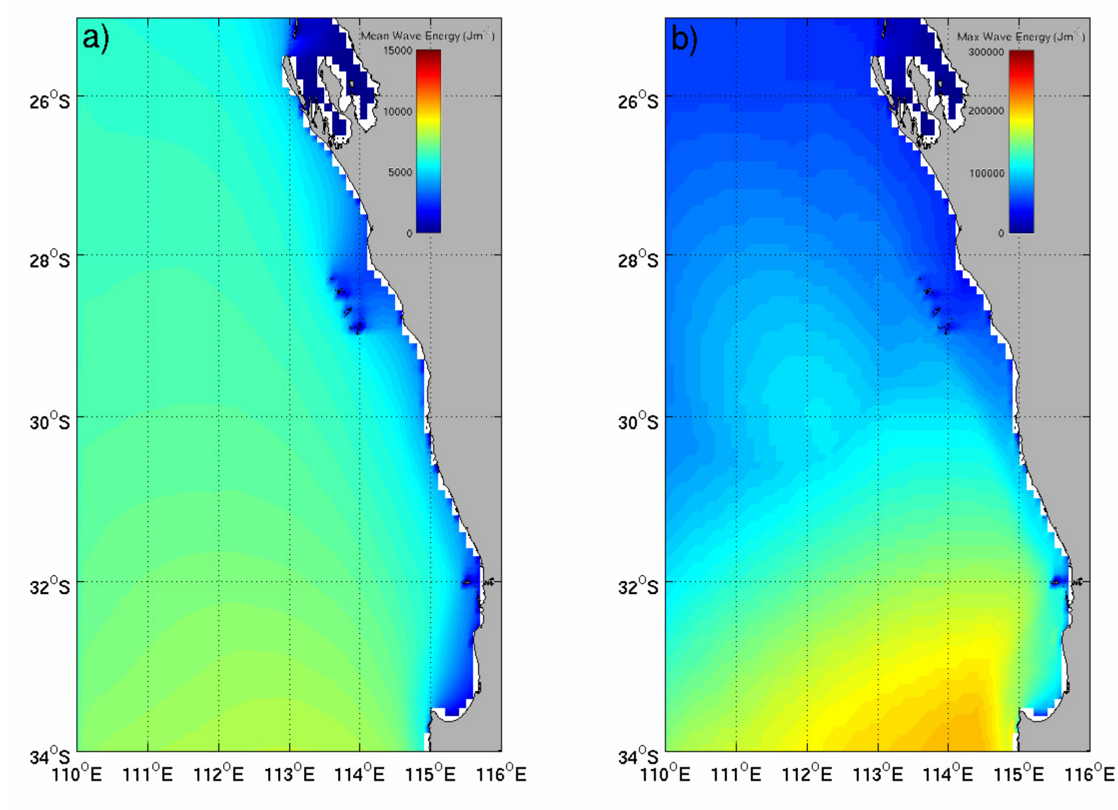

Figure 2.13. Map showing mean (a) and maximum (b) wave energy for the Rottnest region. As swells and storms come from the southwest, the southern Rottnest Shelf has a higher physical energy than the northern Rottnest Shelf. Cape Naturaliste and ridges and reefs on the shelf provide some protection from these southwesterly swells.

2.4. Surface Sediments

The regional sedimentology of the Rottnest region has been studied in several geological surveys; 131 sediment samples were collected on a survey of the shelf from North West Cape to Perth by James et al. (1999); shelf and platform sediments from the Abrolhos shelf have been studied by Collins et al. (1997); the southern Rottnest Shelf, from Fremantle to Cape Naturaliste was comprehensively sampled by Collins (1981, 1986, 1988); and recently, the inner shelf sediments of Cockburn Sound were studied in a Geoscience Australia survey (Skene et al., 2005).

Surface sediments along the western margin from Cape Inscription to Cape Naturaliste are dominated by carbonate bioclasts. On the Rottnest Shelf recent skeletal sediment components have attributes of both warm and cool water carbonates (James et al., 1999). The Houtman Abrolhos region highlights a 'latitudinal overlap' or transition zone in sediment-producing biota. The Houtman Abrolhos platforms are dominated by tropical reef biota (Collins et al., 1997), whereas on the shelf temperate, cool-water species are the most significant producers of carbonate sediment (Collins et al., 1998). Overall, sediments in the region are bordered by warm-water carbonates in the north and the large cool-water carbonate province in the south.

Across the Rottnest Shelf, sediments generally occur as thin, discontinuous sheets over rocky or algal substrates (Collins et al., 1997). Seafloor photography reveals three main sediment distribution patterns. These include: 1) rocky seabed with abundant seagrass, macrophytes and sponges; 2) rippled sand with clumps of calcareous red algae; and 3) open expanses of rippled sands (James et al., 1999). Shelf sediments are dominantly cool water carbonates, composed of mud, sand or gravel made up of the skeletal remains of bryozoans, molluscs (scaphopods, bivalves, gastropods), foraminifers (free and encrusting, benthic and pelagic) and coralline algae (free-living and rhodoliths; Collins et al., 1997; James et al., 1999). In some regions, scattered zooxanthellate coral fragments reflect warm-water sediment types. Other fragments include Pleistocene limestone fragments, local dolomite rhombs and pyrite-blackened calcareous skeletons associated with seagrass roots (James et al., 1999). Glauconite occurs locally in sands and silts from outer ramp and continental slope sediments (Table 2.2). Terrigenous components are more abundant in coastal areas than elsewhere, and include quartzite, granite, siltstone, feldspar and quartz grains. These terrigenous grains are common proximal to large river mouths where they can exceed 50% of surface sediments (Fig. 2.14; Collins et al., 1997; James et al., 1999).

On the basis of grain size and composition, James et al. (1999) has divided surface sediments on the northern Rottnest Shelf into several facies types (Table 2.2; Fig. 2.14). Facies types generally trend parallel to the shelf and can be divided into an inner shelf plain facies (e.g., Skeletal Sand, Quartzose Skeletal Sand, Molluscan Skeletal Sand), a ridge complex facies (e.g., Coralline Algal Rhodolite Gravel), an outer shelf facies (e.g., Bryozoan Skeletal Sand), a mid-ramp (i.e., Carnarvon) facies (e.g., Abraded Intraclast-Skeletal Sand, Fragmented Intraclast-Skeletal Sand), an outer ramp facies (e.g., Planktic-Intraclast Sand, Planktic Sand and Silt, Well-washed Planktic Sand), and a continental slope facies (e.g., Spiculitic or Bryozoan-rich Carbonate Silt).

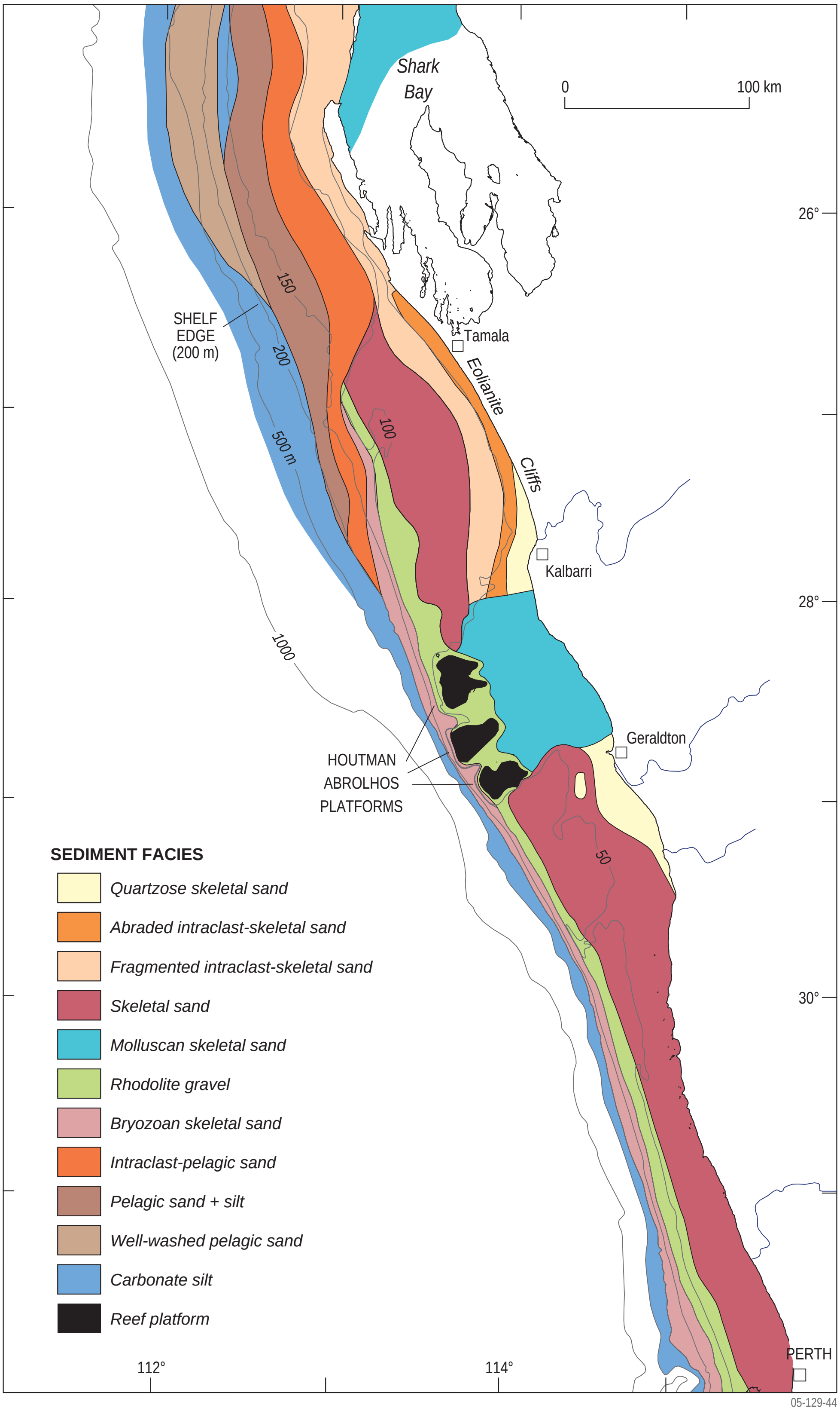

Figure 2.14. Sediment facies map of the northern Rottnest Region from Shark Bay to Perth (modified from James et al., 1999), showing the shelf-parallel facies transition from the inner shelf to the shelf edge.

On the Houtman Abrolhos platforms skeletal carbonate grainstone forms an unconsolidated sand sheet in platform lagoons (Collins et al., 1997). Deposits vary from 0-4 m thick in the windward lagoon, 7 m thick in the leeward lagoon, to 4-13 m thick in the blue holes (Collins et al., 1997). The most important constituents volumetrically are coralline algae, corals and mollusc fragments, with minor amounts of foraminifera, bryozoans and echinoids. Carbonate constituents have variable abundances depending on the platform environment (i.e., shallow or deep lagoon, lagoon sand sheet). Skeletal grainstone is only one of five Holocene facies types on the reef; the others are: 1) coral framestone; 2) algal bindstone; 3) well-bedded coral rudstone; and 4) unlithified coral rudstone (Collins et al., 1998). Shelf sediments surrounding the platforms have distinct windward, leeward and channel facies, which differ from other parts of the shelf (Fig. 2.14).

On the southern Rottnest Shelf, Collins (1988) has identified two major facies types: the Fremantle Blanket and the Rottnest Blanket (Fig. 2.15a). Similar to the northern Rottnest Shelf, sediments have a distinct shelf-parallel zonation and are associated with substrate type (Collins, 1988). Sediments form a thin (<1 m) veneer overlying Pleistocene limestone with the inner shelf consisting of wave-rippled sand and localised algal hard grounds in nearshore regions (Fig. 2.15b). Algal hard grounds and rhodolith pavements occur on offshore ridges on the inner shelf margin. Extensive areas of bioturbated fine sand occur on the outer shelf (Collins, 1988).

In Cockburn Sound, Geoscience Australia collected 63 surficial sediment samples and 12 cores (Fig. 2.16a; Skene et al., 2005). The surficial sediments are dominated by biogenic carbonates with low overall gravel concentrations. Four sediment facies occur in the sand, namely: 1) Nearshore Quartz Sand, comprised of fine to coarse grained gravel quartz sand with shell fragments; 2) Carbonate Banks of well-sorted carbonate sand; 3) an Eastern Shoal Facies comprised of muddy carbonate sand; and 4) a Central Basin Facies comprised of sandy carbonate mud (Fig. 2.16b). Overall, the carbonate content of surficial sediments is generally >70%, with carbonate concentrations of ~90% on the carbonate banks (Fig. 2.16c; Skene et al., 2005).

Table 2.2. Surface sediment facies on the northern Rottnest Shelf shown in Figure 2.14 (after James et al., 1999).

Facies	Description
Skeletal Sand	Poor to well sorted gravels and sands of bryozoans, benthic foraminifers, mollusc fragments, coralline algal rods, lesser gastropods and lithic intraclasts; corallines increase northward; bryozoans decrease to 5% inboard of reef platforms; similar to the Fremantle Blanket on southern Rottnest Shelf (Collins, 1988).
Quartzose Skeletal Sand	Nearshore quartz-rich sediments with relict carbonate particles and >25% terrigenous quartz and rock fragments.
Molluscan Skeletal Sand	Mollusc-dominated carbonate sediment with the coarse fraction >80% bivalves (*Pinna* sp., *Hemicardium* sp.) and fewer gastropods (high-spired forms, e.g., *Murex* sp.); <10% terrigenous grains.
Coralline Algal Rhodolite Gravel	Bimodal mix of rhodolite nodules (3/4) and skeletal sand (1/4); pavement of live rhodoliths with a cortex composed of coralline algae, encrusting foraminifers (*Miniacina* sp., *Gypsina* sp.), bryozoans and serpulids. Part of the Fremantle Blanket of Collins (1988).
Bryozoan Skeletal Sand	Very poorly sorted, mud- to gravel-size sediments; coarse fraction is dominantly encrusting, arborescent and nodular bryozoans and sponges, serpulids, with skeletal echinoid, mollusc, gastropod, bivalve and ahermatypic corals; fine fraction of bryozoans (1/3) and foraminifers (1/4); corresponds to the Rottnest Blanket of Collins (1988).
Abraded Intraclast-Skeletal Sand	Medium to coarse grained, well sorted sand; high proportions of abraded and polished grains with conspicuous speckled orange-brown colour; coarse fraction of limestone or calcrete pebbles and cobbles (1/4), bivalve shells (1/2) and bryozoans (1/4); sand fraction of mostly relict coralline algae and foraminifer grains
Fragmented Intraclast-Skeletal Sand	Poorly sorted sand; coarse fraction (<20%) dominated by bivalves and bryozoans; dead rhodolites abundant at 100 m; modern skeletal grains of bryozoan fragments (<30%); minor relict sand grains
Planktic-Intraclast Sand	Buff to grey variably sorted, fine to very coarse sand with high proportions of intraclasts; intraclasts consist of irregular, fine to granule sized, poorly sorted clasts; vagrant bryozoans, ahermatypic corals, bivalves and foraminifers; glauconite; iron oxides; occasional dead rhodolites
Planktic Sand and Silt	Muddy sand of equal proportions of planktic foraminifers and carbonate silt
Well-washed Planktic Sand	Buff, well sorted clean sands dominated by planktic particles of pelagic foraminifer; no mud; coarse fraction (10%) of bivalves, ahermatypic corals, pteropods with minor sponge spicules and soft corals; local botryoidal glaucony
Carbonate Silt	Spiculitic or bryozoan-rich; carbonate silt of broken pelagic foraminifer, ostracod and pteropod fragments, with bryozoan fragments common on the Rottnest Shelf, which corresponds to part of the Rottnest Blanket (Collins, 1988); local glauconite-filled clasts and bored cobble-sized skeletal bryozoan clasts

*Intraclasts are composed of modern, relict or stranded, rounded to irregular shaped, sand- to cobble-sized grains of skeletal intraclasts (single-skeleton) or lithic intraclasts (numerous cemented skeletons).

*Fractions in brackets are rough estimates only.

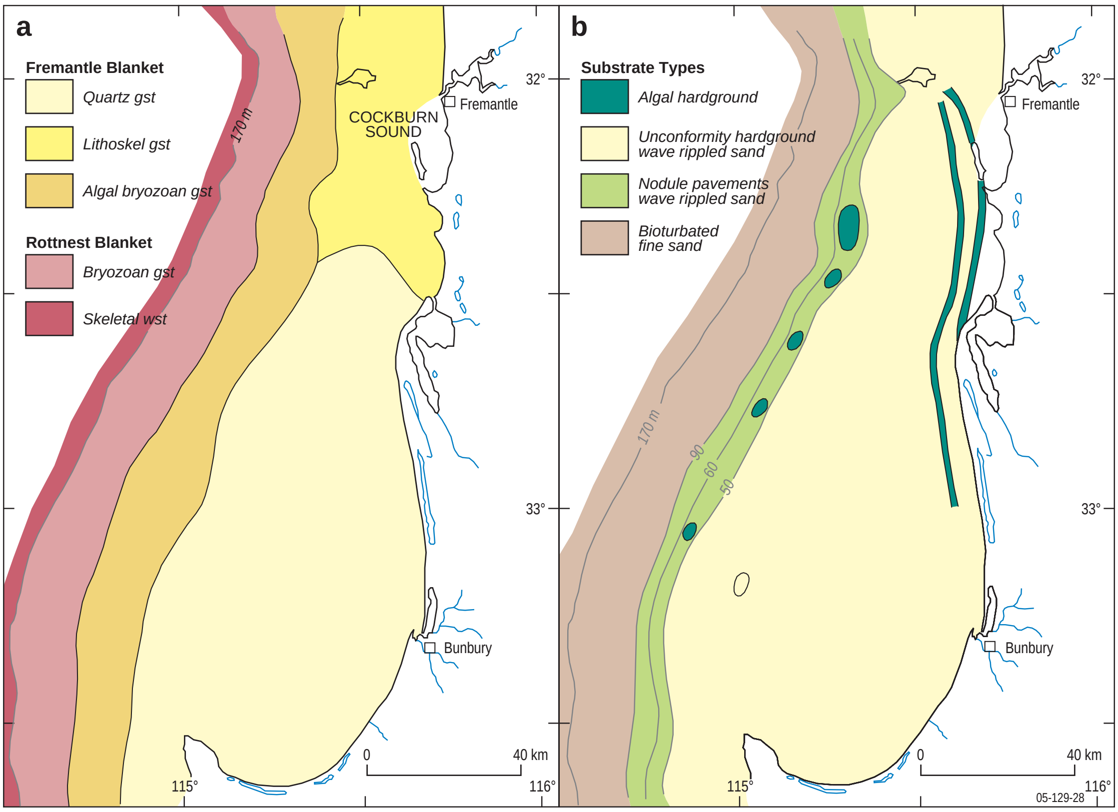

Figure 2.15. Map showing the relationship between substrate and sediment facies on the southern Rottnest Shelf from Fremantle to Cape Naturaliste (redrawn from Collins, 1988); (a) surface sediment facies map (gst = grainstone; wst = wackestone); and (b) substrate map and associated biota.

Deep marine sediments in the planning area generally comprise nannofossil and foraminifera oozes. A core 660 cm long retrieved from 5,147 m water depth in the northern Perth Abyssal Plain shows that surface sediments consist of a red-brown clay (lutite) with manganese micro-nodules (Sayers et al., 2002).

Seagrasses form extensive meadows in shallow water environments along the shelf, such as protected embayments (e.g., Cockburn Sound), lagoons and bays (e.g., Geographe Bay). *Posidonia* meadows occur in 35-45 m water depth on the seafloor on the leeward side of the Houtman Abrolhos platforms (James et al., 1999). *Thalassodendron* proliferates on rocky substrates and occurs in up to 40 m water depth on the inner shelf and ramp (James et al., 1999). On Parmelia Bank in Cockburn Sound, underwater video shows dense seagrass meadows and seagrass patches alternating with bare sand flats (Skene et al., 2005).

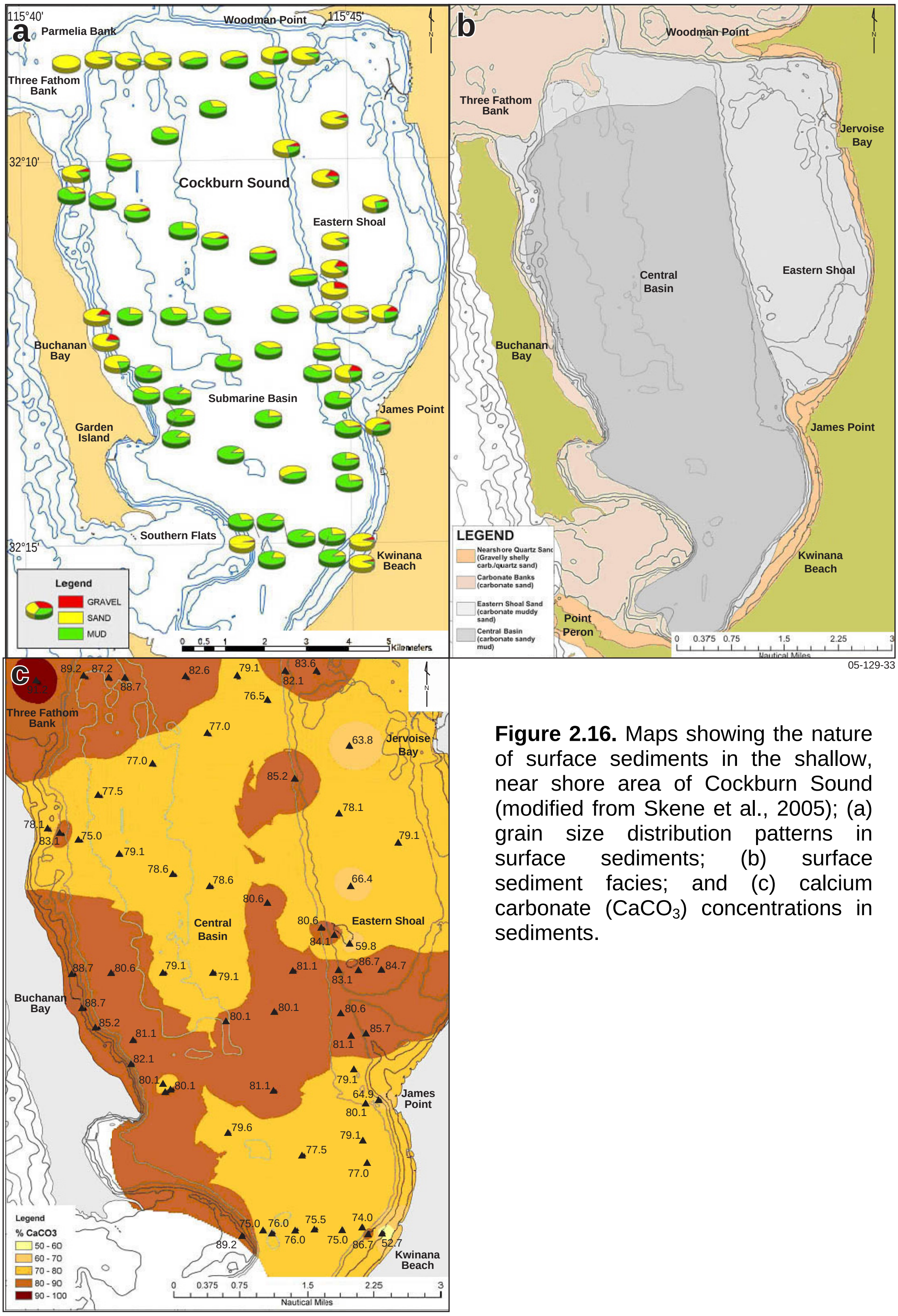

Figure 2.16. Maps showing the nature of surface sediments in the shallow, near shore area of Cockburn Sound (modified from Skene et al., 2005); (a) grain size distribution patterns in surface sediments; (b) surface sediment facies; and (c) calcium carbonate ($CaCO_3$) concentrations in sediments.

Along the Rottnest Shelf, macroalgae occurs frequently on rocky substrates in areas down to 50 m water depth (James et al., 1999). Southern Australian forms such as *Ecklonia* and *Sargassum* are common, with infrequent tropical macroalgal species occurring at Rottnest Island. Tropical species at southern latitudes are inferred to reflect the influence of the LC (see section 2.3). Green calcareous algae such as *Halimeda* occur frequently on the shelf and ramp (James et al., 1999).

The Houtman Abrolhos platforms contain a distinctly warm-water biota, compared to the typically cool-water biota living on the surrounding shelf, and mark the tropical-subtropical transition zone of biota on the Western Australia shelf (Collins et al., 1997). Biotic distribution patterns are different between the western (windward) and eastern (leeward) parts of the platforms. Leeward reefs support rich coral communities of platy and branching corals, and have higher cementation rates than the windward reefs (Zhu et al., 1994; Collins et al., 1998). Leeward reef corals coexist with rare macroalgae. In contrast, on the windward side, macroalgae is an abundant mixture of temperate and tropical brown and red macroalgae communities. The higher energy environments such as the western reefs and lagoons contain poor modern coral growth (Collins et al., 1997). It is likely that physical oceanography controls these unique biotic distribution patterns (see section 2.3) (Collins et al., 1998).

2.5. Late Quaternary Evolution

The Quaternary (1.8 million years ago [Ma] to present) was a period of highly variable climate and fluctuating sea levels, and seafloor structures on the Rottnest Shelf reflect these changes. The distinct inner and outer shelves and upper continental slope terraces were developed by subaerial erosion during periods of low sea level, and shelf features such as subaqueous barrier dune systems, shore-parallel ridges and reefs formed along temporary shorelines as sea levels rose and fell. These remnant Quaternary features dominate the current geomorphology of the Rottnest Shelf and help to shelter the present-day coastline (Fig. 2.17; Collins, 1988; James et al., 1999).

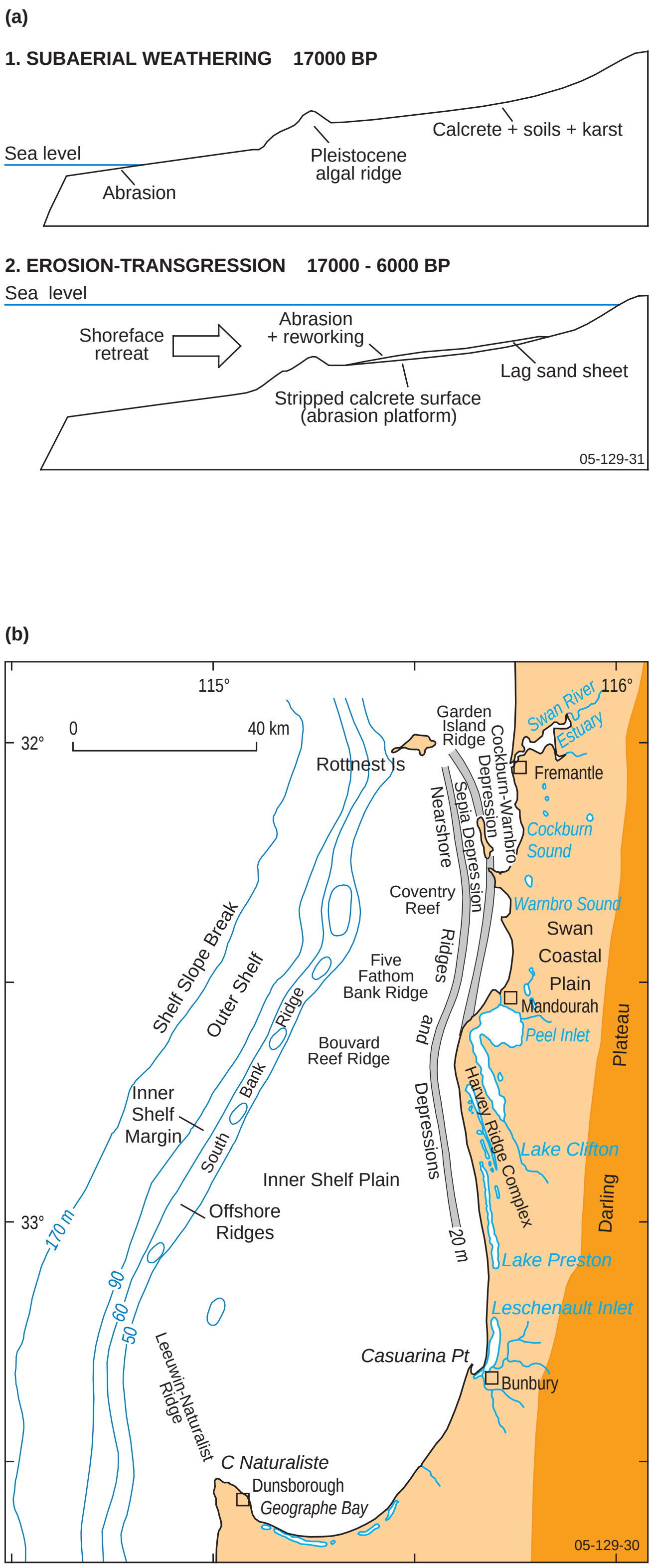

Figure 2.17. Schematic diagram showing Quaternary structures on the southern Rottnest Shelf in cross-section (a) and plan view (b) (modified from Collins, 1988). Nearshore and offshore ridges formed along temporary shorelines during periods of lower sea level.

The strength of the LC also varied with these changing sea levels. During the last glacial when sea level was low, the LC was greatly reduced or absent, allowing for oceanic upwelling to occur along the coast. Sea surface temperatures would have been lower than today, from lower air temperatures and a lack of warm-water input from the LC (McGowran et al., 1997; James et al., 1999). Pearce (1991) has suggested that sea surface temperatures were up to 4°C lower during the last glacial maximum, although this is based on limited core data. At this time the Rottnest Shelf was extremely narrow and the Western Australian Current was stronger. Increased nutrient levels from upwelling would have enhanced cool-water carbonate production and microphyte algae growth, creating a similar environment to the one on the southern shelf today (Collins et al., 1991; James et al., 1999).

There is evidence to suggest a stronger flowing LC during the last interglacial at ~125 ka. Large tropical foraminifera species (e.g., *Marginopora vertebralis*) are found in Pleistocene sediments as far east as Spencer and St. Vincent Gulfs, suggesting the LC had a greater lateral extent (Cann and Clarke, 1993; McGowran et al., 1997; James et al., 1999). Reef-building corals are present in limestones on Rottnest Island, some 500 km south of their modern range (McGowran et al., 1997). Sea temperatures are estimated to have been ~2°C warmer than today and sea level was approximately 2 m above the present (Kendrick et al., 1991; Murray-Wallace and Belperio, 1991; Belperio, 1995).

Deposits from the Houtman Abrolhos reef platforms show at least three generations of coral reef growth. Both the last two generations, last interglacial and Holocene reef growth, are present in outcrop, and are linked to the presence of the LC (Collins et al., 1991; Collins et al., 1996). Last interglacial reef growth is thought to have lasted for 10,000-15,000 years, from ~132 ka to ~117 ka, and Holocene reef growth commenced at around 10 ka (Collins et al., 1993b). The last interglacial platforms outcrop as central platforms that sit 2-3 m above present sea level, and reflect the higher sea level at that time. As a result, no Holocene reef growth has occurred on these outcropping central platforms. Reef growth during the Holocene has been more active on leeward margins. Figure 2.18 illustrates Holocene evolution of the Easter Platform, with the development of distinct blue-hole terrain on the leeward margin. On this leeward margin Holocene reef build up exceeds 26 m, while windward reef build up is only 10 m. The depths of the blue holes are typically 20 m (Collins et al., 1993b).

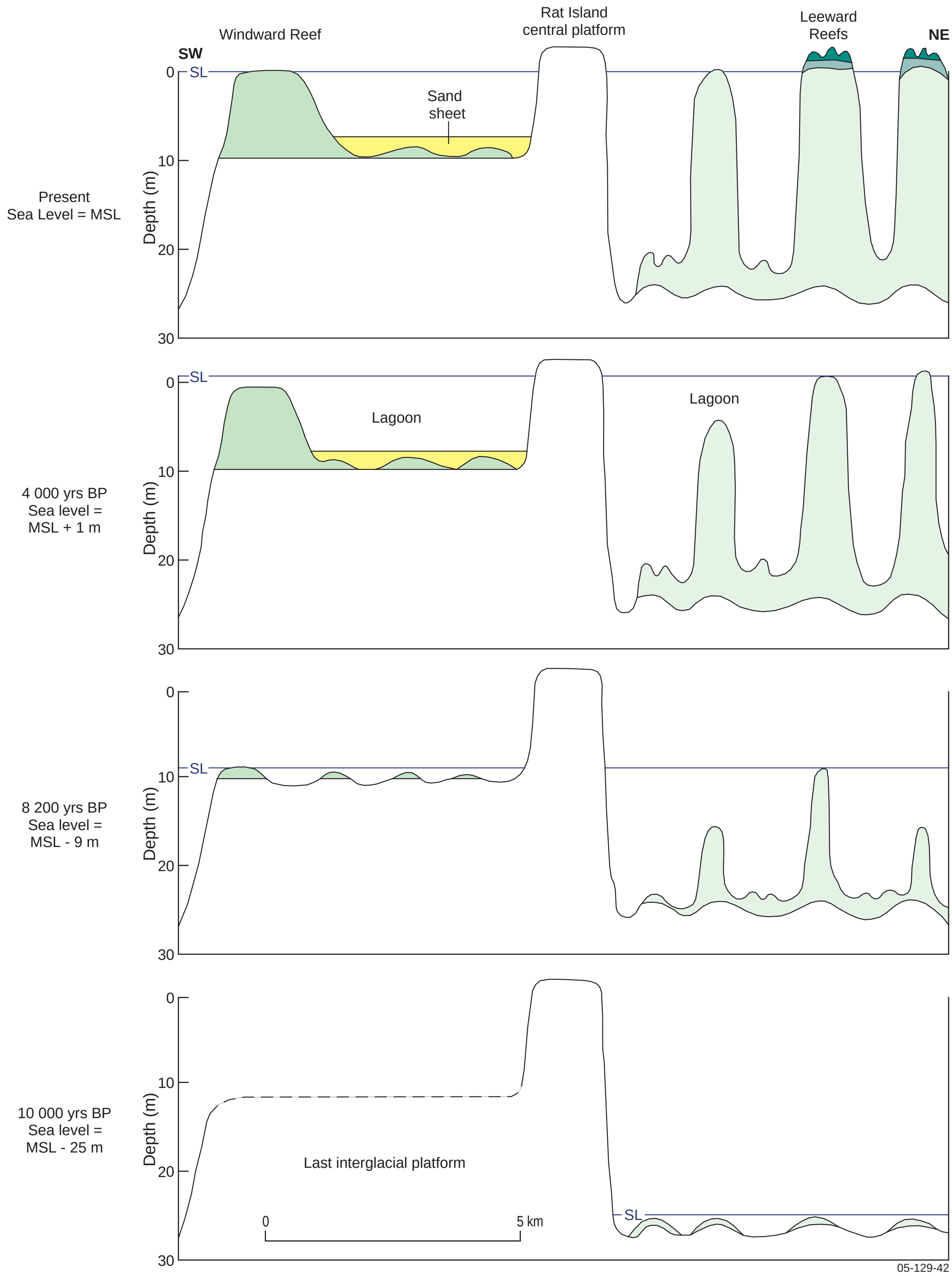

Figure 2.18. Schematic cross-section of Easter Platform, showing Holocene evolution of windward (western) and leeward (eastern) reefs (modified from Collins et al., 1993).

The asymmetry of reef growth is thought to relate to sea level fluctuations and local oceanography (Collins et al., 1998). Leeward reefs have had greater accommodation space and more time to build up, whereas windward reef platforms were submerged much later than leeward platforms. U/Th age determinations indicate that leeward reef growth commenced about 10,000 years ago, with windward reef growth initiating after 8,200 years ago (Collins et al., 1993a). High wave energy and local upwelling have also been suggested as factors for restricted windward coral growth. Nutrients supplied to the outer shelf from upwelling have promoted macroalgae growth on windward reefs, resulting in higher competition for corals (Collins et al., 1993a; Collins et al., 1997).

3. South West

The South West (SW) region of the South Western Planning Area extends from the northern margin of the Naturaliste Plateau and the tip of Cape Naturaliste on the western coast, to Cape Pasley on the southern coast, an area of approximately 483,955 km^2 (Fig. 1.2). The geologic structure, geomorphology and sedimentology of the SW can be ascribed to slow seafloor spreading during the separation of Australia and Antarctica, followed by a prolonged phase of passive margin subsidence, allowing long-term carbonate sedimentation and extensive canyon development.

3.1. Tectonic Setting

The SW region is structurally complex, consisting of several separate geological provinces and structural elements situated beneath the continental slope and rise (Stagg et al., 1999). The Naturaliste Plateau marks the boundary between Australia's western and southern continental margin (Borissova, 2002). The region is largely underlain by Archaean to Early Palaeozoic (>2.5 Ga) basement rocks of the Yilgarn craton. Much of the development of the region was controlled by multiple phases of rifting between Australia, Greater India and Antarctica from the Permian to Early Cretaceous (Powell et al., 1988; Stagg and Willcox, 1992; Stagg et al., 1999; Borissova, 2002; Bradshaw et al., 2003).

The SW is dominated by southern parts of the Perth Basin, the Mentelle Basin, Yallingup Shelf, three sub-basins of the Bight Basin, the Naturaliste Plateau and the Diamantina Zone (Fig. 3.1). The sedimentary basins are depressed crustal blocks containing separate sedimentary successions. Each basin is structurally complex and consists of a fault-bound graben structure divided by tilted fault blocks. The shallow basement of the Yallingup Shelf is recognised to be a totally separate sedimentary province (Bradshaw et al., 2003). The major Perth and Bight Basins are separated by the deep water Mentelle Basin, which contains a western and eastern depocentre (Bradshaw et al., 2003). The Bremer Sub-basin is structurally complex with rift structures continuing into the adjoining Recherché sub-basin. It is rimmed on its northern boundary by a high-angle fault scarp (Stagg & Willcox, 1991, 1996). The small

Denmark Sub-basin shares similar structural features with the Bremer Sub-basin. The western extent of the elongate Recherché Sub-basin stretches south of the Bremer and Denmark Sub-basins.

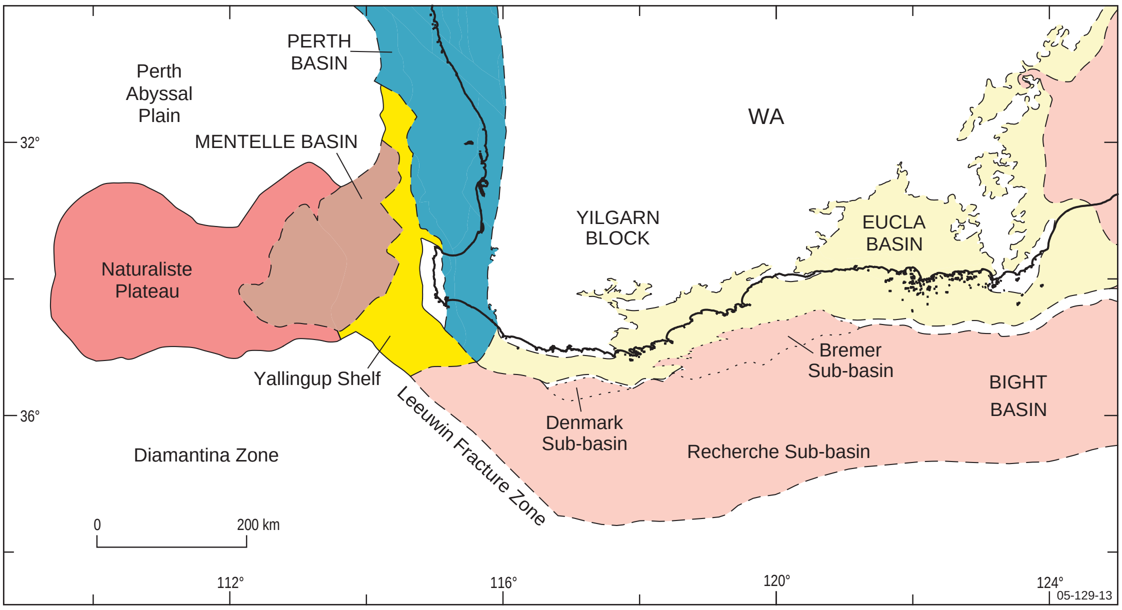

Figure 3.1. Map showing the geologic setting of the SW region (modified from Bradshaw et al., 2003). The region is underlain by several structural elements dominated by the Naturaliste Plateau and western parts of the Bight Basin, which contains several stacked sedimentary basins and depressions.

The Bremer and Denmark Sub-basins have been incised by the Albany canyons (Blevin, 2005). Some canyon development is related to various tectonic phases including subsidence and rapid seafloor spreading which commenced in the Mid Eocene (43 Ma; Exon et al., 2005). The orientations of many submarine canyons are influenced by original rift structures (Stagg and Willcox, 1991; Hill and De Deckker, 2004; Exon et al., 2005).

The large, submerged Naturaliste Plateau is composed of continental crust, overlain by up to 2 km thick sedimentary and volcanic successions (Jongsma and Petkovic, 1977) and was left over from rifting between the Australian, Antarctic and Indian plates during Gondwana breakup (Petkovic, 1975; Borissova, 2002). The evolution of the Naturaliste Plateau was controlled by magmatic activity (Stagg et al., 1999). A 20-90 km wide volcanic domain on its northern margin is evidence of volcanism, and intrusions have formed high basement ridges along the highly-faulted southern margin (Borissova, 2002).

The Diamantina Zone is a structurally complex region of rough topography that extends from Broken Ridge (95°E) in the Indian Ocean to 120-125°E (Talwani et al., 1978). It is composed of ultramafic basalt intrusions and peridotite ridges which are not typical oceanic crust and are interpreted to be a mixture of magmatic and continental crust (Nicholls et al., 1981; Borissova et al., 2004). The origin of the Diamantina Zone is highly debatable. It is considered to be a product of rifting, representing a continent-ocean transition zone of highly stretched continental crust or transitional continental-oceanic crust associated with slow spreading (Nicholls et al., 1981; Chatin et al., 1998; Munschy, 1998; Royer et al., 1999; Brown et al., 2003; Borissova et al., 2004).

3.2. Geomorphology

The SW region has a range of geomorphic features, including a narrow shelf, slope canyons, a deep water plateau and abyssal plain with variable morphology (Fig. 1.4). A false-colour image of the bathymetry illustrates this diverse geomorphology (Fig. 3.2).

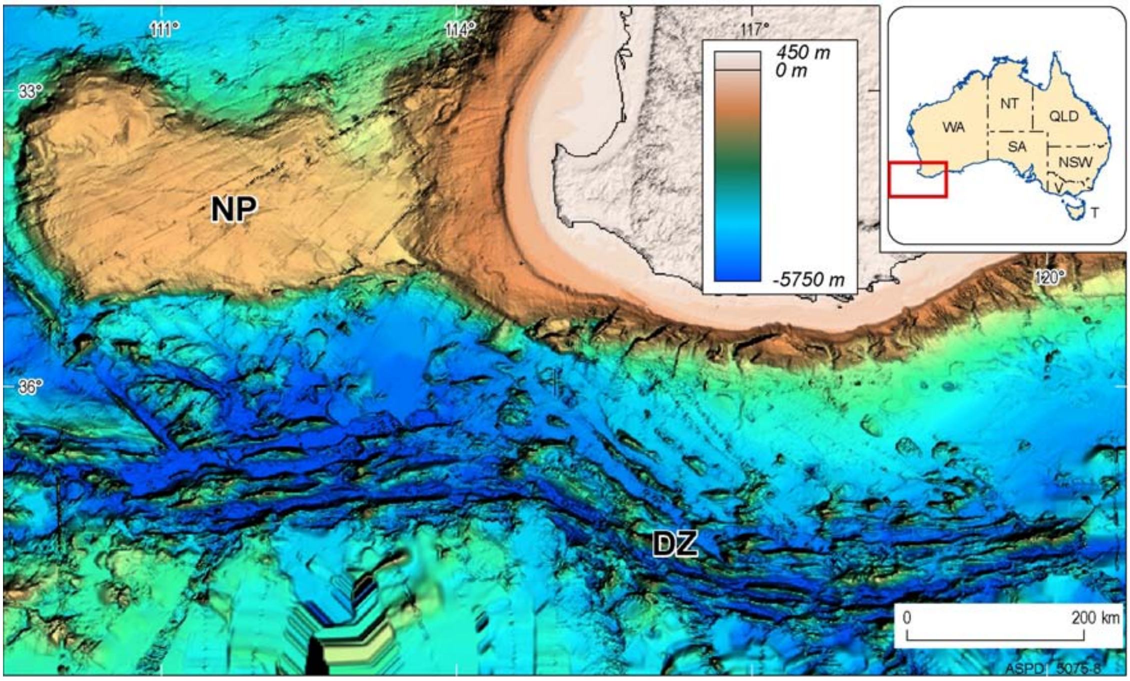

Figure 3.2. False-colour image showing the geomorphology and bathymetry of the SW region, highlighting the Naturaliste Plateau (NP), Australia's deepest submarine plateau, and the Diamantina Zone (DZ), an area of unique and complex topography.

The Recherché Shelf (Fig. 1.3) is a narrow, relatively flat shelf that extends from Cape Leeuwin in the west to Israelite Bay in the east, covering an area of 43,907 km^2 (Table 3.1; Carrigy and Fairbridge, 1954). It is broadest in the east and ranges from 25 to 65 km wide, with an inner zone of islands and crystalline rock outcrops and an outer zone of smooth, sandy seafloor (Harris et al., 2005). Four main rocky reefs, South West, Maude, Brown and Warren Reefs, occur on the shelf (Harris et al., 2005), and the Recherché Archipelago, a chain of approximately 105 islands and 1,500 islets, covers over 470 km of coastline around Esperance (Lee and Bancroft, 2001). Eroded remnants of Precambrian rocks form the numerous small islands and submerged sea-floor highs in the Recherché Archipelago, with the majority of islands being ~2 km across. Islands are generally round in plan view, dome-shaped and have steep sides, with the water depth between them <40 m (Fairbridge and Serventy, 1954; Bone et al., 1994).

Table 3.1. Geomorphic features in the South West region (from Harris et al., 2005).

Geomorphic Feature	Area (km^2)	Percent
Shelf*	43,900	9.07
Slope*	128,860	26.62
Continental Rise*	4,490	0.93
Abyssal-plain/deep ocean floor*	138,100	28.53
Bank/Shoals	1,020	0.21
Canyon	8,070	1.67
Deep/hole/valley	450	0.09
Knoll/abyssal-hills/hills/mountains/peak	66,710	13.78
Pinnacle	550	0.11
Plateau	29,830	6.16
Reef	290	0.06
Ridge	39,660	8.19
Terrace	12,230	2.53
Trench/trough	9,840	2.03
Total	484,000	100.00

*These units are less the surface areas of superimposed features.

The inner zone of islands on the Recherché Shelf offers the coast some protection from the predominant southwesterly swells (Fig. 3.4). Rocky headlands, mainland coastal sand barriers, onshore dune systems and rocky platforms occur in the area, along with more protected, southeasterly facing, crenulate-shaped bays (Woods et al., 1985; Sanderson et al., 2000).

The outer shelf deepens quickly to the shelf break situated at 110-150 m water depth. Numerous, well-developed submarine canyons have cut into the outer shelf and steep continental slope (Fig. 3.3), and cover an area of 8,066 km^2 (Table 3.1). These canyons extend up to 90 km offshore and reach to the lowermost slope and onto the abyssal plain, the largest cutting down to 1,500-2,000 m in places (Conolly and von der Borch, 1967; von der Borch, 1968; Exon et al., 2005). This group of approximately 32 canyons is called the 'Albany Canyons' and encompasses 700 km of continental slope from 115°E to 124°E, including Broke Canyon in the west and Malcolm Canyon in the east (Rollet et al., 2001). Von der Borch (1968) noted that canyons are confined to the continental slope in areas offshore of Cambrian to Precambrian rocks, and are limited or absent in areas offshore of Tertiary basins (von der Borch, 1968; Hill and De Deckker, 2004).

Some individual canyons have been described in detail by von der Borch (1968), and bathymetry maps of the region published by Jongsma and Johnston (1993a,b) show their extents and names. The canyons were recently swath-mapped by R/V *Southern Surveyor* (Exon et al., 2004); the combination of these data with previous bathymetric data has produced detailed bathymetry of the canyons from the shelf break to the edge of the abyssal plain (Fig. 3.3).

On the upper slope canyons have cut into harder, older rocks and as a result have steep sides and high axes slopes, with their directions being structurally controlled (Stagg and Willcox, 1991). On the lower slope canyons have cut into more homogeneous sediment, and as a result canyon walls are less steep and direction is generally downslope. Well-developed canyons have cut as much as 2,000 m into the slope and have broad canyon floors, suggesting that down-cutting has ceased. Smaller canyons may still be incising the margin, as they have little to no canyon floor. This suggests that they have been recently active, and may have transported significant amounts of shelf sediment downslope (Exon et al., 2005).

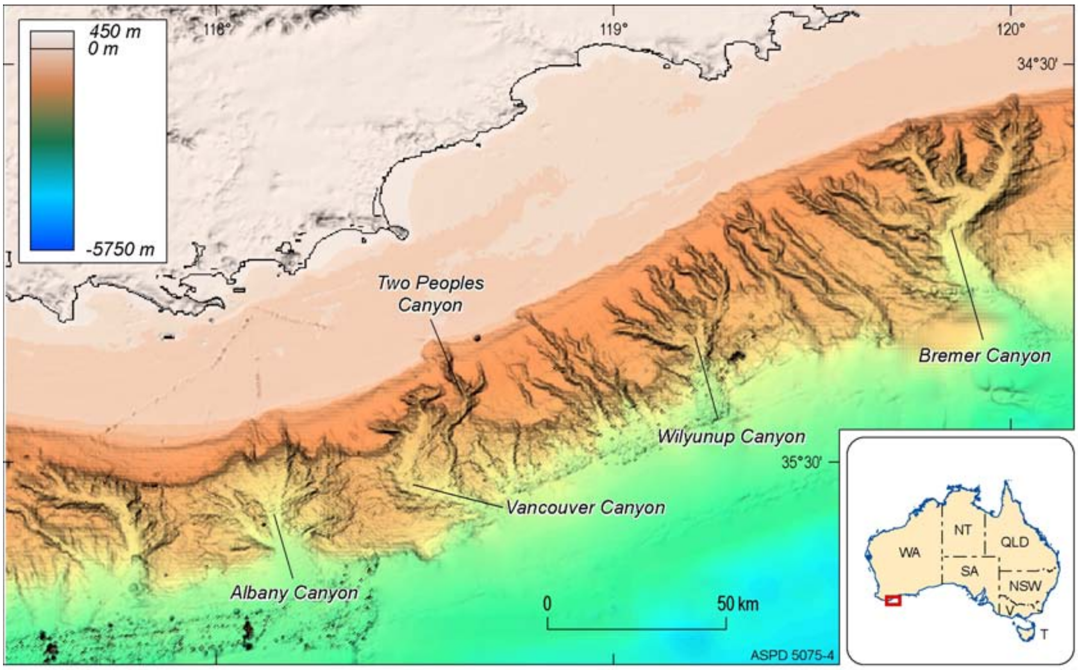

Figure 3.3. False-colour image showing the geomorphology and bathymetry of several canyons in the Albany Group. A flat canyon floor indicates that the canyon is likely inactive, whereas a v-shaped canyon floors suggests that the canyon is or has been recently active.

Due to extensive carbonate production on the continental shelf since the Eocene, abrasive carbonate grains have helped to cut the canyons. Poorly consolidated carbonate sediments 1-2 km thick have been transported by the canyons, forming a very wide continental rise on the southern margin (Exon et al., 2005). The continental rise sits between 3,000 and 5,300 m water depth and in some areas extends up to 250 km beyond the edge of the continental shelf (Conolly and von der Borch, 1967). The rise is thought to have formed from sediment fans joining together, as it is widest offshore of submarine canyons and narrowest offshore of the Great Australian Bight terraces. The limited data suggest that deep-sea sediment fans are present down to about 4,500 m offshore of major canyons such as Wilson Canyon and Albany Canyon (Exon et al., 2005). The continental rise has hilly topography in the upper area and is smoother in the lower area as it merges with the abyssal plain (Conolly and von der Borch, 1967).

The Naturaliste Plateau is the deepest marginal submarine plateau, lying west of Cape Leeuwin and Cape Naturaliste in water depths of 2,000 to 5,000 m (Fig. 3.2; Borissova, 2002). It extends ~400 km E-W and 250 km N-S, making up an area of approximately 90,000 km^2. It is relatively flat with a slight northward dip, and has steep southern and western sides and a more gently sloping northern side. It is bordered by the South Australian Abyssal Plain in the south and the Perth Abyssal Plain in the west and north, and is separated from continental Australia by the Naturaliste Trough to the east. A terrace feature is present on the steep southern side of the Plateau between 4,500 and 5,000 m, before the margin grades into the abyssal plain (Borissova, 2002; Harris et al., 2005).

The Diamantina Zone is an area of extremely rugged topography south of the Naturaliste Plateau. It covers >100,000 km^2 and is up to 200 km wide, containing a complicated series of E-W trending, closely spaced ridges and troughs (Table 3.1; Fig. 3.2). These ridges are exposed oceanic crust with relief of up to 4,000 m (Borissova et al., 2004; Hill and De Deckker, 2004). The Diamantina Zone is thought to be a continent-ocean transition zone, and the rugose topography is thought to be the result of very slow seafloor spreading during the separation of Australia and Antarctica (Tikku and Cande, 2000; Borissova et al., 2004). To the east of the Diamantina Zone, the South Australian Abyssal Plain is marked by shallower depths and smoother topography (Borissova et al., 2004).

3.3. Oceanography

The Leeuwin Current (LC) flows south along the coast of Western Australia and turns east at Cape Leeuwin to flow along the southern coastline, reaching as far as the eastern Great Australian Bight (Ridgeway and Condie, 2004). The warm, tropical water brought south by the LC allows warm-water foraminifera and algae to flourish in an otherwise temperate environment (Maxwell and Cresswell, 1981; Bone et al., 1994). In winter when the current is strongest, temperature gradients of up to 5°C occur between the LC and the colder Southern Ocean water within a few kilometres of the coast (Fig. 2.10; McGowran et al., 1997). Temperatures along the southern coast are between 15° and 21°C, cooling from west to east (Legeckis and Cresswell, 1981). A similar west to east gradient is observed in benthic fauna, from tropical species to temperate species, due to the influence of the LC (Li and McGowran, 1998; Li et al., 1999).

The region has a small tidal range of <0.5 m around Albany and 0.7 m around Esperance (Sanderson et al., 2000). Shelf waters are well mixed in winter due to a strong LC and stratified in summer from cooler Southern Ocean water intruding onto the shelf. During summer cold bottom water (<10°C) is present at >400 m depths off Albany and Esperance (Li et al., 1999).

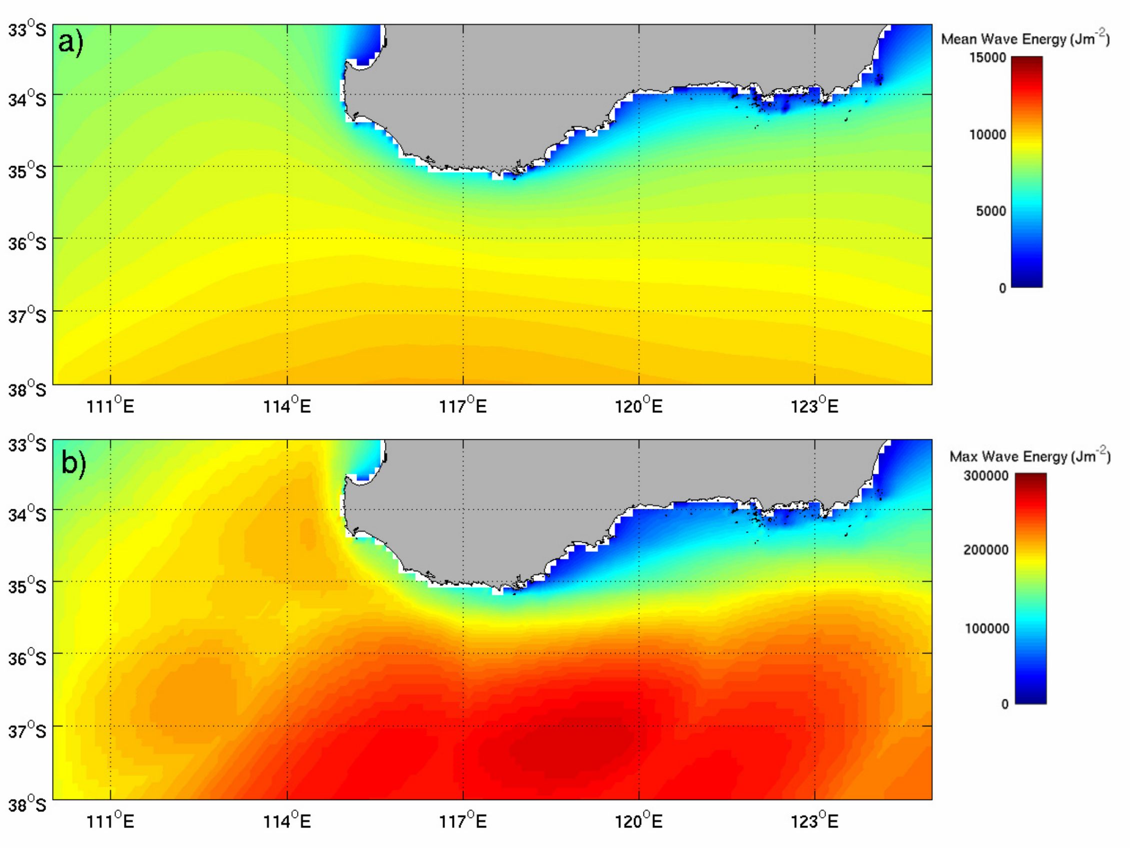

Figure 3.4. Map showing mean (a) and maximum (b) wave energy for the SW region. Southern Ocean swells and storms come predominantly from the southwest, creating a high energy environment. The inner Recherché Shelf is somewhat protected by inshore reefs and the Recherché Archipelago.

The Recherché Shelf is a high energy environment dominated by Southern Ocean swells and storms (Fig. 3.4). The southern margin experiences high modal, deep-water waves and long period swell waves from the southwest (Wright et al., 1982; Short and Hesp, 1982). Wave heights can reach >2.5 m around Cape Leeuwin, where the coast is the most exposed to the southwest swell (Fig. 3.5). These waves rework sediments down to ~100 m water depth on the Recherché Shelf, often transporting sediments off the shelf. Wave erosion occurs down to ~60 m water depth, limiting the amount of carbonate accumulation that occurs in areas shallower than this (James et al., 1992; James et al., 2001). Rocky reefs and outcropping islands along the shelf reduce the amount of wave energy reaching the coast, creating a range of coastal environments (Fig. 3.4). The complex topography created by islands of the Recherché Archipelago and the predominant swell direction result in areas of both sediment erosion and sediment deposition (Sanderson et al., 2000; Ryan et al., 2005). In general, the south coast of Western Australia is more exposed than the west coast (Fig. 2.13 and Fig. 3.5).

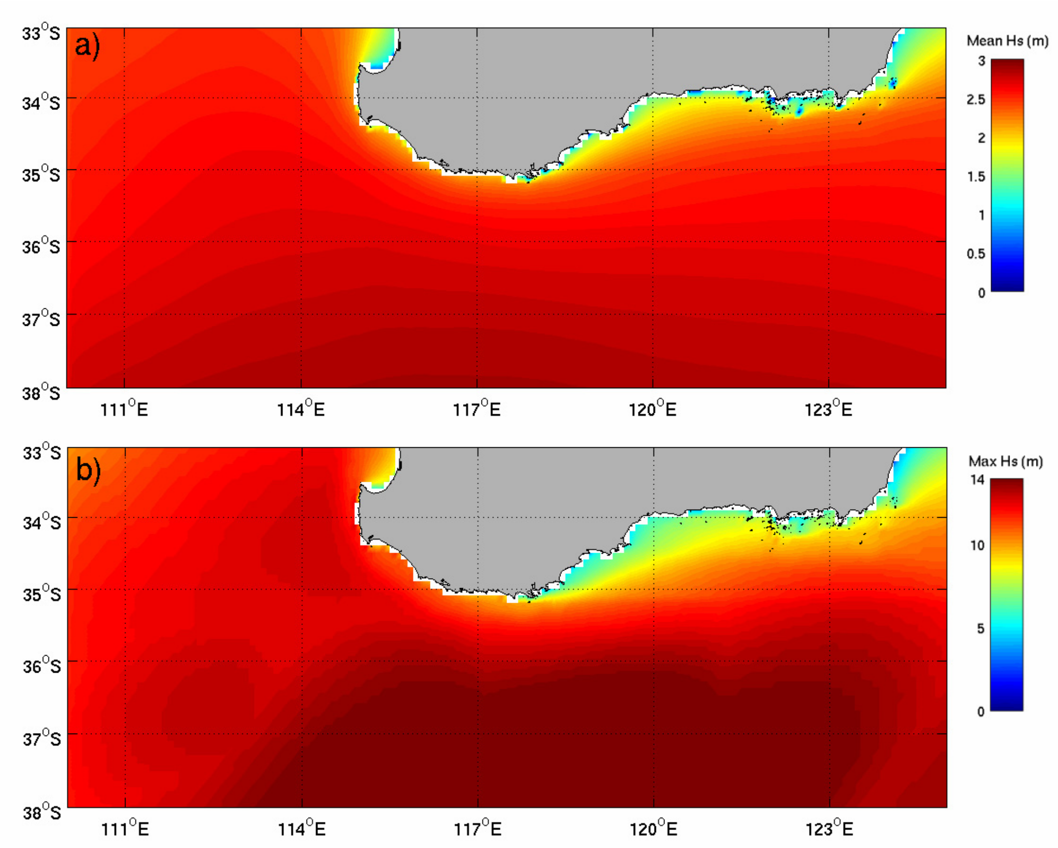

Figure 3.5. Map showing significant wave height for the SW region. Mean wave height (a) is the height of the highest 1/3 if waves based on a seven year mean (Feb 1997 – Feb 2004), and (b) shows maximum wave height for the same period. The SW coastline is exposed to swell and storm waves from the Southern Ocean.

3.4. Surface Sediments

The regional sedimentology of the SW has only been studied in a few geological surveys. Carrigy and Fairbridge (1954) and Carrigy (1956), published the early results of broad trends in continental shelf sediments. More recent work on the area includes studies by Conolly and von der Borch (1967), Cann and Clarke (1993), Li and McGowran (1998) and Li et al. (1999), and Geoscience Australia survey 265 recovered sediment samples from the Albany Canyons (Blevin, 2005). Information on deep marine sediments was sourced from the National Marine Samples database (MARS; Geoscience Australia, 2005).

Surficial sediments in the region are palimpsest, comprising a mixture of modern and relict Pleistocene grains. Surficial sediments along the Recherché shelf are generally bioclastic carbonate sands of shell and coral fragments, with local concentrations of bryozoans, foraminifera and algal fragments (Fig. 3.6; Carrigy and Fairbridge, 1954; Carrigy, 1956). Bryozoan fragments are abundant sedimentary components in carbonate sands on middle to outer parts of the shelf and on the slope, rise and abyssal plain (Conolly and von der Borch, 1967; Wass et al., 1970). Calcareous fragments make up 60-83% of sediment components on the shelf, with lesser amounts of quartz, shell fragments, foraminifers and faecal pellets (Carrigy, 1956). Calcareous sand from middle to outer shelf areas is well-sorted and rounded, due to sediment transport and wave abrasion (Carrigy and Fairbridge, 1954). A small amount of glauconite has formed in some shelf regions (Carrigy and Fairbridge, 1954). Sediments from western areas contain quartz, feldspar and terrigenous fragments which may reflect the supply of material from onshore crystalline shield rocks (Carrigy, 1956; Conolly and von der Borch, 1967).

Offshore from Albany at the western end of the Recherché Shelf, surficial sediments are mainly coarse calcareous sands with local rhodolith beds (Conolly and von der Borch, 1967). Sediments from the shelf edge are fine- to coarse-grained grey-yellow calcareous sands, comprising 50-80% bryozoan fragments with planktic and benthic foraminifers, sponge spicules and relict calcareous grains. Frequent reworked calcareous beachrock fragments found in samples indicate that a large part of the shelf is underlain by beachrock or cemented Pleistocene calcarenites. Samples from this region contain rounded quartz and feldspar grains (Conolly and von der Borch, 1967).

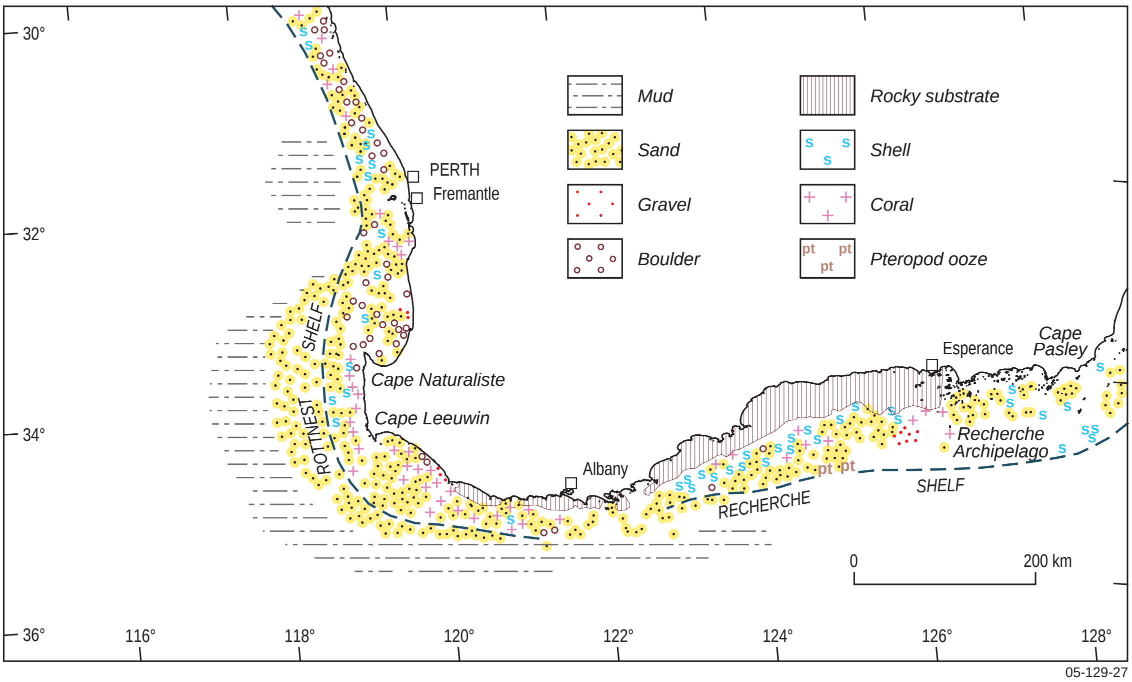

Figure 3.6. Map showing the distribution of major surface sediment facies (modified from Carrigy and Fairbridge, 1954). Sediments are dominated by calcareous components, with minor amounts of terrigenous material, and can be divided into facies types on the basis of their grain size.

On the inner Recherché Shelf, surficial sediments in the Recherché Archipelago generally comprise a mixture of recent and relict bioclastic carbonate sand (Cann and Clarke, 1993). In water depths of <40 m, seabed sediments grade from quartz sand in nearshore regions to coarse bioclastic carbonate sand with lithic material further offshore. Aprons of sand connected to the islands are composed of angular rock fragments, molluscs, bryozoans, algal and foraminifera tests, and include many conspicuous benthic foraminifers (e.g., *Marginopora vertebralis*; Cann and Clarke, 1993; Li et al., 1999). The aprons generally accumulate as a wedge-shaped deposit on the leeward (northeast) margin of the islands. Exposed shelf areas are subject to wave abrasion and comprise limestone reef with little to no sediment cover (Ryan et al., 2005). Oceanographic processes and topography produce heterogenous sedimentary patterns in the Recherché Archipelago (Bone et al., 1994).

Foraminifera occur in sediment samples from all water depths, with a distinct depth zonation on the shelf from nearshore to outer shelf areas (Betjeman, 1969). Dredge samples show that tropical foraminifera species are abundant in western regions and include *Neogloboquadrina duterteri*, *Globorotalia menardii* and *Globigerinoides trilobus* (Li and McGowran, 1998). Tropical species such as *Marginopora vertebralis* are prolific in sediments associated with seagrass in the Recherché Archipelago (Cann and Clarke, 1993). Foraminifera distributions and the occurrence of tropical species such as *Marginopora* at southern latitudes are due to the eastward flow of the warm LC across the SW region (Bone et al., 1994; Li and McGowran, 1998). There is an eastwards increase in temperate taxa, such as *Globorotalia inflata* ranging from <10% in sediments offshore of Bunbury to 20-50% offshore of Esperance. A rapid decrease in tropical and subtropical planktic foraminifera occurs to the east of Cape Leeuwin (Li and McGowran, 1998).

Within the Albany Canyons surface sediments comprise siliceous and calcareous mud and ooze (Blevin, 2005). Calcareous oozes are widespread and are generally unconsolidated to plastic, with some more consolidated chalky samples present. The ooze is white to pale grey and contains calcareous nannofossils, abundant planktic foraminifers, sponge spicules, benthic foraminifers and rare ostracods and echinoid fragments (Blevin, 2005). Other types of surficial sediments recovered from canyons include glauconitic sandstone and mudstone, calcareous marl (e.g., semi-consolidated clay) and bioclastic, foraminifera-rich calcarenite (Blevin, 2005).

Continental slope sediments generally consist of calcareous oozes and local occurrences of clay (Conolly and von der Borch, 1967). A sample collected from 1,395 m water depth southwest of Cape Leeuwin contained yellow-grey biocalcarenite with sponge spicules, pteropods, echinoid spines and abundant foraminifers (Geoscience Australia, 2005). In water depths of ~3,000 m on the continental rise to the south of Esperance, surficial sediments comprise calcareous yellow-brown silty clay, with mottling from burrows (Conolly and von der Borch, 1967). In water depths of 4,594 m south of Albany, surface sediments are brown calcilutite with mottling from burrows, and contain foraminifera tests and manganese micronodules. In water depths of 5,092 m southwest of Esperance, calcilutite surface sediments are also mottled and contain 3% foraminifer tests by weight (Geoscience Australia, 2005).

In deep water, sediments grade into spiculitic ooze, *Globigerina* ooze, Pteropod ooze and abyssal red clays (Carrigy and Fairbridge, 1954). On the deep water Naturaliste Plateau, surficial sediments are pelagic and comprise a sequence of ~30 m thick recent foraminifera-nannofossil ooze (Kennett, 1975; Jongsma and Petkovic, 1977; Borissova, 2002). In northern areas of the plateau only one sediment core has been taken, by Burckle et al. (1967), revealing surficial sediments of coarse-grained foraminiferal sand. Generally, dredged surface sediment samples show that pink-grey limestone and foraminiferal siltstone are exposed on areas of seabed with some areas coated with a manganese crust (Borissova, 2002).

A detailed survey of benthic habitats in the Recherché Archipelago showed seagrass coverage varied between dense, medium, sparse or patchy communities (Everall Consulting, 1999). In water depths of less than 40 m, seagrass banks of *Posidonia*, *Zostera*, *Heterozostera*, *Amphibolis* and *Halophila* species occur (Cann and Clarke, 1993). Around the Remark, Mart, Mondrain, Tory and York Island groups *Halophila* and *Posidonia* species are abundant (Everall Consulting, 1999). Dense and medium seagrass cover has been observed in shallow-water environments fringing granite reefs. Seagrass abundance is inversely correlated with water depth; seagrass density decreases as water depth increases (Walker, 1991; Everall Consulting, 1999). The LC controls seagrass distribution by extending the southern limits of tropical species (Walker, 1991).

Macroalgae occupy shallow waters, from intertidal environments to ~50 m water depth, on rocky limestone and granite reef substrate (Walker, 1991). Different macroalgae assemblages occur as a result of depth and exposure (Goldberg and Kendrick, 2004). In the SW region southern temperate species predominate and include foliose red, green and brown algae assemblages. Rocky subtidal environments contain extensive kelp populations of *Ecklonia radiata* and *Sargassum* spp. (e.g., Recherché Archipelago; Goldberg and Kendrick, 2004). Low profile reefs in the Recherché Archipelago provide habitats for sponges, ascidians, kelp, corals, brown and red seaweed, and red coralline algae (Everall Consulting, 1999). A low diversity of hermatypic corals in the Recherché Archipelago region mark a geographical transition in marine flora from tropical to temperate species east of Cape Leeuwin (Veron and Marsh, 1988; Goldberg and Kendrick, 2004).

The seabed in the region could not be classified based on echo-types as 3.5 kHz and 12 kHz echo-sounder profiles were unavailable for interpretation. It is likely, given the variable morphology of the seabed and the range of sediment facies, that echo-types would be variable. Geoscience Australia surveys have acquired 3.5 and 12 kHz echo-sounding profiles along the southwest margin (e.g., surveys 81 and 187), which are yet to be interpreted.

3.5. Late Quaternary Evolution

Sea level was lower by ~100 m during the majority of the last 120,000 years and the continental shelf in the SW was generally very narrow and shallow. The Albany Canyons would have been situated just off the coast, and would have been active feeder channels for shelf sediment transport to the deep ocean (von der Borch, 1968). The relatively shallow depth of the shelf would have resulted in higher levels of wave erosion and a larger amount of sediment being transport off shelf. Piston cores taken on the continental rise up to 250 km beyond the edge of the shelf contained graded Quaternary turbidite sequences. These turbidites are dominated by shelf and slope carbonate detritus such as bryozoan, mollusc and foraminifer fragments that have been transported onto the lower slope through the canyons during low sea levels (Conolly and von der Borch, 1967). Even during high sea level stands such as the last interglacial maximum, a build up of shelf carbonates, as seen across the Great Australian Bight, would have been mobilised during storm events and transported off shelf, helping to cut canyons (Exon et al., 2005).

The large canyons are estimated to be Middle to Late Eocene in age (ca. 43-40 Ma), when slope gradients became steep enough to allow canyon cutting and a major drop in sea level would have accelerated canyon formation (Exon et al., 2005). However, the smaller canyons probably formed during Quaternary low sea level stands, from displaced carbonate grains and possibly terrigenous input from the coast being transported off the shelf. Unlike the major canyons, these smaller canyons have no canyon floor, suggesting that they are still cutting and have not yet reached base level (von der Borch, 1968; Exon et al., 2005).

4. Great Australian Bight

The Great Australian Bight (GAB) region of the South Western Planning Area extends from Cape Pasley in the west to the southern tip of Eyre Peninsula in the east, an area of approximately 504,150 km^2 (Fig. 1.2). Most of the GAB forms a broad, shallow shelf (Fig. 4.1), comprising an extensive cool-water carbonate province that has been active throughout the Quaternary (James et al., 2001). A broad latitude-parallel shelf, seasonal oceanic upwelling and a lack of terrigenous sediment supply from rivers has created favourable conditions for cool-water carbonate production. As a result, the shelf is part of the largest cool-water province on Earth (James, 2004).

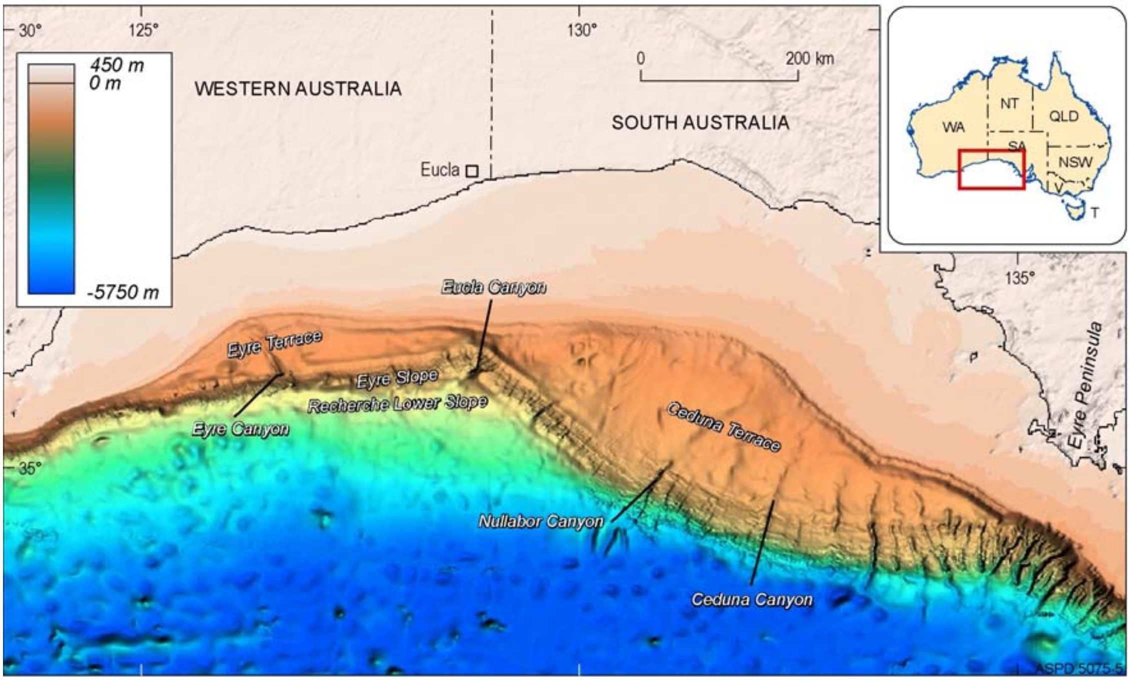

Figure 4.1. False-colour image of the Great Australian Bight, highlighting a broad shelf, mid-slope terraces and abyssal plain. Also included are features and places mentioned in chapter four.

4.1. Tectonic Setting

The GAB occupies central parts of the broader passive continental margin of southern Australia. This margin underwent two major stages of tectonic development related to the breakup of Gondwana and northward continental drift in the Mesozoic (248 to 65 Ma) (Hegarty et al., 1988; Willcox and Stagg, 1990; Totterdell et al., 2000; Norvick et al., 2001; Totterdell and Krassay, 2003). It represents part of a rifted passive margin and comprises a 500 km wide zone of stretched continental crust (Brown et al., 2001; Sayers et al., 2001). The GAB is underlain by a series of deep Mesozoic to Cenozoic sedimentary basins that formed during early rifting between Australia and Antarctica (Fig 4.2; Totterdell and Krassay, 2003). Today the GAB is tectonically stable, bounded to the south by a region of oceanic crust (Veevers et al., 1990; Stagg et al., 1999).

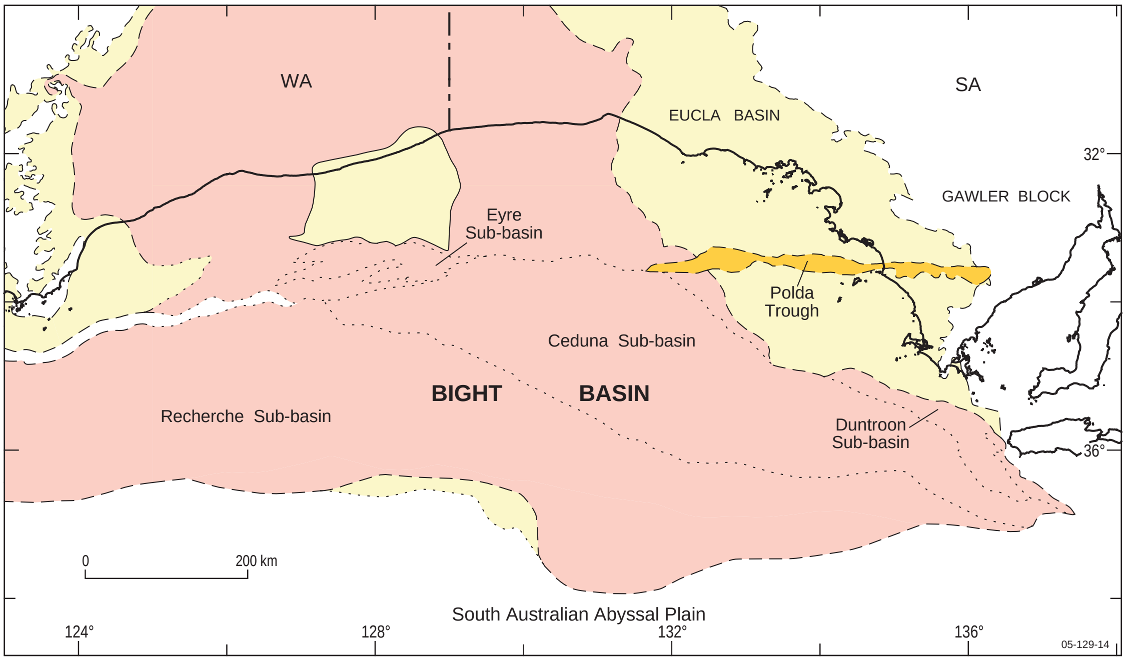

Figure 4.2. Map showing the geologic setting of the Great Australian Bight (modified from Bradshaw et al., 2003). The Great Australian Bight is centred on the Bight Basin, which consists of a series of sedimentary depressions.

The major tectonic element is the large offshore Bight Basin, which underlies the continental shelf and slope from the southern tip of Western Australia to Kangaroo Island (Bradshaw et al., 2003; Totterdell and Krassay, 2003). Much of the Bight Basin sediments are overlain by younger Eucla Basin sediments which extend onshore (Fig. 4.2; Bradshaw et al., 2003). Basin sediments comprise 13-15 km thick Middle Jurassic-Late Cretaceous (165-97.5 Ma) basal siliciclastics overlain by extensive Eocene to Recent cool-water carbonates (Totterdell et al., 2000).

In the vicinity of the GAB, the Bight Basin can be subdivided into four major sub-basins, separated by fault-bound basement blocks (Fig. 4.2; Hegarty et al., 1988; Bradshaw et al., 2003):

1. The small Eyre Sub-basin is located entirely beneath the Eyre Terrace (see Fig. 1.3) and extends over an area of ~9,200 km^2. It contains a 3.5 km thick sequence of rift sediments and overlying Eucla Basin carbonates. The sub-basin is characterised by a series of half grabens.
2. The Ceduna Sub-basin is located beneath the Ceduna Terrace and extends over an area of 126,300 km^2. The basin contains a sequence at least 15 km thick of rift sediments, and is characterised by a series of fault-bounded half grabens.
3. The Recherché Sub-basin stretches from the western to the eastern edge of the Bight Basin, with an extent of more than 377,000 km^2. It contains a sequence up to 11 km thick, bounded by a major basement fault scarp to the north and by an east-west trending basement ridge complex to the south, interpreted by Veevers (1986) to represent the Continent-Ocean Boundary.
4. The small Duntroon Sub-basin adjacent to Kangaroo Island extends over an area of ~9,800 km^2. This sub-basin is a half-graben complex that contains a 10 km thick sequence of sedimentary rocks overlain by a ~2 km thick sequence of Eucla Basin carbonates (Bradshaw et al., 2003).

The evolution of the post-rift passive continental margin of the GAB is characterised by prolonged tectonic stability, slow regional subsidence and reduced terrigenous supply from a deeply weathered continent. Together, these processes and several post-rift marine transgressions have influenced sedimentation, which since the Middle Eocene (44 Ma) has been continuous cool-water carbonate deposition (Feary et al., 2004). Extensive Eocene and thin modern carbonate sediments form a prograding carbonate ramp succession almost 1 km thick (Feary et al., 2004). Seismic records of the carbonate ramp in western parts of the GAB (i.e., the Eyre Terrace) reveal seven seismic sequences that consist of several prograding clinoforms (Fig. 4.3). The carbonate sequence overlies Precambrian crystalline basement and a succession of Mesozoic terrigenous sediments up to 12 km thick, which mark a change from dominantly siliciclastic to continuous carbonate sedimentation (Hine et al., 1999; Feary et al., 2004). Interestingly, the thickness of the Cenozoic carbonate sequence reflects higher carbonate accumulation rates compared to those of today.

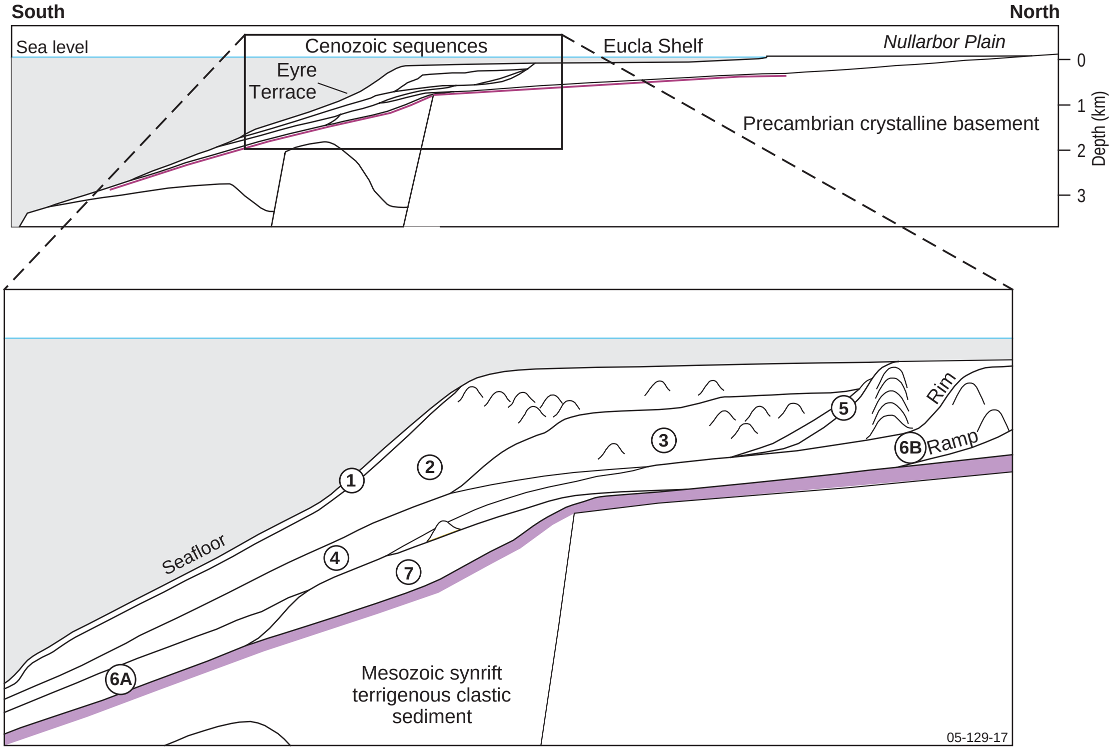

Figure 4.3. Schematic diagram interpreted from seismic profiles of the Eucla Shelf showing the distribution of Cenozoic sediments underlying the GAB (modified from Feary et al., 2004). This section contains seven prograding carbonate sequences (see Feary et al., 2004 for descriptions) and bryozoan mounds, overlying terrigenous Mesozoic sediments and Precambrian basement. The purple line marks a division between Cenozoic sequences (carbonates) and older sequences (siliciclastics).

4.2. Geomorphology

The continental shelf of the GAB is a broad, relatively flat submarine plain, reaching a width of 260 km in the center of the bight and narrowing to ~80 km at the margins (Fig. 4.1). The shelf is the most extensive geomorphic feature in the region, covering 177,130 km^2 or ~35% of the total area (Table 4.1). It is a latitude-parallel shelf which James et al. (2001) has divided into an inner shelf (0-50 m), a middle shelf (50-120 m) and an outer shelf (125-170 m) based on bathymetry (Fig. 4.4). The middle shelf area is the most extensive, resulting in the majority of the shelf being within 40-100 m water depth (James and von der Borch, 1991). Despite wide-spread carbonate production on the shelf, no platform rim has developed, as is common in tropical carbonate settings. This is due to both the low capacity of cool-water carbonates to build reefs, the high levels of seabed erosion and the transportation of sediments off the shelf (James and von der Borch, 1991; James et al., 1994).

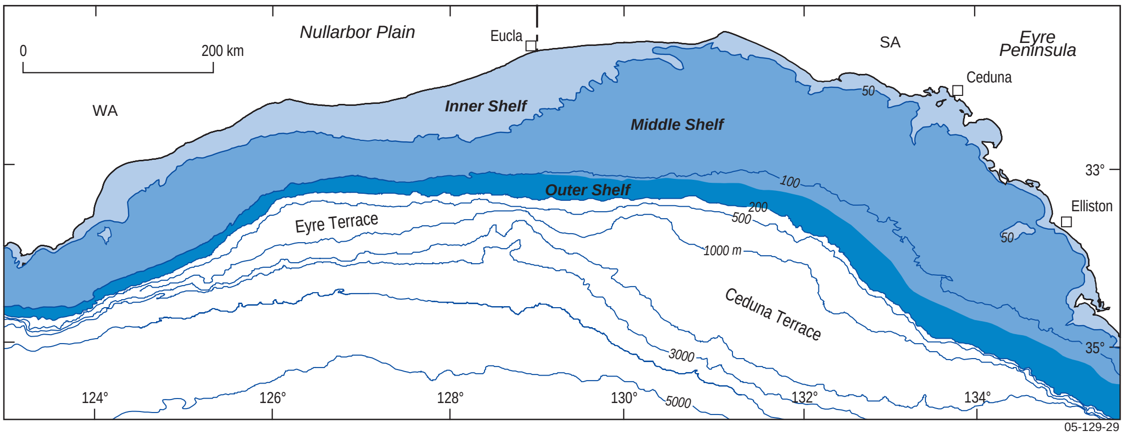

Figure 4.4. Bathymetry map defining the three divisions of the GAB shelf (modified from James et al., 2001); the inner shelf covers 0-50 m, the middle shelf 50-120 m and the outer shelf 125-170 m. The middle shelf is the most extensive and the most carbonate production occurs in this division.

The shallowest area of the GAB shelf is in the north and northwest where the Roe Terrace sits at 30-50 m water depth, forming an extensive, relatively smooth terrace offshore of the town of Eucla. In contrast, the eastern side of the bight deepens to >50 m water depth within a few kilometres of the coast, with the exception of shallow bays such as Smoky and Streaky Bay. Within the zone of wave abrasion (~120 m) sediments are typically rippled and coarse grained (James et al., 1994). Also present on the seafloor are NW-SE trending features aligned obliquely to the coast. These features are thought to be subaqueous dunes deposited by eastern flowing currents (Rollet et al., 2001).

A range of coastal environments occur across the GAB. The western margin from Cape Pasley to the Head of the Bight is dominated by tall limestone sea cliffs that reach up to 100 m in height (Herzfeld, 1997). The eastern margin is more complex with a mix of sea cliffs, scattered islands, rocky headlands, beaches, semi-arid tidal flats and large crescent-shaped bays (James et al., 2001).

Table 4.1. Geomorphic features in the Great Australian Bight region (from Harris et al., 2005).

Geomorphic Features	Area (km^2)	Percent
Shelf*	177,130	35.18
Slope*	105,170	20.89
Abyssal-plain/deep ocean floor*	62,550	12.42
Canyon	11,310	2.25
Knoll/abyssal-hills/hills/mountains/peak	120	0.02
Reef	20	0.00
Terrace	147,150	29.23
Total	503,450	100.00

*These units are less the surface areas of superimposed features.

The shelf has a gentle incline that steepens steadily away from the coast, with the shelf edge at around 200 m water depth (Fig. 4.5; James and von der Borch, 1991; Rollet et al., 2001). The continental slope covers 105,170 km^2 or ~20% of the GAB region (Table 4.1). It is relatively steep and narrow (~20 km) on either end of the GAB but is gentler in the center where two extensive terraces occur (James et al., 2001; Sayers et al., 2003). These terraces cover 147,150 km^2 or ~29% of the region. The Ceduna Terrace is the most extensive, trending WNW-ESE for 700 km and reaching up to 200 km wide. It is situated on the eastern slope and sits at 200-3,000 m water depth. The Eyre Terrace is smaller and thinner, trending E-W with a maximum width of 70 km. It is situated on the western slope at 200-1,600 m water depth (James and von der Borch, 1991; Sayers et al., 2003). These terraces formed from rapid sediment deposition during the late Cretaceous when Australia was rifting from Antarctica (Hill and De Deckker, 2004). Two provinces, the Eyre Slope and the Recherché Lower Slope, are present below the Eyre Terrace on the lower continental slope (Harris et al., 2005; Sayers et al., 2003). The continental rise in this area is smooth and relatively narrow, between 20 and 50 km wide, and grades into the abyssal plain at around 5,500 m water depth (James et al., 1994).

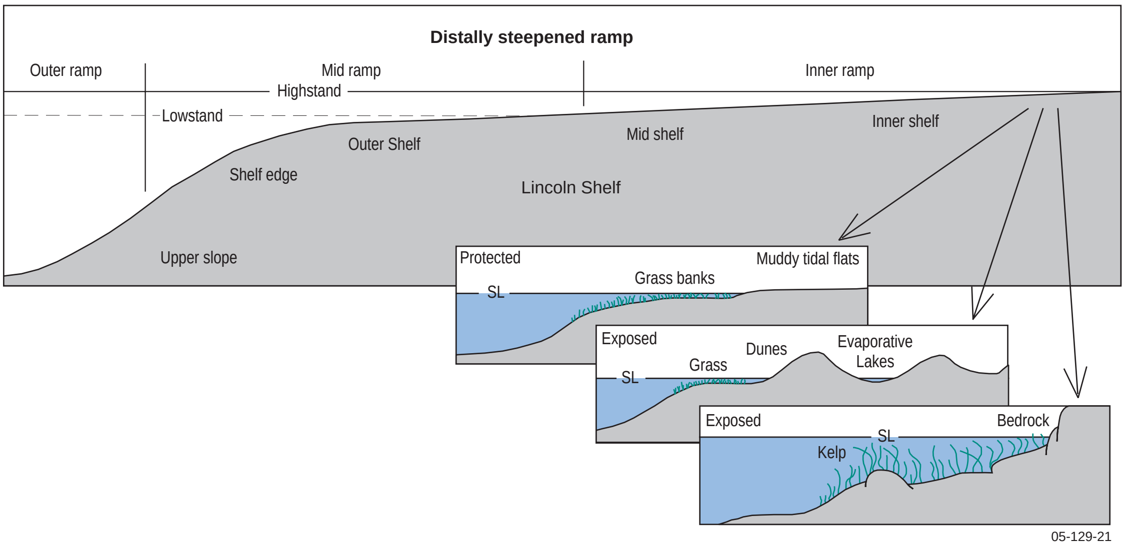

Figure 4.5. Schematic cross-section of the GAB, highlighting the extent and gentle incline of the shelf (redrawn from James et al., 1997). Insets show a range of nearshore habitats based on nearshore morphology and the amount of exposure to Southern Ocean swells. Lowstand sealevel is shown as a dashed line, indicating that the outer shelf would still have been submerged during the glacial periods.

The Ceduna and Eyre Terraces are intersected by numerous downslope gullies, channels and submarine canyons that cover an area of 11,310 km^2 (Table 4.1; Hill and De Deckker, 2004). Large canyons occur on the terraces, although they are broader and more widely spaced than the closely-packed Albany Canyons to the west (e.g., Fig. 3.4 and Fig. 4.1). They are also a distinctly different shape, being broad, shallow structures rather than narrow and deep with steep sides (Rollet et al., 2001). The Eyre and Eucla Canyons are the only well-developed canyons on the Eyre Terrace (von der Borch, 1968). The Ceduna Terrace in comparison, is cut by at least six major canyons, with the largest being the Nullarbor and Ceduna Canyons. The Nullarbor Canyon is the largest and deepest canyon on the terrace and has a series of deep holes several hundred meters deep and up to 5 km across at its base (Hine et al., 1999; Rollet et al., 2001). A small group of narrow canyons occurs on the eastern end of the Ceduna Terrace adjacent to the Murray Canyons Group to the east. These canyons are box-shaped in cross-section and have steep sides, indicating that they are inactive (Hill and De Deckker, 2004).

4.3. Oceanography

Two water masses restrict large-scale upwelling in the GAB: 1) a warm, highly saline water mass called the 'GAB Plume', which forms in the western GAB from high evaporation and surface heating and travels eastwards across the GAB; and 2) the warm, nutrient-poor Leeuwin Current (LC). Despite this, local, periodic upwelling occurs in the eastern and western sections of the GAB, especially during summer when the LC is weak (Fig. 4.6; James et al., 2001).

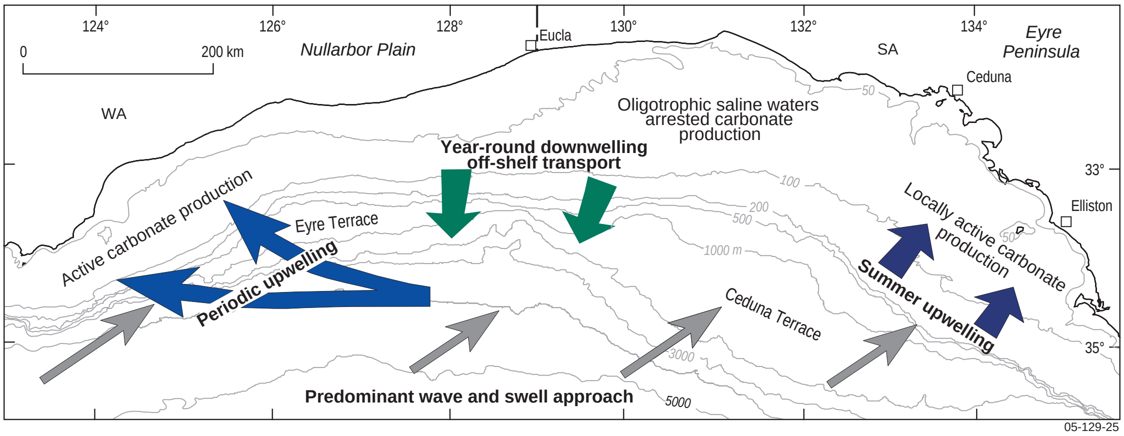

Figure 4.6. Diagram showing the local oceanography of the GAB and its association with carbonate production (modified from James et al., 2001). Carbonate production is highest in areas of seasonal upwelling and lowest in areas of downwelling.

Upwelling of cool, nutrient-rich waters from the deep ocean supplies nutrients to the shelf. Seasonal upwelling occurs in summer with Southern Ocean water upwelling in the eastern GAB and the Flinders Current, a westward flowing undercurrent that sits below 200 m water depth, upwelling in the western GAB (Bye, 1971; James et al., 1994). Carbonate production across the shelf is associated with nutrient supply and is highest in areas of seasonal upwelling (Fig. 4.7). No upwelling occurs in the central GAB, an area where carbonate production is dramatically reduced (James et al., 1994; James et al., 2001).

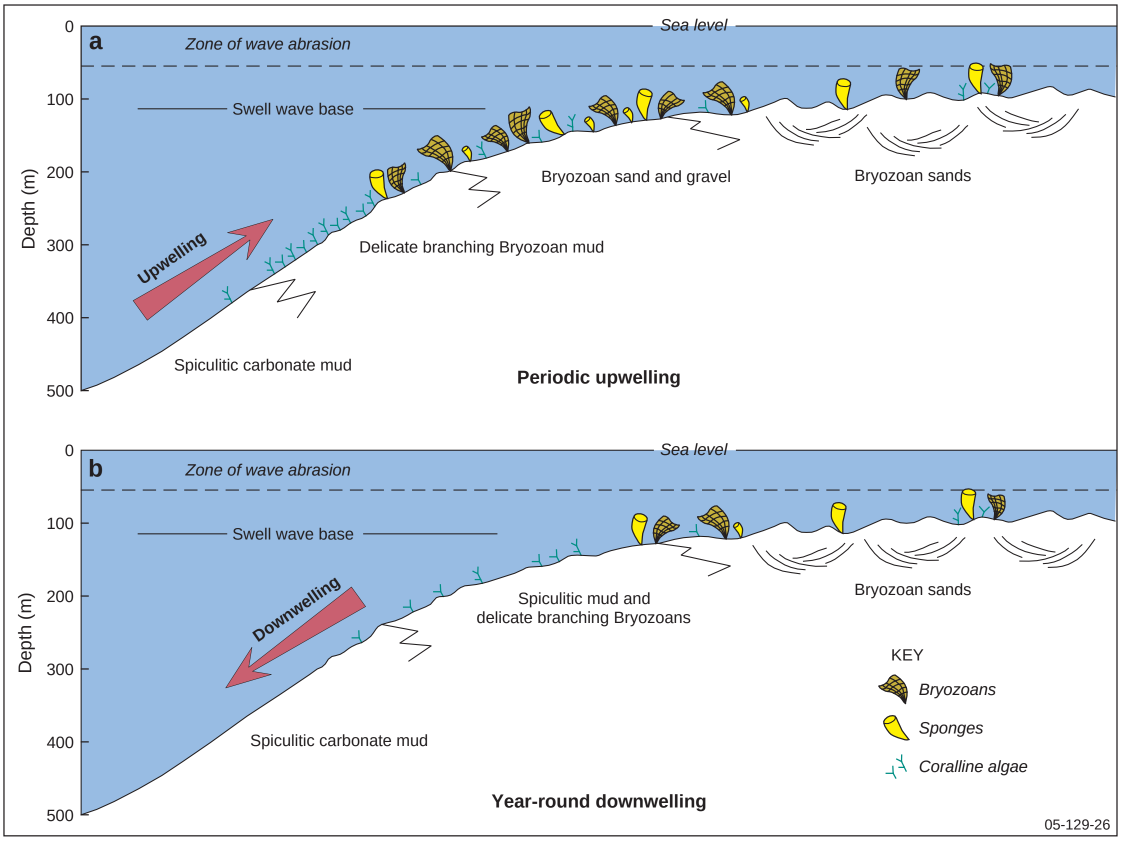

Figure 4.7. Schematic cross-section of the GAB shelf showing the influence of upwelling and downwelling on seabed biota (modified from James et al., 2001). Upwelling brings nutrients to the shelf and promotes growth of carbonate communities. Downwelling is generally warm, saline, nutrient-poor water which reduces the diversity and abundance of carbonate-producing organisms.

This control on upwelling and carbonate production is seen most dramatically on the inner and middle shelf. In summer, the GAB Plume forms in the northwestern GAB, suppressing upwelling in the area. At the same time, the LC is weak and intense local upwelling can occur in the eastern GAB along the Eyre Peninsula, allowing for prolific bryozoan and sponge growth (Griffin et al., 1997; James et al., 2001). Once the GAB Plume moves eastwards in late summer and early autumn, upwelling ceases in the east and sporadic upwelling of the Flinders Current can occur in the west. Downwelling becomes prominent across the bight in late autumn and winter when the LC reaches full strength and the GAB Plume resides in the east. The saline plume eventually downwells off the shelf south of the Eyre Peninsula, an area that is dominated by relict sediments and almost no modern carbonate production. Overall, downwelling occurs nine months of the year, with local, diffuse upwelling in summer

(James et al., 2001). On the outer shelf relatively warm and nutrient-poor waters prevent carbonate production and infauna from flourishing down to ~100 m water depth. However, below this depth, between 150-500 m, cool, nutrient-rich waters are present and carbonate production is enhanced (Li et al., 1999). This local effect of oceanography on the seabed is reflected in the distribution of sediments in the GAB (see section 4.4).

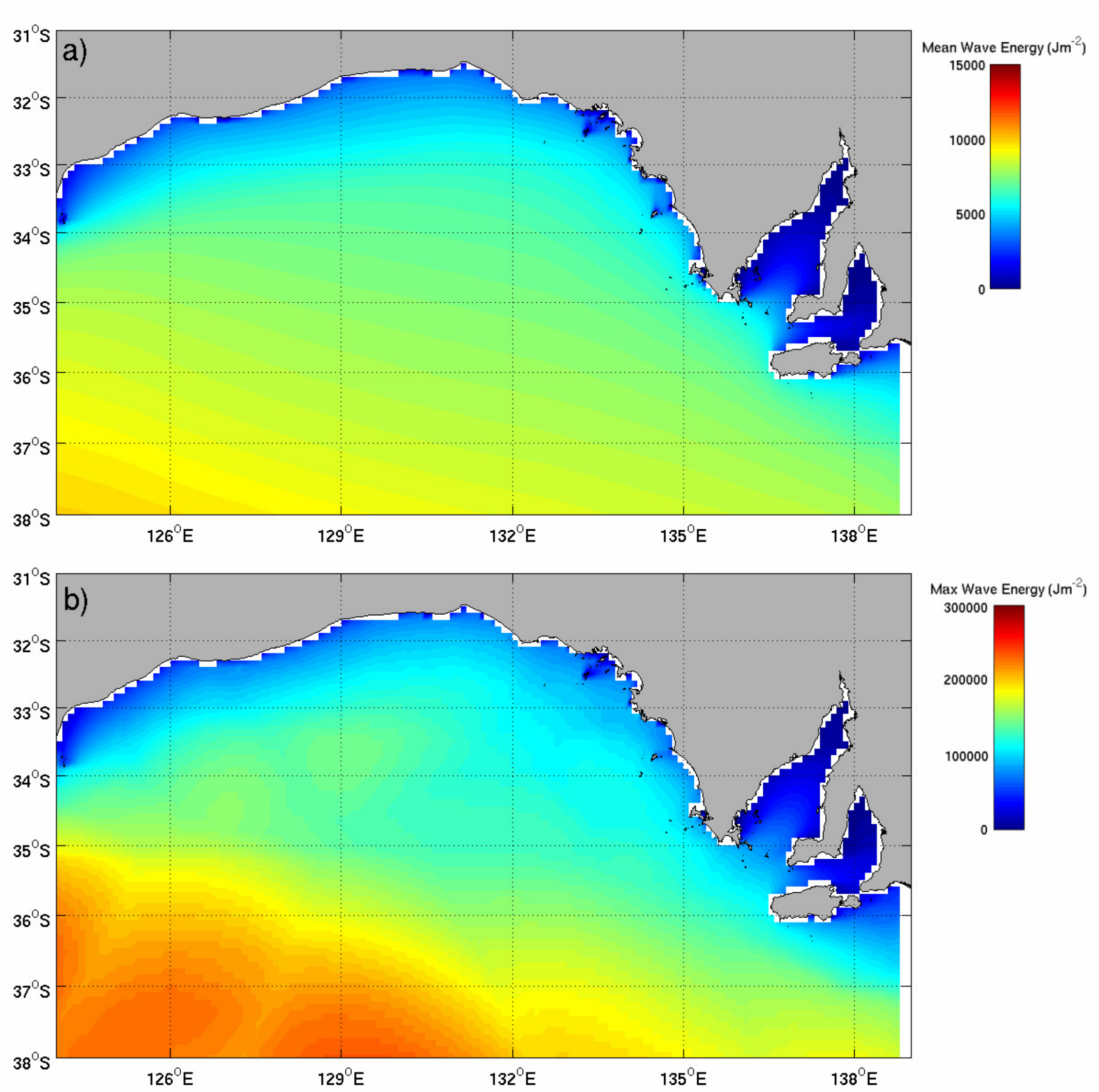

Figure 4.8. Map showing mean (a) and maximum (b) wave energy for the GAB and Spencer and St. Vincent Gulfs regions. Southern Ocean swells and storms come predominantly from the southwest, creating a high energy environment on the GAB, with a more protected setting in the gulfs.

Sea surface temperatures in the GAB range from 14-23°C, with temperatures highest over the shallow Roe Terrace in summer (Bye, 1983; James et al., 2001). The GAB Plume forms in this area and is 2-3°C warmer than surrounding waters (Herzfeld, 1997). Shelf water is stratified in summer due to localised upwelling and is well-mixed in winter because of swell and storm waves and the influence of the LC (James et al., 2001).

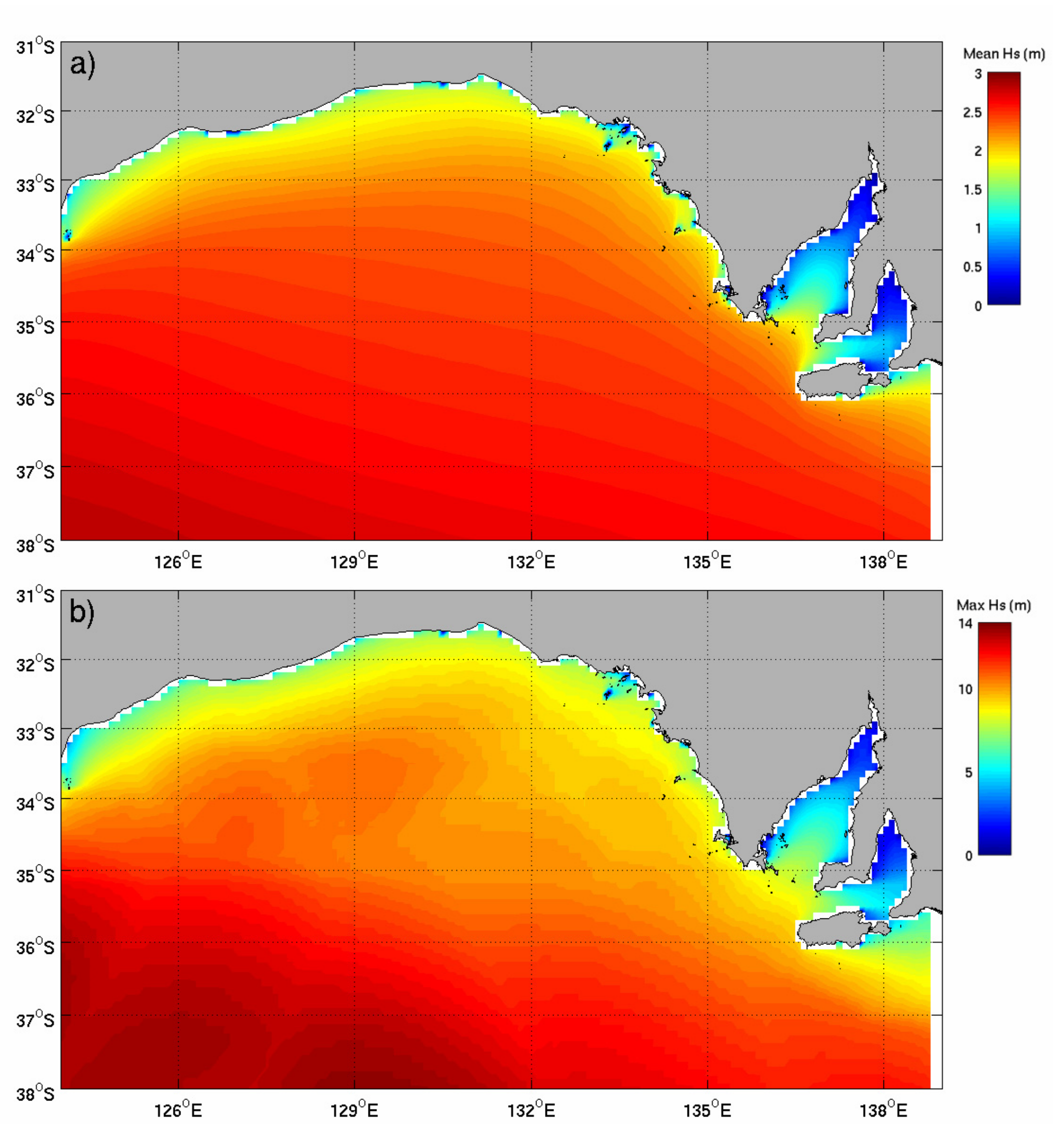

Figure 4.9. Map showing significant wave height for the GAB and Spencer and St. Vincent Gulfs regions. Mean wave height (a) is the height of the highest 1/3 if waves based on a seven year mean (Feb 1997 – Feb 2004), and (b) shows maximum wave height for the same period. The predominant wave direction can be seen to come from the southwest.

The broad continental shelf of the GAB faces the Southern Ocean, resulting in a high energy, storm-dominated platform that experiences high levels of wave erosion. Swells are predominantly from the southwest, therefore the eastern GAB coastline is subject to the highest wave energies. The western GAB is protected by Cape Pasley; however the area is still affected by strong winter storm waves and surges (Fig. 4.8). Swell waves are generally 2-2.5 m high and can reach 12-14 m high on the outer shelf (Fig. 4.9).

Swell and storm waves from the Southern Ocean influence the seafloor down to depths of 120 m, resulting in the formation of an 'unrimmed carbonate platform'. The shelf is a 'shaved shelf', meaning that carbonate accumulation is less than the amount of active erosion, and therefore very little sedimentation occurs (James et al., 1994; James et al., 2001). Most erosion occurs on the middle shelf. Ripples are present to ~80 m and little sedimentation occurs shallower than this depth (James and von der Borch, 1991). In water depths of 70-120 m, swell and storm waves rework and transport sediments during winter, allowing some sedimentation to occur during summer (James et al., 1994; James et al., 2001).

4.4. Surface Sediments

The GAB shelf forms a latitude-parallel cool-water carbonate province that is continuous along Australia's southern margin (James et al., 2001). The GAB is a cool-water, temperate carbonate shelf (James, 1997). It is a bryozoan-brachiopod-foraminiferal province, with surficial sediment components characterised by the skeletal remains of calcareous organisms.

Surface sediments in the GAB have been studied in detail by a number of workers (e.g., Conolly and von der Borch, 1967; Wass et al., 1970; James and von der Borch, 1991; Feary, 1993; James et al., 1994, 2000, 2001; Feary et al., 2000, 2004). High resolution seismic profiles and sediment cores reveal that most of the shelf and slope is overlain by a thin (<2 m) veneer of sediment covering Cenozoic limestones (Fig. 4.3; Sayers et al., 2003; Feary et al., 2004).

Surficial sediments are generally a mixture of modern (Holocene) skeletal carbonate grains and older (Late Pleistocene) relict carbonate material and intraclasts.

Carbonate fragments comprise a diverse cool-water heterozoan assemblage of bryozoans (e.g., articulated, delicate branching and encrusting forms), molluscs (e.g., bivalves and scallops), sponges, coralline algae (e.g., rhodoliths and articulated branches), ahermatypic corals, barnacles, foraminifers, crustaceans, echinoderms, ostracods, pteropods and polychaete worms (James et al., 1994; James, 1997; James et al., 2001). Carbonates dominate shelf sediments due to particularly low terrigenous sediment inputs from southern Australia.

Sediments generally form localised areas of rippled carbonate sand and gravel, interspersed with outcropping hard substrate and local epibenthic carbonate-producing invertebrate communities of bryozoans and algae (Fig. 4.10; James et al., 1994). In the GAB, grain size distribution patterns reflect the different energy regimes between the east and west parts of the bight, with muddy sediments being more common in the west. Carbonate sedimentation on the GAB predominantly takes place on the outer shelf, resulting in the platform prograding oceanward over time (James et al., 2001).

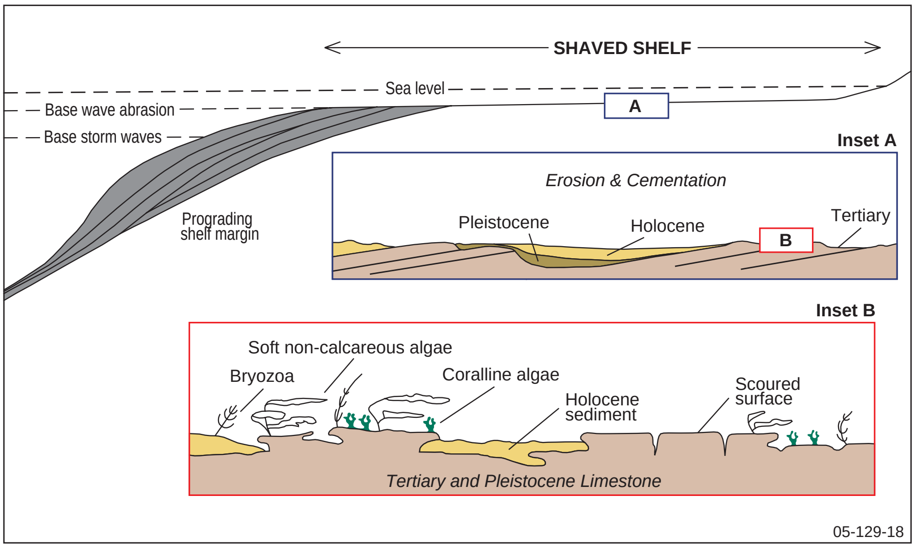

Figure 4.10. Schematic diagram of a ‘shaved shelf’ using the Eucla Shelf as an example (modified from James et al., 1994). Inset (a) shows the seabed on the shelf to consist of a veneer of patchy surface sediments overlying scoured Cenozoic limestone substrate. Inset (b) shows that surface sediments are thin. Bare sediment patches are interspersed with outcropping limestone and scattered epibenthic communities. Clinoforms (prograding sediment structures) are shown on the shelf edge. They are a result of high carbonate accumulation on the outer shelf and upper slope.

Surface sediments on the inner shelf generally contain modern, biofragment-rich rhodolith gravels with minor quartz sand. On the extensive middle shelf in water depths between 40 and 100 m, seabed sediments are eroded by high energy currents and waves, which have created a ‘shaved shelf’ and extensive regions of minimal sediment cover (James et al., 1994). This zone of active resedimentation is dominated by relict sediments such as mollusc shells and bryozoan skeletons. Outer shelf and upper slope sediments are dominated by abundant epibenthic bryozoan and sponge communities. Spiculitic carbonate forms a mud veneer on the slope below ~300 m water depth (James et al., 2001). Mid-slope terraces (i.e., Ceduna and Eyre Terraces) and submarine canyons on the continental slope are covered by a thin layer of pelagic calcareous ooze and mixed terrigenous-carbonate sand, silt and mud rich in skeletal carbonate fragments (Davies et al., 1989). Middle to lower slope sediments consist of foraminifera-nannofossil oozes (Feary et al., 1993). The presence of abundant epibenthic bryozoan and sponge (i.e., Heterozoan) communities on the outer shelf coincides with the region of most active carbonate production, whose distribution reflects oceanographic processes (see section 4.3).

James et al. (2001) has identified 12 sedimentary facies on the shelf and upper slope in less than 500 m water depth (Fig. 4.11). These facies can be divided into: Inner Shelf facies (Rhodolith Gravel, Quartzose Skeletal Sand and Gravel, and Mollusc-Intraclast Sand); Middle Shelf Plain facies (Intraclast sand, Intraclast-Mollusc Sand and Gravel, and Intraclast-Bryozoan Sand); Outer Shelf and Upper Slope facies (Bryozoan sand and Gravel, Bryozoan-Intraclast Sand, Branching Bryozoan sand and Gravel, Spiculitic, Branching Bryozoan Mud, and Coral-Celleporaria Facies); and Slope facies (Spiculitic Mud). Descriptions of these facies types are given in Table 4.2.

Carbonate concentrations are generally high in surface sediments along the southern margin. Calcium carbonate contents in the GAB are generally >80% (Fig. 4.12). These high concentrations reflect the influence of local carbonate production on the shelf. Sediment samples from the terraces and canyons on the outer shelf and slope also have carbonate concentrations of >80%, which may reflect off-shelf sediment transport of calcareous grains into deep water (Davies et al., 1989; Feary et al., 1993; James et al., 2001).

Table 4.2. Surface sediment facies on the Great Australian Bight (after James et al., 2001). Letters in brackets relate to facies shown in Fig. 4.11.

	Facies	Description
INNER SHELF	Rhodolith gravel (A)	Mainly comprises granule to cobble sized rhodoliths; compact, rounded, branching and dendritic forms; minor bivalves, turitellids, oysters, bryozoans and lithic intraclasts in a bryozoan and bivalve rich sand.
	Quartzose Skeletal Sand and Gravel (T1)	Heterogenous sediment of equal amounts of bryozoans and bivalves with lesser quartz, feldspar and crystalline rock fragments. Varies from poorly sorted coarse gravelly sand to rippled fine to medium sand.
	Mollusc-Intraclast Sand (MR)	Mollusc and intraclast rich well sorted fine to medium sands and poorly sorted fine sandy gravels, with minor bryozoans and foraminifera.
MIDDLE SHELF	Intraclast Sand (R)	Intraclast rich (80-90%) well sorted, coarse to very coarse sand; with minor bivalves, bryozoans and corallines; rippled sand in some areas.
	Intraclast-Mollusc Sand and Gravel (RM)	Intraclast rich, well-sorted medium sand to coarse gravel, with a 'salt and pepper' texture; contains large modern molluscs; local areas rich in benthic foraminifera; minor coralline algal rods; widespread rippled sand plain.
	Intraclast-Bryozoan sand (RB)	Dominated by sand sized intraclasts, bryozoan sands and gravels; sponges, rooted bryozoans, gorgonians, serpulid clusters, solitary corals and brachiopods on hard substrates.
OUTER SHELF AND UPPER SLOPE	Bryozoan Sand and Gravel (B)	Poorly sorted to well sorted very fine sand to cobble gravel, rich in broyzoans; minor intraclasts, bivalves, corallines and foraminifera; mud-rich areas are green in colour.
	Bryozoan-Intraclast Sand (BR)	Similar to (B) with abundant intraclasts and bryozoans; varies from a medium to very coarse sand and gravel veneer, rippled or hard substrate.
	Branching Bryozoan Sand and Gravel (BB)	Varies from well sorted medium to very coarse sand, to biomodal very fine sand/silt with bryozoans; minor intraclasts and foraminifera, bivalves, planktic foraminifera and sponge spicules.
	Spiculitic, Branching Bryozoan Mud (SB)	Spicule-rich carbonate mud with minor floating delicate branching bryozoans; fine biofragment fraction; uniform sediment veneer with intensive burrows; relict rhodoliths and coralline rods in shallow areas.
	Coral-Celleporaria Facies*	Clean well sorted coarse sand and gravel, to muddy gravel with abundant bryozoans and solitary corals; minor rhodoliths, sponges, small infaunal echinoids, brachiopods, bivalves and scaphopods; localised to the uppermost slope in the Ceduna sector.
SLOPE	Spiculitic Mud*	Deep water muds (>300 mwd), dominated by fine biofragments with lesser amounts of fine pelagic material; locally winnowed to muddy sands and gravels; grading upslope into BB.

*Not shown on map

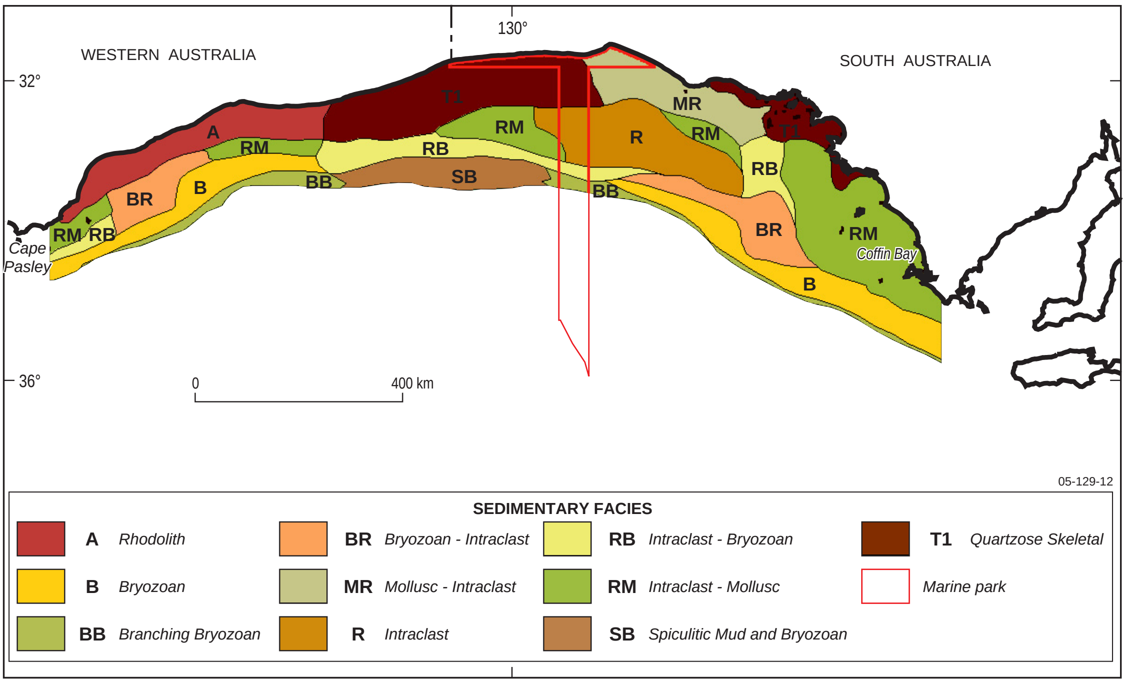

Figure 4.11. Map showing the distribution of surface sediment facies (modified from James et al., 2001). The shelf is mainly covered by carbonate sand and gravel with dominant calcareous components including bryozoans, bivalves and intraclasts. Deposits of rhodolith gravel occur in western parts of the inner shelf, with distribution patterns controlled by principal wind/wave direction. Minor quartz sands occur in central inner shelf regions.

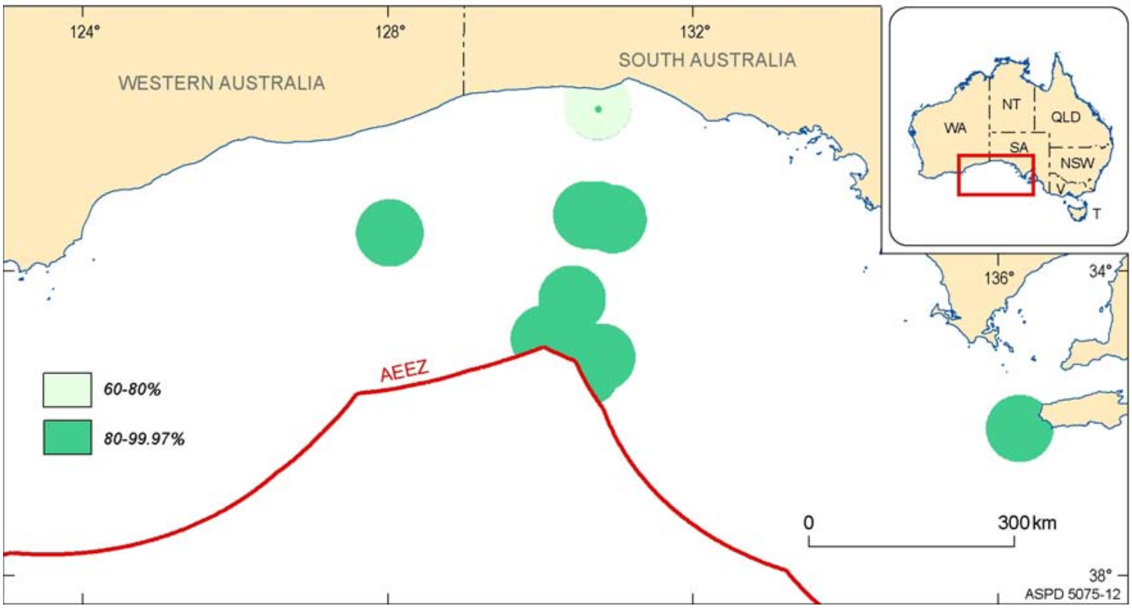

Figure 4.12. Map showing the distribution of calcium carbonate concentrations (modified from Passlow et al., 2005). Analysed sediment samples in the GAB have high carbonate contents overall. Slightly lower percentage carbonate in inshore regions reflects the redistribution of carbonate sediments from inner to outer shelf regions.

Across the GAB shelf, bryozoans and bivalves are common components of surficial sediments (Fig. 4.13; James et al., 2001). Bryozoans and bivalves are significant cool-water carbonate producers in seawater generally colder than 20°C (Brown et al., 1998; Hageman et al., 2000). In the GAB bryozoans dominate outer shelf sediments and are abundant in western and eastern parts. Bryozoan carbonate sand forms a continuous belt along the continental shelf, from Perth to Bass Strait (Wass et al., 1970). Bryozoan fragments comprise articulated, delicate branching and encrusting forms. Bivalves are common on the inner shelf, and in shallow shelf regions sediments comprise bivalve-rich, bioclastic sands (James et al., 1994). Other sediment components include tests of the large benthic foraminifera *Marginopora* sp. (Fig. 4.13; Feary et al., 1993).

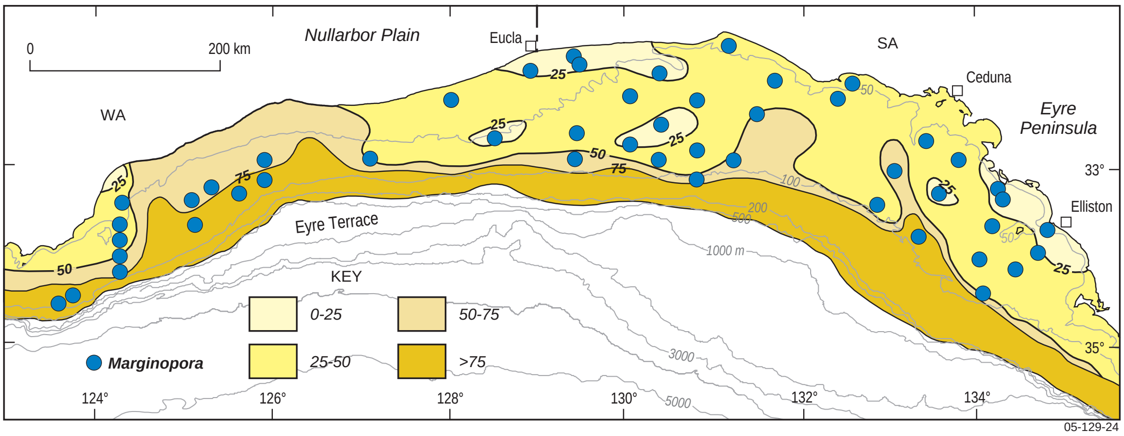

Figure 4.13. Map showing the distribution of bryozoans to bivalves [bryozoans ÷ (bryozoans + bivalves)] and the presence of the large benthic foraminifer *Marginopora* in surface sediments (modified from James et al., 2001).

Seagrass and macrophyte communities are abundant on the inner shelf, where carbonate sediment is being actively produced. On the Roe Terrace, thriving seagrasses and macrophytes are due to warm-temperate conditions (James et al., 2001). Seagrass are spatially associated with protected seabed environments. However, more work is needed to better characterise their distribution and variety across the shelf.

4.5. Acoustic Facies

Seabed echo-types were determined from the echograms of shallow seismic profiles collected in the GAB as part of Geoscience Australia's South and Southwest Regional Project (Rollet et al., 2001). The data set used includes 86,000 line-km of 3.5 kHz records from AGSO surveys 65 and 199 and the AUSTREA-1 survey (Fig. 4.14; Hill et al., 2000, 2001). High-resolution seismic profiles were collected together with sediment samples. Information from these samples was sourced from the Geoscience Australia Marine Samples Database (MARS). Five echo facies types were identified based on the classification of Damuth (1980; Appendix A). The most common echo-types are I and II, with smaller areas of IIIA, IIIC and IIID. Facies I is a grouping of IA and IB combined, and facies II is a grouping of IIA and IIB combined, due to poor data quality. Areas of poor data quality are related to inconsistencies in data resolution due to the depth of penetration of the system.

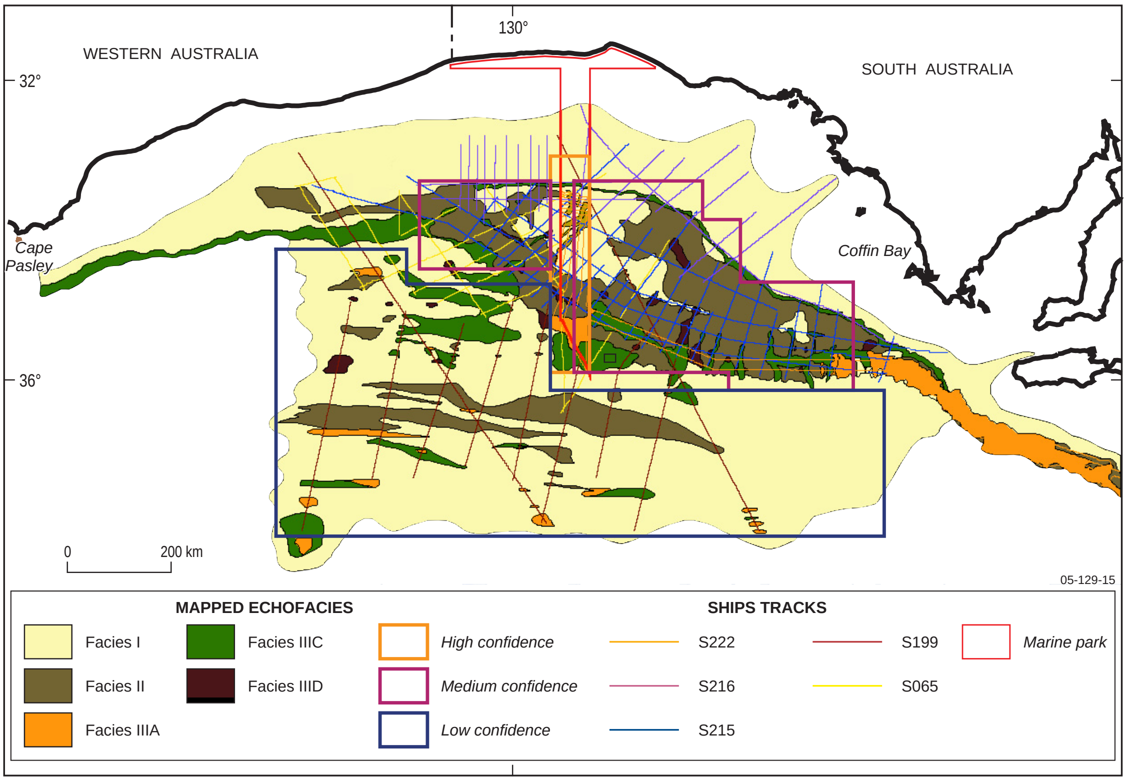

Figure 4.14. Map showing the distribution of acoustic facies in the Great Australian Bight with the location of sediment samples shown (modified from Rollet et al., 2001).

Facies I corresponds to areas of undisturbed layered sediments located on the shelf, the Eyre and Ceduna Terraces and the abyssal plain. Facies II represents areas of disturbed sediment that may have been reworked and formed debris flow deposits. Facies II is restricted to the Ceduna Terrace and the abyssal plain. Morphological features associated with facies III include extreme (IIIA), moderate (IIIC) and low (IIID) topography, on the continental slope, scarps, canyons, depressions and ridges on the abyssal plain. Abrupt facies changes occur on the eastern continental slope (covered by facies II and IIIC), which reflects the spatial complexity of large-scale features, such as changes in slope gradient and the location of canyons. Surficial sediment samples were used to confirm echo-type classifications. Descriptions of these sediments and facies are listed in Table 4.3, with all but one of the acoustic facies confirmed by surface sediments. There is a correlation between surficial sediments recovered from the GAB and the mapped echo-types (Rollet et al., 2001).

Table 4.3. Surface sediment characteristics of mapped acoustic facies (after Rollet et al., 2001).

Echo Facies	Sediment Type	Confidence Level
IA	Grey firm foraminiferal silt massively bedded at surface	Only verified in the GAB Marine Park with 2 samples
IB	Pink-beige bioturbated nanno-foraminiferal ooze	Verified by 26 samples
IIA	Pale brown, sandy foram-nanno ooze; decreasing sand below the surface	Only verified in the GAB Marine Park with 1 sample
IIB	Light grey, foram-nanno ooze with abundant bioturbation and large burrows with black infill	Verified by 18 samples
IIIA	Thin veneer of pale brown sandy foram-nanno ooze overlying brown or grey mudstone	Verified by 11 samples
IIIC	Thin veneer of foram-nanno ooze overlying debris-flow deposits	Verified by14 samples
IIID	Unknown	Not sampled

4.6. Late Quaternary Evolution

The majority of the GAB shelf would have remained submerged during most of the Late Quaternary. Even during periods of very low sea level, such as the last glacial when sea level was at least 120 m below present (Chappell and Shackleton, 1986), the outer shelf would have been submerged (James and von der Borch, 1991). Relict foraminifera specimens indicate that the inner GAB was an area of shallow marine lagoons and bays, while the outer shelf remained a shallow shelf sea, especially in the period between the last interglacial and last glacial (~90 to 20 ka) when sea level ranged between 20 and 120 m lower than today (Li et al., 1999).

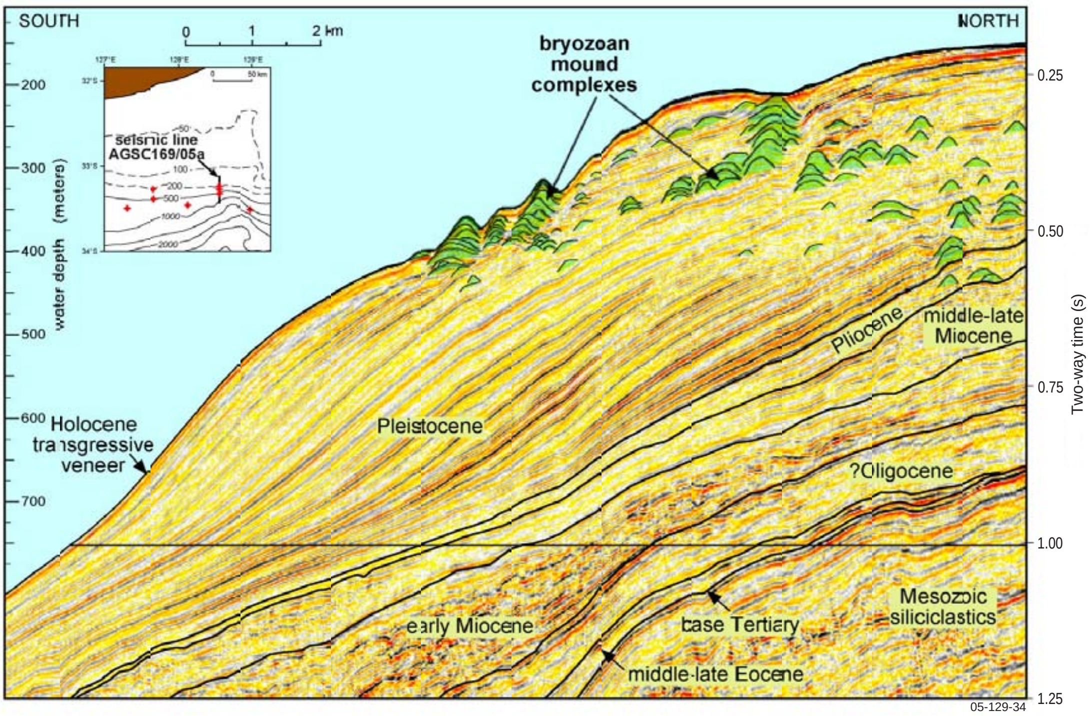

Figure 4.15. Seismic reflection image of the eastern GAB outer shelf and upper slope (from Feary et al., 2004).The image shows the thick Pleistocene clinoform wedge (prograding shelf sediments), and buried bryozoan reef mounds that grew during the Quaternary.

The shelf has been a site of cool-water carbonate production throughout the last 2 Ma. Very high rates of sediment deposition on the outer shelf during the Pleistocene (1.8 Ma to 10 ka) have resulted in progradation of the shelf. Pleistocene sediments are more than 550 m thick and were deposited at rates equal to the fastest growing tropical carbonates systems known. Lobe-shaped, prograding sediment structures (clinoforms) can be seen in seismic profiles of the shelf (Fig. 4.10 and 4.15; James, 1997, 2004). Also in the seismic profile are bryozoan reef mounds which have been interpreted as cool-water reefs that grew on the outer shelf during the Pleistocene. Similar structures are common in the geologic record but not in the recent past. They are the first examples to be found in the Quaternary, and are also the first to be found in their original depositional setting (Hine et al., 1999; James et al., 2000).

Bryozoan mound growth is attributed to a weakening of the LC during glacial periods, allowing for increased upwelling and higher productivity in the region. Nutrient levels would have been similar to those in Antarctic waters today, and prolific carbonate production was high enough to form these carbonate mounds (Bone and James, 2002). They are presently found in water depths of ~200-350 m, have up to 65 m vertical relief and extend laterally for hundreds of meters. None are growing today; they were drowned when sea level rose rapidly after the last glacial maximum and are now buried under a thin layer of Holocene sediments (James et al., 2000, 2001).

Overall, oceanographic conditions throughout the Holocene have been similar to those of today, with year-round downwelling in a high-energy environment, and prolific carbonate production occurring on the outer shelf. It is thought these patterns also persisted throughout most of the Quaternary (James et al., 2001).

5. Spencer and St. Vincent Gulfs

The Spencer and St. Vincent Gulfs region of the South Western Planning Area extends from the southern tip of Eyre Peninsula in the west, south to the Lincoln Shelf and the southern edge of Kangaroo Island, to the southern tip of Fleurieu Peninsula in the east, a total area of approximately 59,270 km^2 (Fig. 1.2). Spencer Gulf is the larger of the two gulfs and is a triangular-shaped embayment 300 km long (Fuller et al., 1994). Gulf St. Vincent and Investigator Strait together are 210 km in length (Bye, 1976). Both gulfs have shallow, restricted northern regions that are enclosed by sand spits; Ward Spit in Spencer Gulf and Long Spit in Gulf St. Vincent (Fig. 5.1). Shallow depths support broad subtidal seagrass meadows, intertidal sandflats, mangrove woodlands, samphire-algal marshes and supratidal evaporate flats (Barnett et al., 1997).

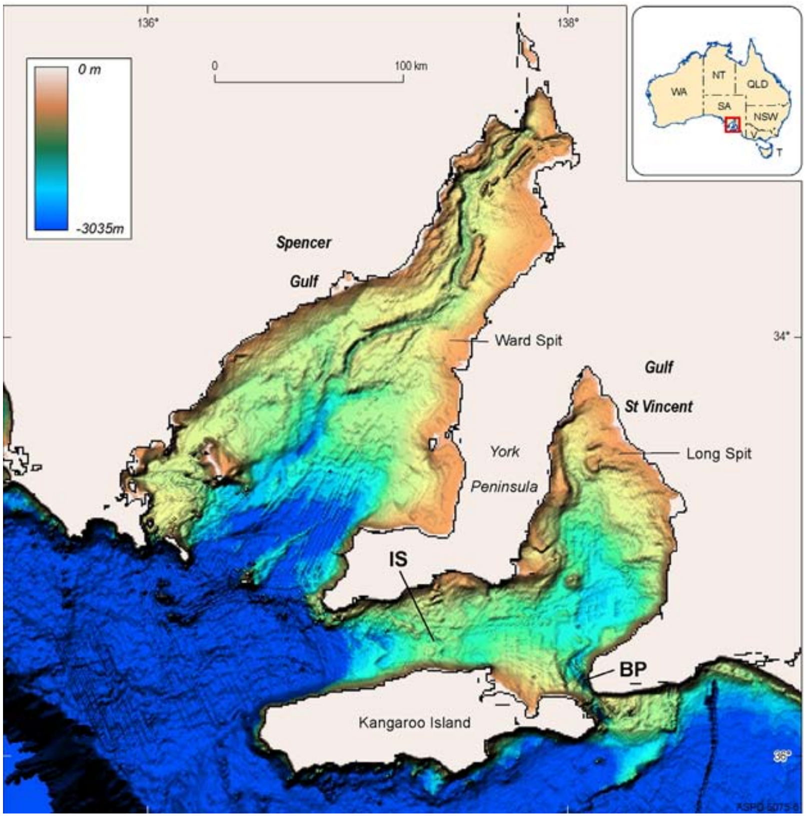

Figure 5.1. False-colour image of the bathymetry of Spencer Gulf and Gulf St. Vincent. Shallow, northern regions of each gulf encompass the area above Ward Spit (Spencer Gulf) and Long Spit (Gulf St. Vincent). Areas below these spits have been referred to in the text as 'southern Spencer Gulf' and 'southern Gulf St. Vincent'. IS = Investigator Strait; BP = Backstairs Passage.

5.1. Tectonic Setting

Spencer Gulf and the Gulf St. Vincent are underlain by two submerged sedimentary basins: the Pirie Basin and the St. Vincent Basin (Fig. 5.2). The two basins formed as a result of tectonic activity during the Tertiary (65 to 1.8 Ma). This activity included episodes of faulting and regional tectonic uplift (Cooper, 1985; Leonard, 2003). The gulfs occupy active intra-cratonic grabens, and recent seismic activity in the nearby Flinders Ranges indicates tectonic changes continue to affect the structure and morphology of the region (Leonard, 2003; Sandiford, 2003).

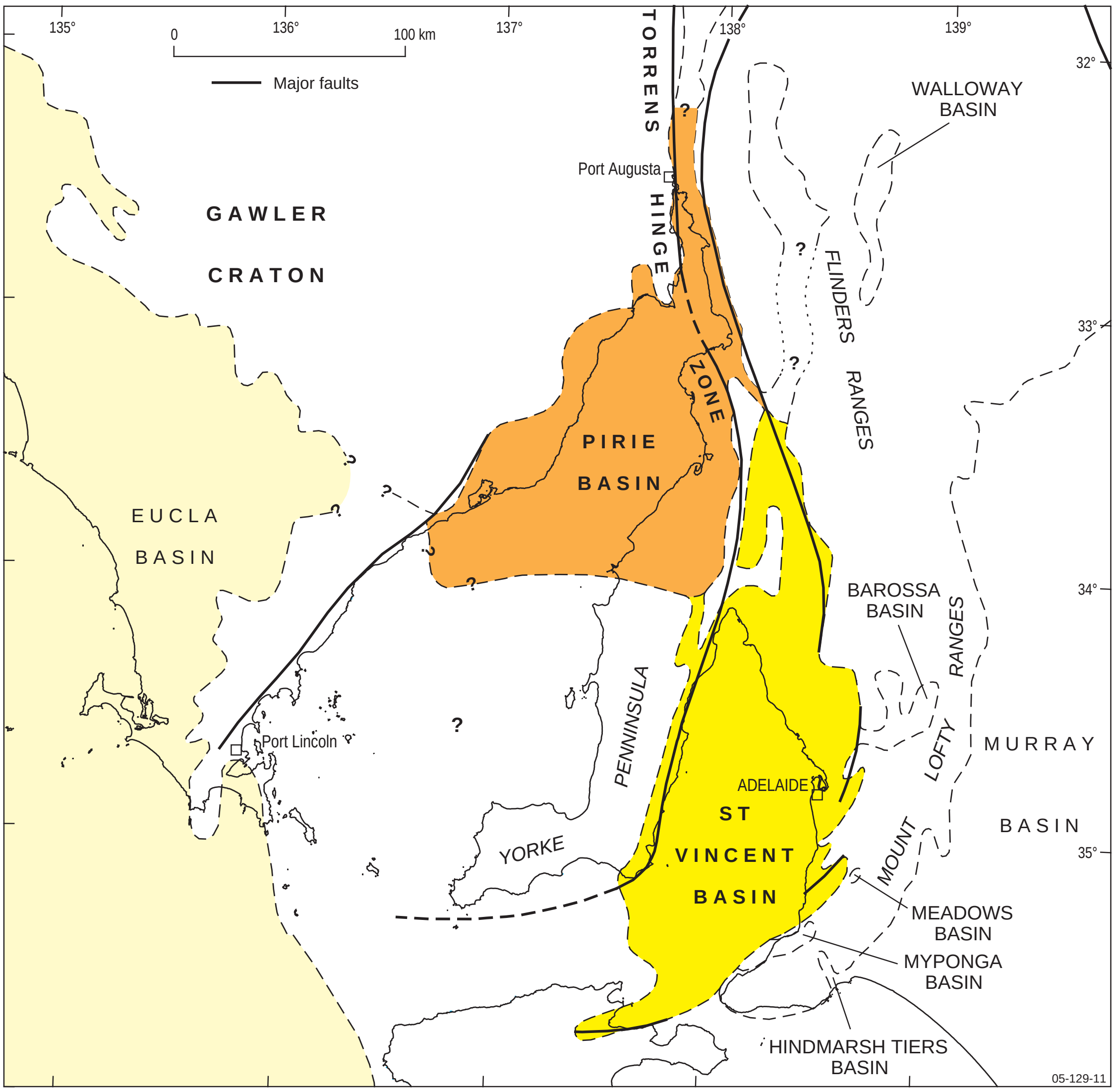

Figure 5.2. Map showing the geologic setting of the Spencer and St. Vincent Gulfs region (modified from Alley and Lindsay, 1995). The marine incursions of the Gulfs submerge part of continental Australia, which is underlain by two main tectonic elements: the Pirie Basin and the St. Vincent Basin.

The Pirie and St. Vincent Basins are connected in the north by a narrow onshore trough and contain similar early and middle Tertiary sediments (Alley and Lindsay, 1995). The basins are both underlain by Proterozoic-Cambrian basement rocks that outcrop on several offshore islands (Cooper, 1985; Fuller et al., 1994). Kangaroo Island is a basement high forming the southern margin of the St. Vincent Basin (Cooper, 1985). Stratigraphically, the Tertiary succession passes upwards from non-marine clastic sediments into a temperate water marine limestone sequence <1.5 km thick, which is the result of marine transgression (Cooper, 1985; Benbow et al., 1995). Character of Cenozoic sediments has been determined from drill cores, including a core from Troubridge Island, Yorke Peninsula, where 259 m of sediment was penetrated (Stuart, 1970; Stoian, 2002).

The Torrens Hinge Zone is a transitional area that separates the two major geological provinces in the region: the Gawler Craton (west) and the Late Precambrian Adelaide Geosyncline (east). The Torrens Hinge Zone marks a tectonic depression that formed as a result of rifting between Australia and Antarctica (Veevers, 1982; Cooper, 1985; Preiss, 2000).

5.2. Geomorphology

The continental shelf is the dominant geomorphic feature in the Spencer and St. Vincent Gulfs region. The shelf includes Spencer Gulf, Gulf St. Vincent, Investigator Strait and the Lincoln Shelf and covers a total area of 49,980 km^2, or 91.7% of the region (Table 5.1). The continental slope covers 1,300 km^2 and is cut by well-developed, narrow canyons that cover an area of 1,060 km^2. Other geomorphic features in the region include tidal sandwaves (800 km^2), banks and shoals (340 km^2) and deep valleys (530 km^2).

Spencer Gulf and Gulf St. Vincent are shallow bodies of water, with depths less than 50 m in Spencer Gulf (Petrusevics, 1993; James et al., 1997) and 41 m in Investigator Strait and Gulf St. Vincent (Bye, 1976). A bedrock ridge at 50 m water depth marks the entrance to Spencer Gulf. It is incised by two main channels that carry bottom waters from the gulf onto the shelf (James et al., 1997; Bowers and Lennon, 1987). Numerous islands rise from the ridge and form a partial barrier against incoming ocean waves and swells (James et al., 1997). Spencer Gulf is divided into two sections: a deeper southern area and a much shallower northern area (Fig. 5.1). The main basin of southern Spencer Gulf has an asymmetric topography in cross-section, with a gently sloping side on the west and a steeply sloping side on the east (James et al., 1997). Overall, three quarters of the gulf is less than 30 m deep (Gostin et al., 1988).

Table 5.1. Geomorphic features in the Spencer and St. Vincent Gulfs region (from Harris et al., 2005).

Geomorphic Features	Area (km^2)	Percent
Shelf*	49,980	91.66
Slope*	1,300	2.37
Bank/Shoals	340	0.62
Basin	510	0.93
Canyon	1,060	1.93
Deep/hole/valley	530	0.97
Knoll/abyssal-hills/hills/mountains/peak	10	0.01
Reef	20	0.03
Tidal-sandwave/sand-bank	800	1.47
Total	54,550	100.00

*These units are less the surface areas of superimposed features.

Northern Spencer Gulf has water depths less than 25 m (Gostin et al., 1984b). Ward Spit divides the southern and northern areas of the gulf and confines exchange between them to a narrow channel called the Flinders Channel, which runs up the center of the northern gulf (Shepherd and Hails, 1984; Corlis et al., 2003). Intertidal sand and mud flats flank the channel, along with a series of low terraces and scarps covered in seagrass (Fig. 5.3). These sublittoral terraces show both depositional and erosional processes (Hails et al., 1980; Shepherd and Hails, 1984).

Carbonate banks are well developed offshore from Redcliffe Point in the northeast of Spencer Gulf (Fig. 5.3). Banks have grown to low water level and form steep sided channels that extend down to ~10 m water depth. Channels deeper than 10 m generally do not support seagrasses due to erosion and scouring of the seafloor by tidal currents (Belperio et al., 1984; Gostin et al., 1984b; Hails et al., 1980). On these erosional surfaces sandwaves and megaripples are present. They cover a large area of the Flinders Channel floor and are oriented normal to the tidal flow, with wave lengths 2-20 m and heights up to 1.3 m. It is thought that the megaripples are made up of reworked local material rather than new material that has been transported into the northern gulf (Hails et al., 1980; Shepherd and Hails, 1984; Gostin et al., 1984b).

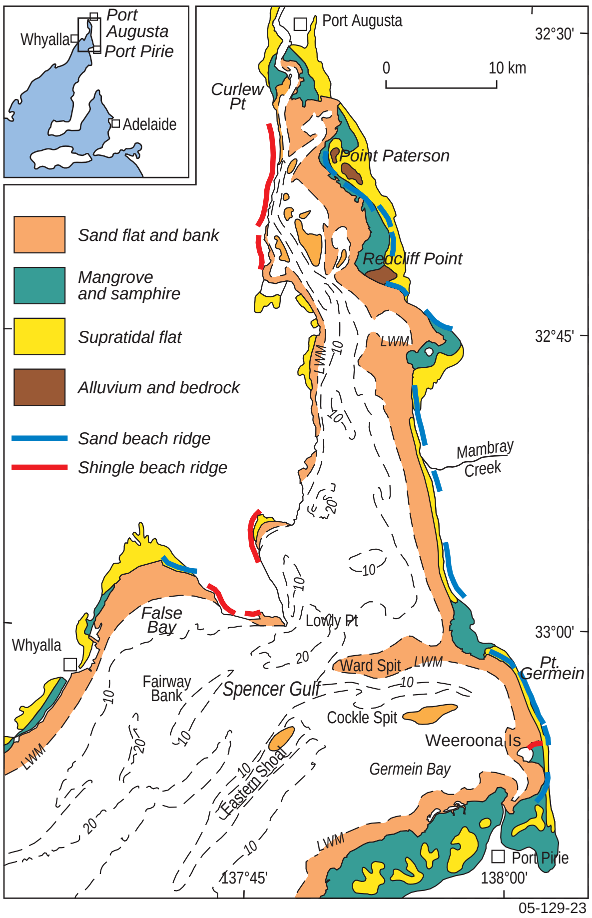

Figure 5.3. Map showing the bathymetry and environments of northern Spencer Gulf (modified from Hails et al., 1984a). The coloured areas make up the extensive intertidal and supratidal zones, a result of shallow depths and a high tidal range.

The maximum depth of 41 m in Gulf St. Vincent occurs in the centre of the southern area. Both entrances to the gulf are shallower; Backstairs Passage has a 35 m deep sill and Investigator Strait is <30 m deep due to an N-S trending bar at its mid-point (James et al., 1997; Li et al., 1998). Tidal current sand ridges and scours are present in both entrances (Harris, 1994b). Northern Gulf St. Vincent is bounded in the south by a latitudinal line through Long Spit and has a maximum water depth of 20 m (de Silva Samarasinghe et al., 2003). The northern area has an asymmetric topography with a 20 m deep channel along the western side and gently grading flats on the eastern side (Fig. 5.1; de Silva Samarasinghe, 1998).

5.3. Oceanography

Oceanography in both Spencer Gulf and the Gulf St. Vincent is characterised by salinity levels increasing towards the head of each gulf (Bye, 1976, 1981; Nunes and Lennon, 1986; Lennon et al., 1987). This is the result of evaporation exceeding freshwater input from precipitation and land runoff at the head of each embayment (Pritchard, 1952, 1967). Both Spencer Gulf and Gulf St. Vincent extend into arid continental Australia, where high evaporation rates and the absence of perennial rivers result in salinities as high as 49‰ at the head of Spencer Gulf (Bye, 1983; Gostin et al., 1988; Fuller et al., 1994) and 42‰ at the head of Gulf St. Vincent during summer (Fig. 5.4) (de Silva Samarasinghe et al., 2003). In addition, concentrated brines form in salt marshes, channels and salt pans on extensive tidal flats in northern Spencer Gulf and Gulf St. Vincent, contributing to the high levels of salinity (Nunes and Lennon, 1986; Bye and Harbison, 1991). Across the mouths of the two gulfs, salinity is controlled by less saline shelf waters intruding into the embayment, and salinities do not deviate significantly from 36.5‰ (de Silva Samarasinghe and Lennon, 1987; Li et al., 1998).

As Spencer Gulf and Gulf St. Vincent are relatively shallow, they have large seasonal temperature ranges (Lennon et al., 1987). Sea surface temperature in Spencer Gulf ranges from ~12° to ~24°C. Gulf waters are cooler than shelf waters in winter and warmer in summer due to restricted mixing between the two (Nunes and Lennon, 1986; Bullock, 1975). Sea Surface temperature frontal systems have been observed at the mouths of Spencer Gulf and Investigator Strait during summer months, with frontal temperature differences of 3-4°C in surface waters and 7-8°C in bottom waters (Fig. 5.5). They develop from the concurrence of relatively warm gulf waters and cooler shelf waters (Petrusevics, 1993). These fronts suggest that there is little mixing of the two water masses during the summer-autumn period which has implications for the dilution and/or removal of anthropogenic toxins from gulf waters (Nunes Vaz et al., 1990; Petrusevics, 1993; Corlis et al., 2003).

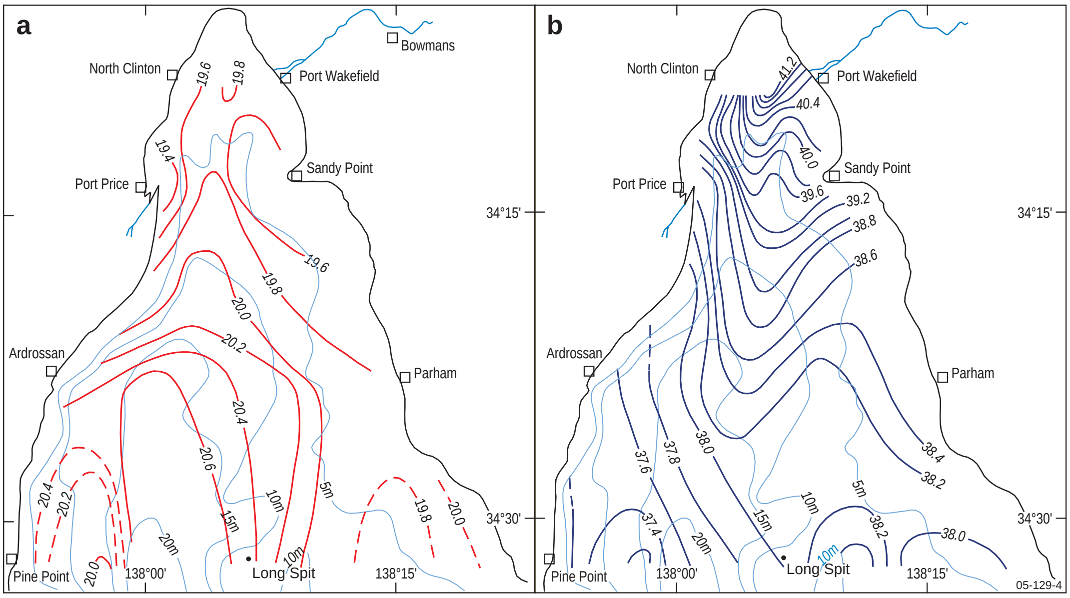

Figure 5.4. Temperature (a) and salinity (b) profiles of Gulf St. Vincent measured in April, 1982 (modified from de Silva Samarasinghe, 1989). There is little change in temperature across the gulf. In comparison, a steep salinity gradient is observed, with salinities increasing towards the head of the gulf due to high levels of evaporation, low land runoff and low rainfall. This salinity profile classifies it as a 'negative' estuary, with an opposite salinity profile to 'positive' estuaries which are common on the east coast of Australia.

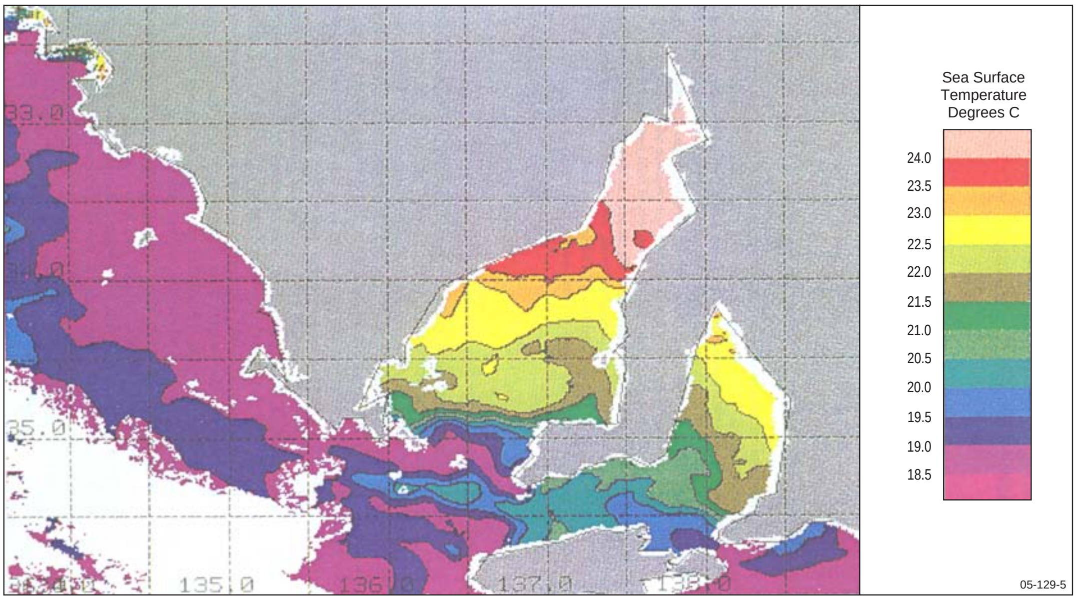

Figure 5.5. An AVHRR satellite image of seasonal sea surface temperature frontal systems at the mouths of Spencer Gulf and Investigator Strait (from Petrusevics, 1993). Grey areas represent land and white areas represent cloud. Frontal temperature differences of 3-4°C in surface waters and 7-8°C in bottom waters have been observed. This suggests that there is limited exchange between gulf waters and shelf waters when these frontal systems are present.

In Spencer Gulf the general water circulation is clockwise, with shelf waters flowing into the gulf along the west coast and deflecting eastwards due to the Coriolis effect (Nunes and Lennon, 1987; Fuller et al., 1994). Outflow is generally confined to the eastern side and is denser and more saline than the inflow due to the high rates of evaporation. A similar circulation pattern is present in Gulf St. Vincent, with saline outflow occurring through both Investigator Strait and Backstairs Passage (Fig 5.6) (Bye, 1983; Li et al., 1998). Because of these patterns an east-west salinity gradient is observed in both gulfs (Bye and Whitehead, 1975; Nunes and Lennon, 1986; de Silva Samarasinghe et al., 2003). A moderate, north-flowing boundary current, called the 'Port Lincoln Boundary Current' is evident at all depths along the western coast of Spencer Gulf (Bullock, 1975).

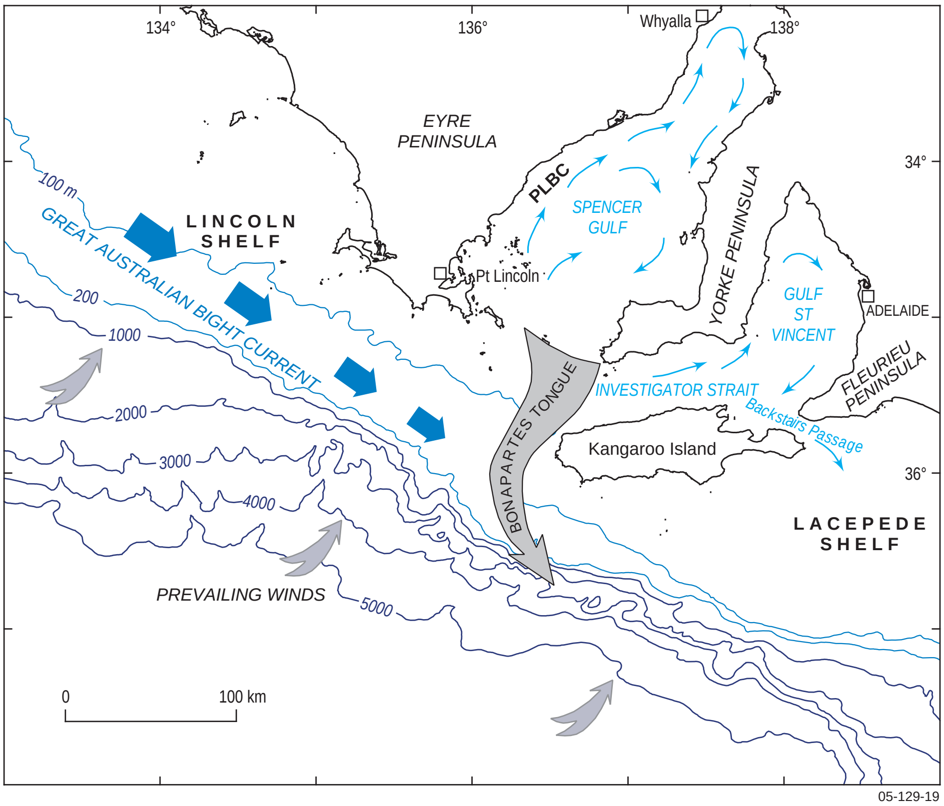

Figure 5.6. Diagram showing oceanography of the Spencer and St. Vincent Gulfs region, highlighting the clockwise water circulation pattern in each gulf (modified from Li et al., 1998). PLBC = Port Lincoln Boundary Current, a northward-flowing boundary current present along the western coast of Spencer Gulf. Bonaparte's Tongue is a density current of saline water that flows out of Spencer Gulf in Austral autumn, when water temperatures start to cool and saline water at the head of Spencer Gulf becomes too dense to maintain stability in the water column. The dense water sinks and flows out across the shelf.

Sediment grain size distribution in southern Spencer Gulf is predominantly influenced by the clockwise circulation patterns. Mobile sediments appear aligned with the northward-flowing Port Lincoln Boundary Current in the west and with bottom outflow in the east. The deepest, central part of the gulf area is the least affected by this clockwise circulation and fine-grained sediments accumulate here. Northern Spencer Gulf is characterised by low energy with restricted tidal flushing and as a result, sediments are less affected by waves and currents (Fuller et al., 1994). Likewise, northern Gulf St. Vincent appears to be a closed system, showing little exchange of water or sediments with the southern gulf (Bullock, 1975). Tidal currents of 0.5-2.0 ms^{-1} scour the bottom of Investigator Strait, being strongest in the center of the strait and weakening towards the coast (James et al., 1997).

The tidal regime in both gulfs is unique because the two local tides, one from the east and one from the west, have the same amplitude (Bye, 1976; Barnett et al., 1997). This results in a tidal range in the order of 2 m, four times greater than the tidal range across the Rottnest, SW and GAB regions (Green, 1984). The two tides enhance each other but also cancel each other out, resulting in periods of almost no tidal movement. These periods are known as 'dodge tides' and occur once a fortnight, lasting for as long as a day (Green, 1984; de Silva Samarasinghe and Lennon, 1987; de Silva Samarasinghe, 1989).

As Spencer Gulf surface waters cool during the Austral autumn, the high-salinity water residing at the head becomes dense enough to form an outflowing bottom density current. The current is referred to as 'Bonaparte's Tongue' by local oceanographers and is around 20 km wide and 20 m thick (Fig. 5.6; Bowers and Lennon, 1987; Lennon et al., 1987). It flows out the mouth of the gulf and across the Lincoln Shelf for over 100 km, falling over the edge of the shelf and finding its own density level at 250 m water depth (Figs. 5.7, 5.8). The outflow of this dense water occurs in regular pulses over a period of approximately three months. These pulses are a result of a density decrease after each outflow, followed by another density increase caused by evaporation and further decreases in sea surface temperature (Lennon et al., 1987; Corlis et al., 2003). Smith and Veeh (1989) found the current to be rich in particulate organic matter but depleted in dissolved phosphorous, nitrogen and carbon. The growth and diversity of calcareous benthic organisms is dramatically reduced in the areas influenced by this highly saline, nutrient-depleted water (James et al., 1997; James, 2004).

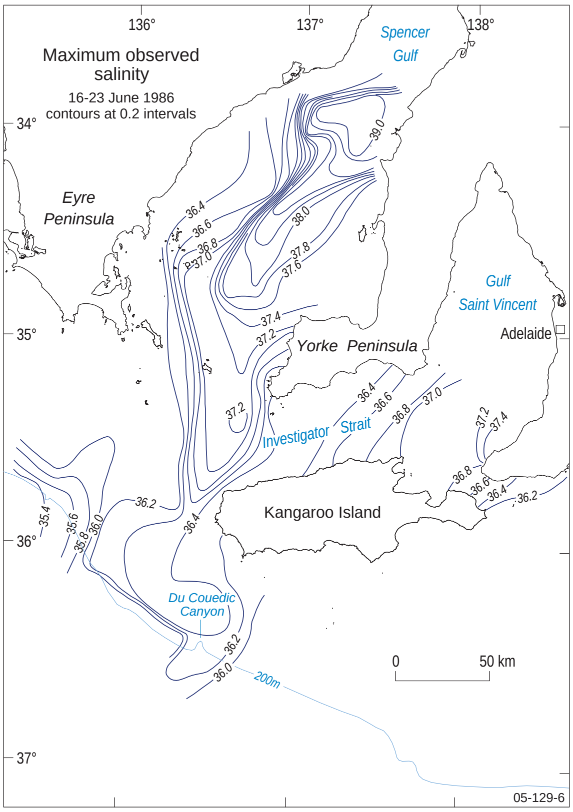

Figure 5.7. Salinity contours in Spencer Gulf, showing the density current, 'Bonaparte's Tongue' flowing out of the gulf and across the shelf (modified from Lennon et al., 1987).

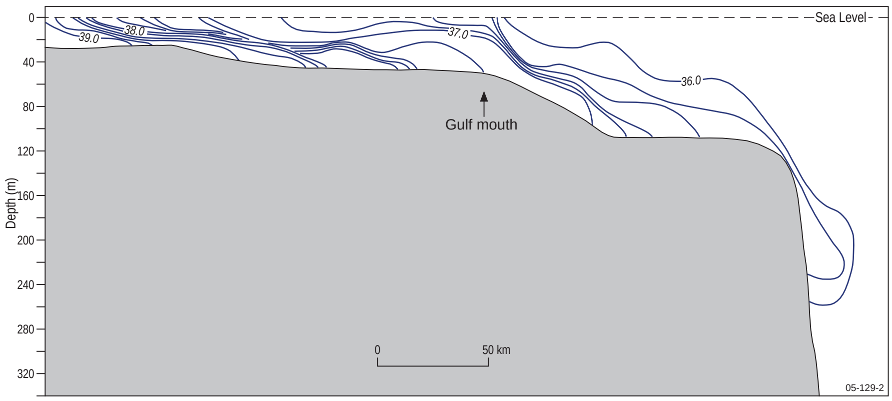

Figure 5.8. Figure 5.7 in cross-section, with salinity contours showing the density current flowing out of Spencer Gulf and residing off the shelf at its own density level (modified from Lennon et al., 1987).

5.4. Surface Sediments

The regional sedimentology of the gulfs has been the focus of several studies, including a special edition on the Spencer Gulf region in *Marine Geology* (Hails and Gostin, 1984). A survey of southern Spencer Gulf, Investigator Strait and the Lincoln Shelf collected 69 surface sediment samples (James et al., 1997), and several smaller surveys have been completed by Gostin et al. (1988) and Fuller et al. (1994). A broad study of the Gulf St. Vincent was undertaken by Shepherd and Sprigg (1976). Shepherd (1983) has examined the regions seagrass. Foraminifera have been the focus of work by Cann et al. (1993, 2002), Cann and Murray-Wallace (1986) and Li et al. (1998).

The Spencer and St. Vincent Gulfs region is part of the large area of cool-water carbonate deposition that exists along the southern margin of Australia (James and von der Borch, 1991; James et al., 1997). Overall, the shelf region includes carbonate environments of a distally steepened ramp. The gulfs are situated on the protected inner ramp, and the Lincoln Shelf is on the exposed mid ramp. Together, these carbonate environments form a prograding carbonate platform (James et al., 1997). In the gulfs, surficial marine sediments display a clear zonation from subtidal to supratidal areas, related to water depth (Gostin et al., 1988).

Seabed sediments across the region are composed of mixed terrigenous-carbonate material (Gostin et al., 1984a). They are palimpsest; containing both modern and Pleistocene carbonate and terrigenous grains (Fuller et al., 1994). Overall, biogenic carbonate is the dominant sediment component. Biogenic sediments contain bryozoans (B), coralline algae (A), molluscs (M), and foraminifers (F), which are known as the BAMF Carbonate Factory (James et al., 1997). In the Gulf St. Vincent and Investigator Strait, this biogenic carbonate is generated from two main sources; within the gulf itself and from the continental shelf southwest of Investigator Strait (Waters, 1982). Terrigenous sediment concentrations are typically low, and inversely proportional to the amount of carbonate (Burne and Colwell, 1982; James et al., 1997).

Up to 4 m of Holocene surficial sediments have accumulated in northern parts of Spencer Gulf (Fig. 5.9; Hails et al., 1984b). Sediments in the area contain four main sedimentary facies (Table 5.2). Gastropods, bivalves, foraminifera, coralline algae and quartz grains are the dominant components (Burne and Colwell, 1982). The gulf margins contain nearshore intertidal muddy gastropod-rich sediments, which are inhabited by cyanobacterial mats and mangroves (Gostin et al., 1988). Shallow water sediments include poorly-sorted muddy bioclastic sand and seagrass, with muddy carbonate sands dominant in water depths greater than 30 m. Sediments on the 0.5-3.0 m high megaripple field (i.e., sandwaves) are composed of well-sorted and medium-grained sand on crests and poorly sorted sands in troughs (Fig. 5.10). Surface sediments collected from sandwaves are often shell-rich, with carbonate concentrations ranging from 25% to 95% by weight (Hails et al., 1980; Shepherd and Hails, 1984). Extensive intertidal and supratidal flats (i.e., sabkha) are well-developed in northern parts of Spencer Gulf (Table 5.2; Hails et al., 1984b; Gostin et al., 1988).

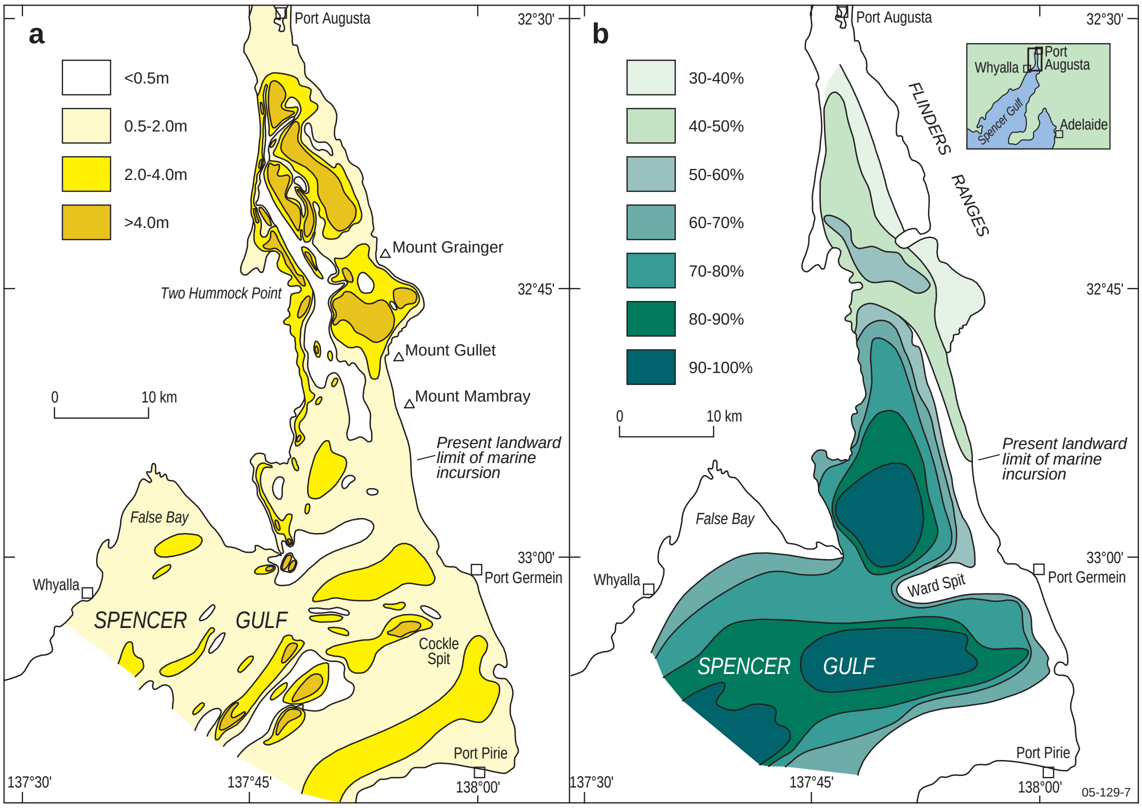

Figure 5.9. Surficial sediment characteristics of northern Spencer Gulf (modified from Hails et al., 1984b); (a) Isopach map of Holocene sediment thicknesses, and (b) contour map showing the distribution of calcium carbonate concentrations in surface sediments.

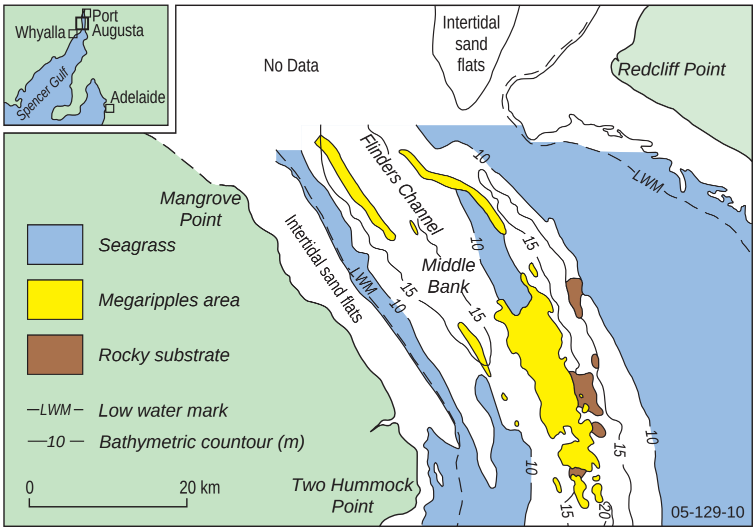

Figure 5.10. Map showing the area of megaripples in northern Spencer Gulf (modified from Shepherd and Hails, 1984). The distribution of seagrasses, outcropping substrate and megaripples is illustrated, showing the relationship between seagrass communities and substrate type.

The Lincoln Shelf and southern parts of Spencer Gulf have a patchy covering of surficial sediment that is less than 10 m thick. The substrate is exposed on some areas of seabed, revealing Cenozoic limestone (James et al., 1997). In this area, surficial sediments have been classified into six facies (Fig. 5.11; James et al., 1997): 1) surficial sediments are generally carbonate-rich sands and gravels with abundant molluscs and bryozoans (Fuller et al., 1994); 2) bivalve sands of whole and fragmented bivalves dominate the inner shelf; 3) bryozoan sands are common on middle to outer shelf areas; 4) coarse-grained gravels of coralline algae occur along the western margins of Spencer Gulf; 5) foraminifera sand occurs at the mouth of the gulfs and out to the shelf edge; and 6) a belt of poorly sorted, bryozoan–coral gravel facies extends laterally along the narrow shelf edge (James et al., 1997).

Modern sediments from the gulfs and Lincoln Shelf contain recent and reworked carbonate grains. In northern Spencer Gulf, the highest carbonate concentrations of >90% occur in central deep water regions (Fig. 5.9). Skeletal carbonate fragments of bryozoans, bivalves, coralline algae and benthic foraminifera make up >90% of surficial sediments, contributing to the carbonate content (Colwell and Burne, 1978; Hails et al., 1984b; Gostin et al., 1988, James et al., 1997; Li, et al., 1998). Relict carbonate fragments are a significant sediment component in southern Spencer Gulf (Fuller et al., 1994).

Table 5.2. Surface sediment facies in northern Spencer Gulf (after Hails et al., 1984b).

	Facies	Description
SUBTIDAL	Seagrass bank / platform	Poorly-sorted, variable mixture of shell, shell fragments, quartz sand and a little mud; seagrass fibres with occasional clumps of fibre.
	Seagrass tidal channel	Similar to above, but coarse-grained in channel; some organic debris layers.
	Megaripple field	Well-sorted medium quartz sand with shell fragments, cross-bedded and layered.
	Channel floor gravel	Mud and shell or eroded channel floor with/without gravel lag.
INTERTIDAL	Samphire / algal flat	Thin veneer of reddish-brown terrigenous clay underlain by grey, mottled mud; massive to bioturbated structure.
	Mangrove / algal flat	Pebbly sands, to sandy muds and silts near tidal channels; muds in mangrove forest; oxygenated; mangrove roots; decalcification.
	Sandflat or beach	Well-sorted quartz and shelly sands; generally oxidised; yellow to cream colour; disarticulate bivalves; flat bedding; isolated *Zostera* sp. colonies with finer grained sediment.
SUPRATIDAL	Coastal dune	Quartz and shelly sand, or *gypsiferous* silt.
	Stranded beach ridge	Quartz and shelly sand or gravel.
	Supratidal flat or sabkha	Laminated to poorly bedded, or massive spongy (fenestral) structure; grey to cream carbonate mud and mottled sandy clays; isolated gypsum crystals and gypsum sand layers; occasional white dolomitic blebs.

Terrigenous sediment inputs are generally low, except in northern parts of Spencer Gulf where terrigenous components make up 85% of surface sediments. Such high terrigenous concentrations in these areas are a result of material being eroded from the nearby Flinders Ranges and introduced into the gulf by local drainage (Burne and Colwell, 1982; Fuller et al., 1994). It is also possible that these terrigenous sediments were transported from the shelf into the shallow northern regions during sea level transgression. Terrigenous components include well rounded, stained quartz and angular lithic fragments derived from aeolian dust and erosion of Proterozoic sediments and Pleistocene dunes (i.e., aeolianites). In some cases, fragments of substrate scoured from the seabed are incorporated into surficial sediments (Burne and Colwell, 1982; Hails et al., 1984b; Fuller et al., 1994).

Other sediment components include calcareous worm-tubes, bryozoans, echinoid and mollusc fragments, sponge spicules, ostracods, scaphopods, seagrass and seagrass root fibres, cyanobacterial mats, faecal pellets, red algae and mixed carbonate/terrigenous aggregates (Burne and Colwell, 1982). Isolated coralline algae accumulations occur in some areas of seabed (Shepherd and Sprigg, 1976; Gostin et al., 1988), with *Lithothamnium*, *Jania* and *Corallina* being important species for carbonate sediment production (Gostin et al, 1984).

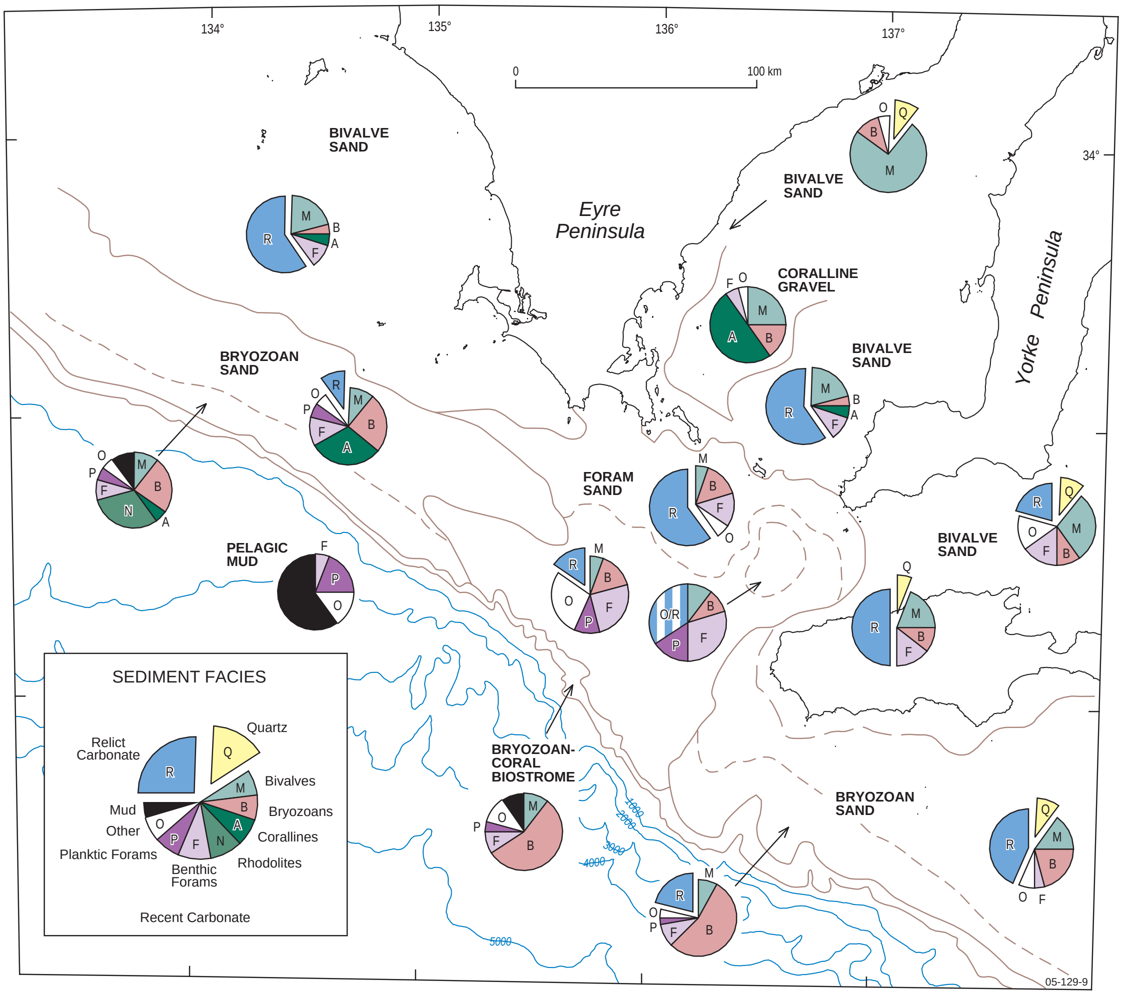

Figure 5.11. Surface sediment facies for southern Spencer Gulf and Gulf of St. Vincent, Investigator Strait and Lincoln Shelf (modified from James et al., 1997). Facies types are labelled and pie charts show the proportion of sediment components. Sediments on the inner shelf contain abundant bivalves, with bryozoans dominating outer shelf sediments. Arrows point to sample sites of corresponding pie charts.

Seagrass meadows are extensive in Spencer Gulf, Gulf St. Vincent and Investigator Strait, and support one of the largest temperate ecosystems of its kind on earth (SARDI, 2001). Figure 5.12 shows the distribution of seagrasses and other benthic communities in Gulf St. Vincent. Seagrasses occur on shallow platforms and banks in northern Spencer Gulf, and border Gulf St. Vincent in water depths of <10 m (Shepherd and Sprigg, 1976; Gostin et al., 1984a; Shepherd and Hails, 1984; Gostin et al., 1988). The distribution of seagrass communities is strongly influenced by light penetration to the seabed, water depth, currents, temperature and salinity (Shepherd, 1983). Seagrass meadows occur with sandwaves and other irregularities on the seabed, as they grow where current speeds are reduced and the settlement and accumulation of skeletal carbonate particles is enhanced (Hails et al., 1980; Shepherd, 1983; Gostin et al., 1984a). Overall, *Posidonia australis* forms the most abundant seagrass community in the gulfs, with several other common species present (e.g., *Amphibolis antarctica*, *Heterozostera tasmanica* and *Halophila ovalis*; Shepherd and Sprigg, 1976; Shepherd, 1983). Seagrasses support coralline algae, foraminifera, diatoms, bryozoans and sponges, all of which attach to seagrass leaves (Burne and Colwell, 1982; Cann et al., 2000).

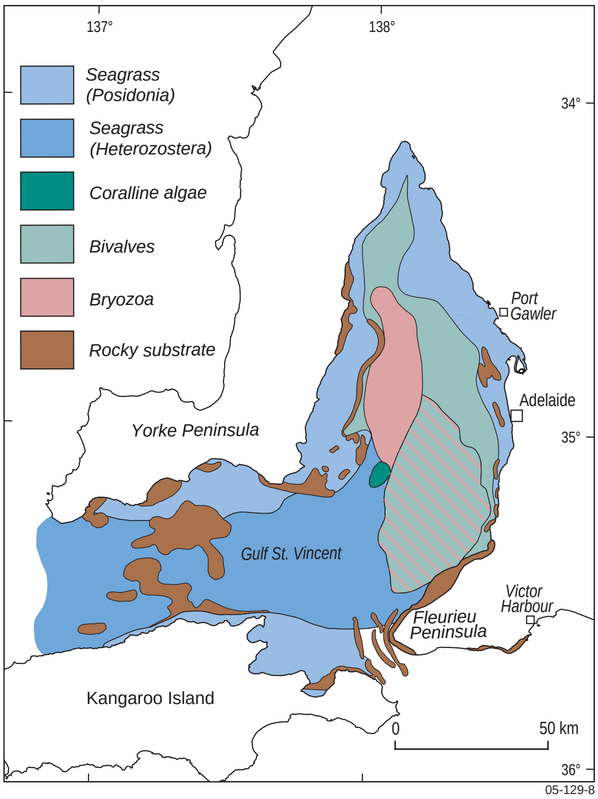

Figure 5.12. Map showing the distribution of benthic communities in Gulf St. Vincent (modified from Gostin et al., 1988), with emphasis on the distribution of seagrass (highlighted in shades of blue). *Posidonia* sp. dominate the shallow-water gulf margins and *Heterozostera* sp. grow in central deep water regions.

5.5. Acoustic Facies

Echo-type classification in the Spencer and St. Vincent Gulfs region is limited due to patchy data coverage. In 2001 a single seabed echo-type was determined from shallow seismic profiles collected from the Gulf St. Vincent and Backstairs Passage as part of Geoscience Australia Rig Seismic survey 89 in southeastern Australia (Fig. 5.13) (Butler et al., 2001). Geoscience Australia utilized Damuth's (1980) scheme to classify data from the region. Echo-types were interpreted from 12 kHz data echo-sounding profiles. Due to the restricted coverage of the survey and the frequency of the echo-sounder, only echo type: IA (i.e., sharp, continuous with no sub-bottom reflectors; see Appendix A) was observed. This echo type has been ground-truthed with 13 surface sediment samples. The surface sediment is described as ranging from calcareous sand to quartz sand. However ground-truthing for this echo-type against sediment data requires further verification through analysis of sediment mineralogy. The acoustic interpretation for this study area was given a confidence rating of 3 on a scale of 1 to 4, determined primarily from echo-sounder frequency (M. Fellows pers. comm., 2005).

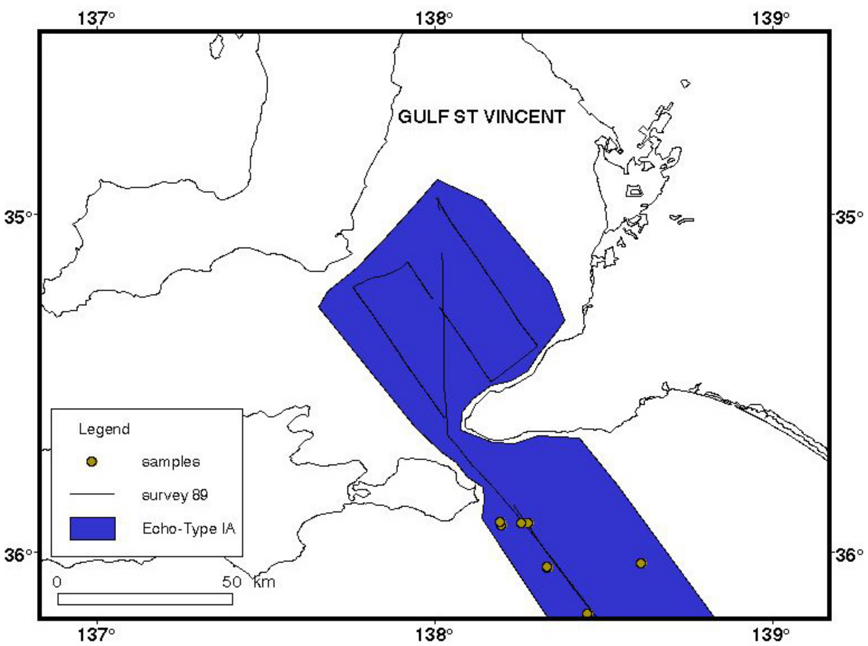

Figure 5.13. Map showing the distribution of acoustic facies for Gulf St. Vincent and Backstairs Passage. Locations of surface sediment samples and ship track are also shown for reference. It is likely that this echo-type extends to other regions of Gulf St. Vincent, but more shallow seismic data is required.

A general interpretation of seabed character is gained from incomplete shallow seismic data from the northern Spencer Gulf. Based on shallow seismic profiles from Gostin et al. (1984), sub-bottom reflectors show an almost uniform coverage of modern surficial sediments in a 0.5-2 m thick drape over Quaternary sediments (Fig. 5.14; Gostin et al., 1984b). The upper reflector is generally distinct, continuous and of irregular morphology. Morphological features include a scoured channel floor, large and small megaripples (i.e., sandwaves), and seagrass banks (Gostin et al, 1984). Megaripple fields are common in the far north of Spencer Gulf (Shepherd and Hails, 1984).

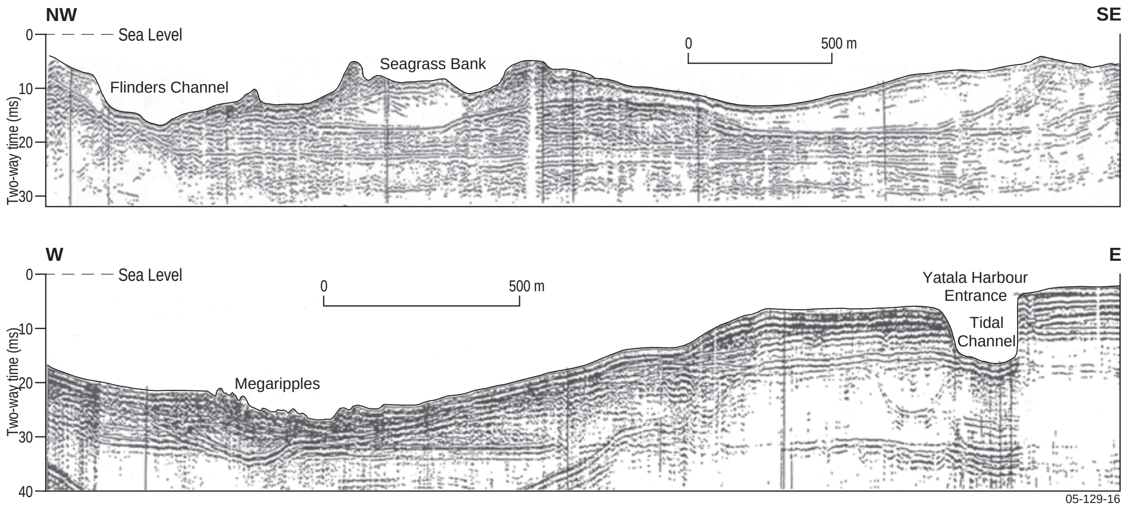

Figure 5.14. Shallow seismic profiles from northern Spencer Gulf showing the variable morphology and type of sub-bottom reflectors that characterise the seabed (modified from Gostin et al., 1984b).

5.6. Late Quaternary Evolution

Fluctuations in sea level over the last 125 ka are recorded in geomorphic structures and sediment facies distributions in Spencer Gulf and Gulf St. Vincent (Murray-Wallace and Belperio, 1991; Bryant, 1992). Based on the Quaternary stratigraphy of Spencer Gulf, each successive Quaternary marine inundation resulted in the establishment of ephemeral lakes and the formation of beach ridges, aeolian sand dunes and distal alluvial fans (Gostin et al., 1984b). Past sea level fluctuations are recognised from elevated offshore bars and exposed shingle ridges (Belperio et al., 1984), seafloor strand line deposits (Fuller et al., 1994), and facies boundaries such as seagrass (Belperio et al., 1984) and mangroves (Belperio, 1993).

When sea level was below -50 m, such as during the last glacial (~20 ka) when sea level was at least 120 m below present (Chappell and Shackleton, 1986), both gulfs would have been cut off from the ocean, being either subaerially exposed or covered with shallow water (Fuller et al., 1994). Quaternary *Posidonia* sp. seagrass facies and relict Pleistocene foraminifera species found in Spencer Gulf suggest that the area was covered in shallow water rather than being subaerially exposed during these times (Belperio et al., 1984; Li et al., 1998). The northern areas of each gulf would have been exposed or isolated during most of the Late Quaternary due to their shallow depths. Figure 5.15(b2) shows sea level through time and highlights when sea level was higher than the depth of northern Spencer Gulf (-25 m). In comparison, the gulfs had greater lateral extents during the last interglacial period as sea level was at least 1 m higher than today (Hails et al., 1984a). Figure 5.15 illustrates the Quaternary formations in northern Spencer Gulf (a), with the timing of these deposits matched with changes in sea level through time (b1) (Hails et al., 1984a).

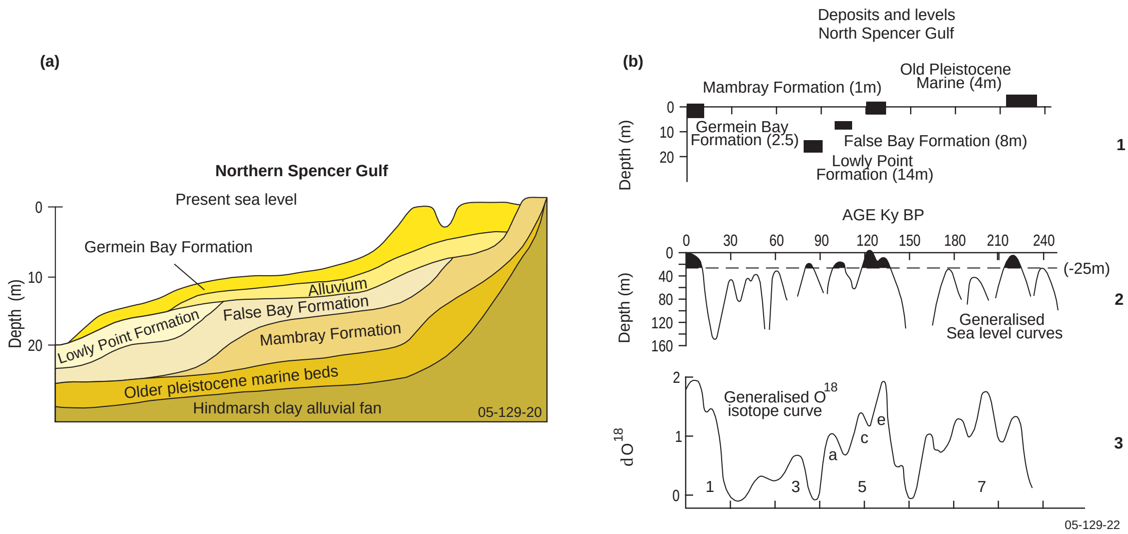

Figure 5.15. Quaternary formations in northern Spencer Gulf (a), with the timing of each formation (b1) correlated to the times when northern Spencer Gulf was flooded (b2). The generalised isotope curve in relation to sea level fluctuations is shown for reference (b3) (modified from Hails et al., 1984a).

Water temperatures in Spencer Gulf during the last interglacial are thought to have been warmer than today, due to the occurrence of the tropical foraminiferal species *Marginopora vertebralis* in Quaternary sediments. This tropical foraminifera does not exist in the modern gulf as conditions are unsuitable. The presence of this species implies that the Leeuwin Current or its equivalent was strong enough to reach as far east as the gulfs during the last interglacial (Cann and Clarke, 1993), and indicates that the warmer water influenced species diversity and therefore community structure in the gulfs.

Considerable work has been completed on Holocene relative sea level fluctuations in the gulfs. A rapid sea level rise to about +2 m above the present occurred between 11,000 years BP and 6,400 years BP (Fuller et al., 1994). As some seagrass species only grow in certain water depths, their occurrence in Quaternary sediments can be used as sea level indicators. These seagrass indicators, in conjunction with the commencement of shallow marine sedimentation in the gulfs, suggest that both Spencer Gulf and Gulf St. Vincent were flooded between 7,000 and 8,000 years BP. Seagrass facies indicators also suggest that the Holocene sea level maximum of +2 m existed until at least 1,740 ± 170 years BP (Hails et al., 1984a; Belperio et al., 1984). The fall to present levels occurred sometime between 1,740 and 1,640 years BP and appears to be abrupt, which Belperio et al. (1984) suggest is the result of local tectonic uplift. After this fall, the wide intertidal and supratidal areas evolved on relict seagrass bank surfaces, with intertidal sedimentation becoming established at around 1,700 years BP. Mangrove and samphire colonisation was established at around 1,400 years BP and since then, very little sedimentation or progradation has occurred (Belperio et al., 1984). This indicates that environments in the gulfs have been relatively stable since this time.

6. Implications for Regional Marine Planning

Information on the geomorphology, sediment type and hydrodynamics of various habitats is important in the conservation of habitat diversity. The South Western Planning Area (SWPA) has a large geological gradient that ranges from shallow inner shelf environments to the deep abyssal plain. Distinct seabed features and sedimentary provinces such as inshore reefs and islands, the carbonate-dominated shelf, canyons, ridges and troughs, a well developed continental rise, and large areas of abyssal plain all potentially provide areas for unique habitats.

The SWPA also has a large environmental gradient and therefore the potential for a range of habitat types. The western coast has a longitude-parallel shelf with a gradient from sub-tropical to warm-temperate environments, adjacent to an onshore area with Mediterranean climate. In comparison, the southern coast is a latitude-parallel shelf with warm temperate environments on the inner shelf and cool-temperate environments on the outer shelf, adjacent to an arid-climate hinterland. These physiographic and climatic regimes result in a range of potential habitat areas in the marine environment. This chapter outlines some examples of how the information in this report can be applied to regional marine planning, in particular habitat mapping and the relationships between sediments and biota.

6.1. HABITAT MAPPING

The Houtman Abrolhos Islands support a mixed habitat of tropical and temperate species due to their latitudinal position and the supply of warm water from the southward flowing Leeuwin Current. Situated at 28-29°S, the islands form the most southerly coral reefs in the Indian Ocean, and support a unique community structure vastly different from their tropical reef counterparts. The environmental diversity and topographic complexity (such as 'blue-hole' terrain) of the reefs provides habitat for approximately 184 species of 42 coral genera (Veron and Marsh, 1988). Compared to other 'high-latitude' coral reefs (Hatcher, 1985), the number of genera present at the Houtman Abrolhos Islands is much higher. Calcium carbonate production and associated reef growth is not significantly different from tropical reefs (Kinsey, 1985).

The success of the reefs is attributed to the presence of the Leeuwin Current, and is therefore dependent on the strength or occurrence of the current through time (Collins et al., 1991). At the latitudinal limits of coral reef growth, minor decreases in sea surface temperature (e.g., from climate change and variations in Leeuwin Current activity) adversely affect coral reef growth and species diversity. In addition, the islands may also act as a refuge for corals during times of increased sea surface temperature due to their high latitude position. Therefore the Houtman Abrolhos Islands can provide insight into coral responses to climate change and may be important for the management of coral reefs in the face of rising global temperatures.

The Naturaliste Plateau is Australia's deepest temperate-water marginal plateau and forms an important environment for deepwater habitats. The plateau is isolated from the continental shelf and slope by the Naturaliste Trough and acts as an underwater 'biological island' on the edge of the abyssal plain, providing habitat for fauna unique to these depths (DEH, 2001). As the plateau is separate from the continental shelf and slope, it may contain biota that is biogeographically isolated from the mainland slope environments. It forms an isolated biogeographical province (Heap et al., in press) and may therefore encourage the evolution of endemic species (Boehlert and Genin, 1987; Gofas, 2002.; NOAA, 2003). Although the region is poorly understood, the complex and rugged topography is suitable for hosting a diverse fauna and provides a relatively untouched environment for benthic biota. Recognition, mapping and management of the habitats on the plateau would ensure that the deepwater benthos is preserved and the environmental condition is maintained. In October 2005, GA and DEH are conducting a survey to the northeast margin of the plateau to investigate benthic habitats in canyons, and to document the geological and biological transitions between shelf, slope and plateau seabed environments.

Deepwater terraces such as the Carnarvon Terrace, the Ceduna Terrace and the Eyre Terrace are extensive, generally flat structures situated in mid-depths (e.g., 500-3,000 m). Studies from other areas have found that biodiversity peaks at mid-slope depths (Rex, 1981; Paterson and Lambshead, 1995; Gage et al., 2000). These terraces are areas of net sediment deposition and would support different deepwater habitats than the adjacent continental slope where gradients are higher and mass movements are more common. The terraces are also situated in similar depths as the Naturaliste Plateau, yet deepwater habitats on the terraces would differ than those on the plateau as they are connected to the continental shelf and slope and receive more organic matter derived from the shelf. Differences in the hydrodynamics, levels of disturbance and availability of trophic resources would result in different habitat types on the terraces compared to those on the surrounding continental slope and the Naturaliste Plateau.

The Diamantina Zone is a unique, isolated and very deep water area of complex topography on the Australian margin and would potentially support a range of unique habitats for deepwater species. The area consists of ridges, troughs and seamounts with relief up to 4,000 m, with ultramafic basement rock outcropping on some areas of seabed. This complex area is expected to support a high diversity of endemic fauna, sustaining habitats similar to those occurring on and around the Tasmanian Seamounts in the South Eastern Marine Planning Area. Such complex topography results in highly variable environmental conditions, such as water depth, water temperature, trophic conditions and ocean current systems (Heinz et al., 2004). This range of environmental conditions may create distinctive community structures and have the potential to support a variety of unique habitat types. For example, exposed rocky substrate may support epibenthic invertebrates, whereas seabed covered in soft sediment may support sparse epibenthic communities and more abundant infaunal organisms. Likewise, topographic highs may sustain a complex community structure that ranges from phytoplankton to marine mammals (Greenpeace, 2005), whereas trenches and troughs may sustain a community structure dominated by benthic invertebrates (NOAA, 2005). Previous work in the South Eastern Planning Area and other regions show that seamounts and pinnacles are biologically highly productive with diverse species composition. They can create obstacles to current flow, resulting in the formation of eddies and circular currents, turbulent mixing and localised upwelling and downwelling. These physical processes may result in increased local primary and secondary productivity and the trapping of particles, nutrients or organisms (Simpson and Heydorn, 1965; Rogers, 1994; Heinz et al., 2004). This accumulation of particles and nutrients promotes phytoplankton growth, which in turn encourages a variety of marine life, such as whales and dolphins, fish species and benthic biota (Greenpeace, 2005). As with the Naturaliste Plateau, seamounts may act as isolated 'biological islands' on the abyssal plain (Boehlert and Genin, 1987; NOAA, 2003), or 'stepping stones' for species dispersal and migration (Wilson and Kaufman, 1987). Due to the similar environments, the Diamantina Zone should be considered in this context in regional marine planning due to its diverse geomorphology and oceanography and the potential for diverse habitats and endemic species.

The SWPA has some of the largest areas of abyssal plain on the Australian margin, and thus contains some of the most extensive deep benthic habitats. Very little is known about these habitats, their condition or the density and diversity of species present due to a lack of samples collected. These areas of abyssal plain may not have high diversity compared to shallow water environments (Gray et al., 1997; Gray, 2002), however large numbers of species have been found to coexist in deep-sea soft sediment (Hessler and Sanders, 1967). These areas may be important habitat areas due to their continuity and extent, and may provide habitat for rare or endemic species. They may also act as conduits or corridors for species migration between areas of high diversity (MBI, 2003; Gage, 2004) and should therefore be considered for management. The areas of abyssal plain in the SWPA are the final deposition areas of sediments and nutrients from the continental shelf and slope, and are at the base of the largest and most well-developed canyon system in Australia. Future research on deep water seabed sediments and the supply of sediments and nutrients to the deep ocean would provide information on the importance of the abyssal plain to habitats on and around it.

The SWPA is one of the most heavily canyonised areas on the Australian margin. Canyons can display higher secondary productivity and species diversity than surrounding slope areas of similar depth or distance offshore (Vetter et al., 1998; Gili et al., 1999; Hooker et al., 1999). They are pathways for transporting sediments, nutrients and biota off the continental shelf and slope and onto the abyssal plain, either acting as a sink for this relatively organic-rich material or directing it into deeper water

(Shepard, 1961). Canyons that have been recently active, distinguished by an incised floor, may support different habitats than canyons that are inactive. Canyons that are actively transporting material would provide a more dynamic sedimentary environment with higher seabed disturbance than more stable, inactive canyons, influencing the type of habitats they would sustain.

Canyons are also conduits for upwelling and downwelling, processes that influence environmental variables such as nutrient availability and water temperature. Upwelling of water from the deep ocean supplies nutrients to the continental shelf and slope, important for phytoplankton blooms and the production of local fisheries (Webb and Morris 1984; Pearce and Pattiaratchi, 1997). Gili et al. (1999) attributed the great density and diversity of benthic and pelagic fauna found in canyons along the Mediterranean coast to vertical circulation and up-canyon currents. Canyons can also form a link between habitats of different water depth. For example, individual canyons in the Albany group generally show a depth range of 200 to 4,000 m along their length, connecting a large range of depth-related habitat types.

The majority of canyons in the Albany group cut into the shelf or occur just off the shelf edge. These ‘cutting' or ‘incised' canyons are affected by different hydrodynamic and sedimentary processes than canyons with heads occurring further down slope, and would therefore support different habitats. Cutting canyons experience high sediment load from offshore transport and receive organic material sourced from productive shelf waters. The Perth Canyon is a major cutting canyon in the SWPA, and provides a link between continental shelf habitats and deep-water habitats. In contrast, ‘blind' canyons such as those on the Eyre and Ceduna Terraces, are not connected to the continental shelf. They would probably receive less sediment load and less organic matter (eg., Monaco et al, 1990), and would be less influenced by shelf processes and habitats. Blind canyons on the Eyre and Ceduna Terraces may act as conduits for deep water upwelling that may be important for whale feeding and calving grounds (DEH, 2001). The GA/DEH survey to the Naturaliste Plateau occurring in October 2005 will investigate benthic biota and habitats in ‘blind' and shelf-cutting canyons on the north eastern margin of the plateau and on the adjacent continental shelf, to develop an understanding of deep-water sedimentary processes and benthic habitats.

The density and distribution of canyons have implications for canyon habitats and the interactions between them. Broadly spaced canyons such as those on the GAB terraces may support unique habitats that have evolved in isolation (Gili et al., 1998, 1999), whereas canyons in the Albany Group and on the western margin are numerous and closely spaced, and may show some interconnectedness or exchange between them. It is possible that canyons spaced closely together would experience the same physical and sedimentary processes, resulting in similar canyon habitats. Also, numerous canyons would result in high amounts of organic matter reaching the abyssal plain. Therefore, biodiversity may be higher on the abyssal plain in regions of closely spaced canyons. Research into the relationships between canyon distribution and biota may provide insight into canyon habitats, which would be useful in the management of canyons that have bathymetry data but lack sedimentological, hydrodynamic and/or biological data.

The SWPA contains the most extensive area of continental rise on the Australian margin, and should therefore be considered in regional marine planning. A well developed continental rise is present on both the western and southern margins. It is most extensive adjacent to heavily canyonised areas, such as south of the Albany Canyons and offshore of the Perth Canyon, as a result of high sediment loads being transported by the canyons onto the abyssal plain. The continental rise probably formed during rifting of Australia from India and Antarctica during the Cretaceous and is likely to be inactive at present. Therefore the rise would provide a stable environment for deep water benthos.

The world's largest modern cool-water carbonate province extends across Australia's southern margin, with the most extensive area occurring in the GAB. The carbonate province is an iconic feature both on the Australian margin and in the world. Geomorphology, sedimentology and hydrodynamics interact to create ideal conditions for cool-water carbonate production. The broad latitude-parallel shelf of the GAB provides an extensive area of accommodation space for temperate carbonate-producing organisms. Little to no terrigenous sediment input from continental Australia allows carbonate organisms to flourish without being smothered or buried. As a result, carbonate sediments make up over 80% of shelf sediments (James et al., 2001). Hydrodynamically, seasonal upwelling across the GAB supplies nutrients from the deep ocean onto the shelf. This upwelling is proportional to the amount of carbonate production, and therefore regulates the carbonate factory (James et al., 1994, 2001). Due to the extent of Australia's cool-water carbonates, this region has been recognised for its global significance for cool-water carbonate habitats by numerous publications (e.g., James et al., 1994, 1997, 2001 and James, 1997, 2004), and it is has been used as a type-case example for shallow cool-water environments seen in the rock record.

The continental shelf provides an extensive habitat for carbonate-producing biota on the inner shelf (<50 m) and outer shelf (120-170 m). Along the southern margin the shelf supports some of the highest levels of biodiversity for seaweeds, seagrasses, bryozoans and ascidians in the world, with approximately 85-90% of shelf biota endemic to the region. This is due to the area's tectonic stability, its isolation from other temperate regions in the world, and its unique combination of geomorphology, sedimentology and oceanography (SARDI, 2001; James et al., 1994). Overall, the shelf has a high physical energy, and variable seabed morphology creates both stable and unstable benthic environments that support a range of seabed habitats. For example, submerged ridges on the Rottnest Shelf provide habitat for algal hardgrounds and a high diversity of foraminifera (James et al., 1999); headlands and bays along the southern coast, such as Cape Pasley, Israelite Bay and Streaky Bay, create low energy settings which provide a sheltered sedimentary environment for seagrass colonisation, and high energy; and open areas such as the GAB shelf provide exposed substrate for epibenthic organisms to attach to. Seagrass meadows in sheltered settings such as Cockburn Sound provide habitats for encrusting foraminifers and coralline algae which live attached to seagrass leaves, and for bivalves and gastropods which live in surrounding sediment. Exposed environments along the Recherché and GAB shelves have high sediment mobility and therefore are less likely to support extensive benthic habitats. On the GAB middle to outer shelf (50-170 m), exposed limestone substrate is interspersed with patches of mobile sediment that are intermittently reworked by storm waves. Outcropping substrate is a result of the unique GAB 'shaved shelf' environment and forms an important environment for epibenthic communities such as bryozoans, sponges and coralline algae. The extent and depth range of the continental shelf in the GAB also allows for abundant growth of such communities on the outer shelf and upper slope, due to high levels of upwelling and a deeper, less energetic environment. Such diverse continental shelf habitats warrant consideration in regional marine planning.

Spencer Gulf and Gulf St. Vincent are some of the largest marine incursions into continental Australia. Shallow water depths, a high tidal range and highly saline waters support unique benthic habitats. The combination of shallow depths and a high tidal range in the northern areas of each gulf have resulted in extensive subtidal and supratidal environments that support some of the largest areas of temperate seagrasses, mangroves and saltmarshes in Australia. Furthermore, the gulfs support one of the largest temperate seagrass ecosystems on Earth (SARDI, 2001). Both Spencer Gulf and Gulf St. Vincent have restricted interaction with the open ocean, and gulf waters and sediments have long residence times in the gulfs. This has implications for the occurrence and subsequent removal of pollutants in gulf waters, sourced from industrial ports and population centers such as Port Pirie and Adelaide. The gulfs should be considered in regional marine planning for their important subtidal seagrass populations and the susceptibility of benthic habitats to pollutants.

6.2. SEDIMENT AND BIOTA RELATIONSHIPS

Much of our understanding of the relationship between sediments and biota in the SWPA is from benthic environments on the continental shelf. Sparse data are available for deep water benthos, whereas shelf areas have been surveyed and studied in detail, providing scientists with a more comprehensive understanding of these seabed areas.

Rhodolith gravel beds on the northern Rottnest Shelf and in the western GAB (Table. 4.2) form a pavement of living rhodolites (i.e., algae nodules) in water depths

~35-55 m (Collins, 1988; James et al., 2001). Although the distribution of living rhodolith beds on the Rottnest Shelf is influenced by water movement and bioturbation, the beds are generally associated with a thin sandy carbonate sediment substrate and are unlikely to develop in sites of rapid sediment accumulation or on thick sandy deposits (Foster, 2001). In the vicinity of the Abrolhos platforms, rhodoliths form on carbonate sands that contain up to 10% coral fragments (James et al., 1999). In the western GAB, rhodoliths are found on carbonate sands that consist of skeletal mollusc and coralline algae fragments with a component of mud. Importantly, rhodolith nodules have very slow growth rates and form a benthic community that supports red, green and brown macroalgae, epifaunal bivalves (e.g., *Arca*), oysters (e.g., *Malleus*) and other invertebrates (Foster, 2001; James et al., 2001).

On the GAB shelf the distribution of epibenthic biota varies as a result of substrate type; however biotic abundances are also closely related to upwelling (James et al., 1994). Seabed observations indicate that bryozoans and sponges are more abundant on hard substrates than on soft sediment substrates. Rocky substrates of Tertiary or Pleistocene limestone that are not covered in sediment contain higher abundances of attached bryozoans and sponges and other sessile benthic invertebrates. Rippled, sandy soft sediments contain almost no epibenthos. Deep water environments could also contain similar epibenthic distribution patterns. In water depths of <60 m, seabed abrasion influences epibenthic distribution patterns. Available hard substrates for bryozoan and sponge colonization is reduced by the continual deposition of skeletal carbonate sediment, which produces 'islands' of epibenthic communities surrounded by sediment (James et al., 2001). In addition, some epibenthic bryozoans dwell on ephemeral substrates; they live attached to sessile, benthic invertebrate hosts (Hageman et al., 2000).

Molluscs are an abundant benthic community within inner shelf surficial sediments across the SWPA. Although mollusc distributions show correlation with water depth, bivalves and gastropods are commonly associated with clean, well-sorted sands or coarse gravels on the Rottnest Shelf, Recherché Shelf, GAB shelf and in the gulfs. Bivalve species diversity and abundance show a positive correlation with sandy carbonate sediments in these regions, which are frequently inhabited by sparse vagrant populations. Bivalve faunal abundances of >80% have been recorded in coarse to medium grained carbonate sediment landward of the Abrolhos reefs [where their distribution is not restricted by water depth] (James et al., 1999). At 35-60 m water depth, *Placamen*, *Venus*, *Circe*, *Tellina* sp. and *Glycymeris* sp. are common and gastropods are less abundant (Collins et al., 1997). In Spencer Gulf, shallow subtidal and intertidal infaunal bivalves dominate samples, with a change in species dominance from *Spisula trigonella* to *Bittium granarium* as intertidal inundation decreases on the gulf margins (Burne and Colwell, 1982; Fuller et al., 1994).

The distribution of seagrass is closely related to sediment grain size and the amount of sediment sorting. Although water depth influences seagrass distribution, seagrasses are associated with poorly sorted sandy and muddy organic-rich sediments. For example *Posidonia* species prefer sandy substrates and *Amphibolus* species favour muddier substrates (James et al., 1999). In Cockburn Sound, seagrasses grow on a substrate of poorly sorted sand with varying proportions of shell gravel composed of whole shells and shell fragments (Skene et al., 2005). Seagrass meadows in Spencer Gulf have a positive correlation with very poorly sorted muddy carbonate sands, which occur in sandwave troughs and on the gently sloping gulf margins (Gostin et al., 1988). These sediments are rich in mollusc shell fragments of variable size (i.e., *Circe rivularis*, *Dosinia victoriae* and *Glycymeris striatularis*), and fragments of bryozoans, coralline algae and foraminifers (Burne and Colwell, 1982). Sand and shell fragments become bound by seagrass root systems and form a poorly sorted sediment mat. Given the association of seagrasses with shallow water depths and poorly sorted sandy substrates, nearshore regions with these substrates (e.g., protected embayments such as Cockburn Sound, Spencer Gulf and Gulf St. Vincent) could provide suitable sites for seagrass colonisation and associated biota.

In Spencer Gulf and Gulf St. Vincent, there is a close relationship between the distribution patterns of sediments, benthic fauna and water depth. Benthic environments have a continuous sediment-biota zonation from subtidal to supratidal settings. There is a transition from muddy, fine carbonate sands in water depths of >30 m to skeletal carbonate and terrigenous sands in intertidal areas (Gostin et al., 1988). Fauna in the low intertidal zone include molluscs, crustaceans and polychaete infauna, with gastropods, foraminifera and small quantities of bivalves occurring on the high intertidal zone. Muddy sediments in intertidal benthic environments contain abundant gastropods and support mangroves and cyanobacterial mats (Gostin et al., 1988). Landward of the intertidal zone is an extensive supratidal zone of bare carbonate and gypsiferous flats, devoid of biota except for halophytic grasses (Burne and Colwell, 1982). The zonation of seabed sediments and biota is the result of a specific set of environmental conditions, dominated by salinity and a broad tidal range. The close interaction between sediments and biota in these benthic environments requires consideration, due to the potentially negative effects of heavy metal contamination (Ward and Young, 1984).

6.3. SUMMARY

In support of the major objectives of Australia's Oceans Policy, this report has provided geoscience information to aid in the management of Australia's ocean resources. As a complete inventory of all biota on the seabed is not feasible to obtain, geoscience data will always be an integral part of the management of these ocean resources. It is possible to map geomorphology and sediment type relatively easily, and consequently use the data as a surrogate to infer biodiversity and habitat types on the seabed. Using geomorphic and sedimentary information to determine the distribution, abundance and nature of seabed habitats enables environmental managers to recognise representative regions that may require consideration – including candidate areas for marine protected areas – as well as allowing quantitative comparisons to be made between regions that can be incorporated into management strategies. In addition, historical information that can be readily inferred from surface and subsurface sediments and biota is needed to quantify the temporal and spatial stability of habitats. This assessment of habitat stability is essential for future planning decisions, as management strategies need to account for the differences between habitats that evolve quickly and those that evolve more slowly.

One of the most significant issues associated with Regional Marine Planning is understanding the relationship(s) between geomorphology and sediment/substrate type with biota. While significant progress is beginning to be made in this emerging science area, particularly in the area of "seascape" maps, further research into the nature of these relationships is needed to improve our understanding of the complex interactions that characterise seabed environments, and should be a high priority for government agencies, universities and other research organisations. Expanding and enhancing national databases containing baseline geological and biological data for Australia's oceans to support this surrogacy research must also be a high priority.

7. References

Alley, N.F. and Lindsay, J.M., 1995. Tertiary: Pirie Basin. *In:* Drexel, J.F. and Preiss W.V. (Eds.), *The Geology of South Australia, Volume 2: The Phanerozoic, Geological Survey of South Australia, Bulletin*, 54, 175-178.

Barnett, E.J., Harvey, N., Belperio, A.P. and Bourman, R.P., 1997. Sea-level indicators from a Holocene, tide-dominated coastal succession, Port Pirie, South Australia. *Transactions of the Royal Society of South Australia*, 121 (4), 125-135.

Baxter, K.J., 2003. Broad scale classification and prediction of marine habitats: integrating GIS and rule based modelling. *In:* Woodroffe, C.D. and Furness, R.A. (Eds.), *Coastal GIS 2003: an integrated approach to Australian coastal issues*, Proceedings, 7-8 July 2003. *Wollongong Papers on Maritime Policy*, 14, 125-137.

Belperio, A.P., 1993. Land subsidence and sea level rise in the Port Adelaide estuary: implications for monitoring the greenhouse effect. *Australian Journal of Earth Sciences*, 40, 359-368.

Belperio, A.P., 1995. Quaternary: Coastal and marine sequences. *In:* Drexel, J.F. and Preiss, W.V. (Eds.), *The Geology of South Australia, Volume 2: The Phanerozoic*. *Geol. Surv. S. Aust. Bull*, 54, 220-240.

Belperio, A.P., Hails, J.R., Gostin, V.A. and Polach, H.A., 1984. The stratigraphy of coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, South Australia. *Marine Geology*, 61 (2-4), 297-313.

Benbow, M.C., Alley, N.F. and Lindsay, J.M., 1995. Tertiary: Introduction. *In:* Drexel, J.F. and Preiss W.V. (Eds.), *The Geology of South Australia. Volume 2: The Phanerozoic*. *Geological Survey of South Australia, Bulletin*, 54, pp151.

Betjeman, K.J., 1969. Recent Foraminifera from the western continental shelf of Western Australia. *Contrib. Cushman Found. for Foraminiferal Research*, 20, 119-138.

Blevin, J.E. (Ed.), 2005. Geological framework of the Bremer and Denmark sub-basins, southwest Australia, R/V *Southern Surveyor* Survey SS03/2004, Geoscience Australia Survey 265, post-survey report and GIS. Geoscience Australia, Record 2005/05.

Boehlert, G.W. and Genin, A., 1987. A review of the effects of seamounts on biological processes. *In:* Keating, B., Fryer, P., Batiza, R. and Boehlert, G. (Eds.), Seamounts, islands and atolls. *Geophys. Monograph*, 43, 319-334.

Bone, Y., Clarke, J. and James, N.P., 1994. Carbonate sediments of Woody Island, Esperance region, Western Australia. *Abstracts - Geological Society of Australia*, 37, 34.

Bone, Y. and James, N.P., 2002. Bryozoans from Pleistocene high-energy, cool-water, continental-slope mounds, Great Australian Bight, southern Australia. *Abstracts - Geological Society of Australia*, 67, 352.

Borissova, I., 2002. *Geological framework of the Naturaliste Plateau*. Geoscience Australia, Record 2002/20.

Borissova, I., Colwell, J. and Stagg, H., 2004. Naturaliste Plateau, southwestern Australia; a relic of Indian-Antarctic-Australian breakup. *In:* McPhie, J. and McGoldrick, P. (Eds.), *Dynamic Earth; Past, Present and Future*. *Abstracts - Geological Society of Australia*, pp 198.

Bowers, D.G. and Lennon, G.W., 1987. Observations of stratified flow over a bottom gradient in a coastal sea. *Continental Shelf Research*, 7, 1105-1121.

Bradshaw, B., Rollet, N., Totterdell, J. and Borissova, I., 2003. A revised structural framework for frontier petroleum basins on the southern and southwestern Australian continental margin. *APPEA Journal*, 43 (1), 819.

Brown, K. M., Bone, Y. and James, N. P., 1998. Calcareous epiphytes; their significance as carbonate producers. *Abstracts - Geological Society of Australia*, 49, pp 55.

Brown, B.J., Muller, R.D. and Struckmeyer, H.I.M., 2001. Anomalous Tectonic Subsidence of the Southern Australian Passive Margin: Response to Cretaceous Dynamic Topography or Differential Lithospheric Stretching? *PESA Eastern Australasian Basins Symposium*, 563-570.

Brown, B.J., Muller, R.D., Gaina, C., Struckmeyer, H.I.M., Stagg, H.M.J. and Symonds, P.A., 2003. Formation and evolution of Australian passive margins: implications for locating the boundary between continental and oceanic crust. *Geol. Soc. Australia Spec. Publ. 22 and Geol. Soc. America Spec. Pap. 372*, 223-243.

Bryant, E., 1992. Last interglacial and Holocene trends in sea-level maxima around Australia: Implications for modern rates. *Marine Geology*, 108, 209-217.

Bullock, D.A., 1975. The general water circulation of Spencer Gulf, South Australia, in the period February to May. *Transactions of the Royal Society of Australia*, 99, 43-53.

Burckle, L. H., Saito, T., and Ewing, M., 1967. A Cretaceous (Turonian) core from the Naturaliste Plateau southeast Indian Ocean. *Deep Sea Research and Oceanographic Abstracts,* 14 (4), 421-422.

Burne, R. V. and Colwell, B., 1982. Temperate carbonate sediments of northern Spencer Gulf, South Australia, a high salinity "foramol" province. *Sedimentology*, 29 (2), 223-238.

Butler, A., Harris P., Lyne, V., Heap, A., Passlow, V., Smith, R., 2001. *An Interim, Draft bioregionalisation for the continental slope and deeper waters of the South-East Marine Region of Australia*. Unpublished report.

Bye, J.A.T., 1971. Variability south of Australia. *Proceedings of the International Science Symposium*, Sydney, Australia, 119-135.

Bye, J.A.T., 1976. Physical oceanography of Gulf St. Vincent and Investigator Strait. *In:* Twidale, C.R., Tyler, M.J. and Webb, B.P. (Eds.), *Natural History of the Adelaide Region*. Royal Society of South Australia, Adelaide, 143-160.

Bye, J.A.T., 1981. Exchange processes for upper Spencer Gulf, South Australia. *Ibid*, 105, 59-66.

Bye, J.A.T., 1983. Physical oceanography. *In:* Tyler, M.J., Twidale, C.R., Ling, J.K. and Holmes, J.W. (Eds.), *Natural History of the South East*. Royal Society of South Australia.

Bye, J.A.T. and Harbison, P., 1991. Transfer of inland salts to the marine environment at the head of Spencer Gulf, South Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 84 (1-4), 357-368.

Bye, J.A.T. and Whitehead, J.A. Jr., 1975. A theoretical model of the flow in the mouth of Spencer Gulf, South Australia. *Estuarine and Coastal Marine Science*, 3 (4), 477-481.

Cann, J. H., Belperio. A. P., Gostin, V. A. and Rice, R. L., 1993. Contemporary benthic Foraminifera in Gulf St Vincent, South Australia, and a refined Late Pleistocene sea-level history. *Australian Journal of Earth Sciences*, 40, 197-211.

Cann, J.H., Belperio, A.P., and Murray-Wallace, C.V., 2000. Late Quaternary paleosealevels and paleoenvironments inferred from Foraminifera, northern Spencer Gulf, South Australia. *Journal of Foraminiferal Research*, 30 (1), 29-53.

Cann, J.H., Harvey, N., Barnett, E.J., Belperio, A.P., and Bourman, R.P., 2002. Foraminiferal biofacies, eco-succession and Holocene sea levels, Port Pirie, South Australia. *Marine Micropaleontology*, 44 (1-2), 31-55.

Cann, J. H. and Murray-Wallace, C. V., 1986. Holocene distribution and amino acid racemisation of the benthic foraminifer Massilina milleti, northern Spencer Gulf, South Australia. *Alcheringa*, 10 (1), 45-54.

Cann, J.H. and Clarke, J.D.A., 1993. The significance of Marginopora vertebralis (Foraminifera) in surficial sediments at Esperance, Western Australia, and in last interglacial sediments in northern Spencer Gulf, South Australia. *Marine Geology*, 111 (1-2), 171-187.

Carrigy, M.A., 1956. Continental shelf sediments of south-western Australia. Unpublished *M.Sc. Thesis*, University of Western Australia, 79 p.

Carrigy, M. A. and Fairbridge, R W., 1954. Recent sedimentation, physiography and structure of the continental shelves of Western Australia. *Journal of the Royal Society of Western Australia*, 38, 65-95.

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

Chatin, F., Robert, U., Montigny, R., and Whitechurch, H., 1998. La Zone Diamantine (Ocean Indien oriental), temoin de la separation entre l'Australie et l'Antarctique: arguments petrologique et geochimique. *C. R. Acad. Sci. Paris,* 326 (12), 839-845.

Collins, L.B., 1981. Post-glacial non-tropical shelf carbonate sedimentation of the Rottnest Shelf, Western Australia. Abstracts - Geological Society of Australia (No.3), pp 54.

Collins, L.B., 1986. Temperate skeletal carbonate sediments, Rottnest Shelf, Southwest Australia. *In: Sediments down-under; 12th international sedimentological congress;*

abstracts. Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, pp. 65.

Collins, L.B., 1988. Sediments and history of the Rottnest Shelf, southwest Australia: a swell-dominated, non-tropical carbonate margin. *Sedimentary Geology*, 60, 15-49.

Collins, L.B., Wyrwoll, K.-H. and France, R.E., 1991. The Abrolhos carbonate platforms: geological evolution and Leeuwin Current activity. *Journal of the Royal Society of Western Australia*, 74, 47-57.

Collins, L.B., Zhu, Z.R., Wyrwoll, K.-H., Hatcher, B.G., Playford, P.E., Eisenhauer, A., Chen, J.H., Wasserburg, G.J. and Bonani, G., 1993a. Holocene growth history of a reef complex on a cool-water carbonate margin: Easter Group of the Houtman Abrolhos, Eastern Indian Ocean. *Marine Geology*, 115, 29-46.

Collins, L.B., Zhu, Z.R., Wyrwoll, K.-H., Hatcher, B.G., Playford, P.E., Chen, J.H., Eisenhauer, A. and Wasserburg, G.J., 1993b. Late Quaternary evolution of coral reefs on a cool-water carbonate margin: the Abrolhos Carbonate Platforms, southwest Australia. *Marine Geology*, 110, 203-212.

Collins, L.B., Zhu, Z.R. and Wyrwoll, K.H., 1996. The structure of the Easter Platform, Houtman Abrolhos Reefs: Pleistocene foundations and Holocene reef growth. *Marine Geology*, 135, 1-13.

Collins, L., Zhu, Z.R. and Wyrwoll, K.-H., 1997. Warm water platform and cool-water shelf carbonates of the Abrolhos Shelf, southwest Australia. *In:* James, N.P. and Clarke, J.A.D. (Eds.), *Cool-water carbonates.* SEPM (Society for Sedimentary Geology) special publication No.56, pp 23-36.

Collins, L.B., Zhu, Z.R. and Wyrwoll, K.H., 1998. Late Tertiary-Quaternary geological evolution of the Houtman Abrolhos carbonate platforms, northern Perth Basin. *In: The Sedimentary Basins of Western Australia 2*: Proceedings of the Petroleum Exploration Society of Austrialia, Symposium, 647-663.

Colwell, J.B. and Burne, R.V., 1978. *Drilling in the Spencer Gulf area of South Australia, February and March 1978.* Bureau of Mineral Resources, Geology and Geophysics (Department of National Resources), Record 1978/88.

Colwell, J. B., Symonds, P. A., and Crawford, A. J., 1994. The nature of the Wallaby (Cuvier) Plateau and other igneous provinces of the West Australian margin. AGSO Journal of Australian Geology and Geophysics, 15(1), 137-156.

Conolly, J.R. and von der Borch, C.C., 1967. Sedimentation and physiography of the sea floor south of Australia. *Sedimentary Geology*, 1, 181-220.

Cooper, B. J., 1985. The Cainozoic St. Vincent Basin; tectonics, structure, stratigraphy. *Spec. Publ., S. Aust. Dept. Mines and Energy*, 5, 35-49.

Corlis, N.J., Veeh, H.H., Dighton, J.C. and Herczeg, A.L., 2003. Mixing and evaporation processes in an inverse estuary inferred from [Delta]H and [Delta]O. *Continental Shelf Research*, 23 (8), 835-846.

Cresswell, G.R., 1991. The Leeuwin Current - observations and recent models. *Journal of the Royal Society of Western Australia,* 74, 1-14.

Cresswell, G.R. and Golding T.J., 1980. Observations of a south-flowing current in the southeastern Indian Ocean. *Deep-Sea Research*, 27A, 449-466.

Cresswell, G.R. and Peterson, J.L., 1993. The Leeuwin Current south of Western Australia. *Australian Journal of Marine and Freshwater Research*, 44, 285-303.

Cresswell, G.R., Boland, F.M., Peterson, J.L. and Wells, G.S., 1989. Continental-shelf currents near the Abrolhos Islands, Western Australia. *Australian Journal of Marine and Freshwater Research*, 40(2), 113-128.

Damuth, J. E., 1980. Use of high-frequency (3.5 - 12 kHz) echograms in the study of near bottom sedimentation processes in the deep sea. *Marine Geology*, 38, 51-75.

Davies, H L, Clarke, J. D. A., Stagg, H. M. J., Shafik, S., McGowran, B., Alley, N. F. and Willcox, J. B., 1989. Maastrichtian and younger sediments from the Great Australian Bight. *Bureau of Mineral Resources, Geology and Geophysics*, Report 288.

DEH (Department of Environment and Heritage), 2001. *New Marine Areas to be Assessed for Conservation.* Media release by the Department of Environment and Heritage. Internet document from http://www.deh.gov.au/ (Direct link: http://www.deh.gov.au/minister/env/2001/mr26sep01.html), accessed 05/09/05.

de Silva Samarasinghe, J.R., 1989. Transient salt-wedges in a tidal gulf: a criterion for their formation. *Estuarine, Coastal and Shelf Science*, 28 (2), 129-148.

de Silva Samarasinghe, J.R., 1998. Revisiting Upper Gulf St. Vincent in South Australia: the Salt Balance and its Implications. *Estuarine, Coastal and Shelf Science*, 46 (1), 51-63.

de Silva Samarasinghe, J.R., Bode, L. and Mason, L.B., 2003. Modelled response of Gulf St. Vincent (South Australia) to evaporation, heating and winds. *Continental Shelf Research*, 23 (14-15), 1285-1313.

de Silvia Samarasinghe, J.R. and Lennon, G.W., 1987. Hypersalinity, flushing and transient salt-wedges in a tidal gulf - an inverse estuary. *Estuarine Coastal and Shelf Science*, 24 (4), 483-498.

Everall Consulting, 1999. *Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherche Archipelago: draft aquaculture plan for the Recherche Archipelago, Western Australia*. Fisheries W.A., Perth, pp 49 and maps.

Exon, N., Blevin, J., Hocking, R., Heap, A., Taylor, B., Burch, G., Mitchell, C. and O'Leary, R., 2004. Geological framework of the Bremer and Denmark Sub-basins, southwest Australia: RV *Southern Surveyor* Cruise SS03/2004 (Geoscience Australia Cruise 265). *National Facility Oceanographic Research Vessel Cruise Summary, RV Southern Surveyor*, SS3/2004, 20 p., (http://www.marine.csiro.au/nationalfacility/voyagedocs/2004/sum_ss03_2004.pdf).

Exon, N. F. Hill P. J. Mitchell C. and Post A., 2005. Nature and origin of the submarine Albany canyons off southwest Australia, *Australian Journal of Earth Sciences*, 52, 101-115.

Fairbridge, R.W. and Serventy, V.N., 1954. Physiography. *In:* Fairbridge, R.W. and Serventy, V.N. (Eds.), *The Archipelago of the Recherché*, pp. 9-28.

Falvey, D.A. and Veevers, J.J., 1974. Physiography of the Exmouth and Scott Plateaus, Western Australia, and adjacent northeast Wharton Basin. *Marine Geology*, 17, 21-59.

Feary, D.A., et al., 1993. *Geological sampling in the Great Australian Bight: scientific post-cruise report - R/V RIG SEISMIC cruise 102*. Australian Geological Survey Organisation, Record 1993/18.

Feary, D.A et al., 2000. Leg 182 summary: Great Australian Bight Cenozoic cool-water carbonates. *Proceedings of the Ocean Drilling Program, Part A: Initial Reports*, pp 182.

Feary, D.A., Hine, A.C., James, N.P. and Malone, M.J., 2004. Leg 182 synthesis: Exposed secrets of the Great Australian Bight. *Proceedings of the Ocean Drilling Program: Scientific Results*, 182 (Spec. Iss.), 1-30.

Fellows, M., 2005. *Personal communication.*

Felton, E.A., Miyazaki, S., Dowling, L., Pain, L., Vuckovic, V. and le Poidevin, S.R., 1993. *Carnarvon Basin, W.A., Report 8*, Bureau of Resource Sciences, Canberra.

Foster, M.S., 2001. Rhodoliths: Between Rocks and Soft Places. *Journal of Phycology*, 37, 659-667.

Fuller, M.K., Bone Y., Gostin, V.A. and von der Borch, C.C., 1994. Holocene cool-water carbonate and terrigenous sediments from southern Spencer Gulf, South Australia. *Australian Journal of Earth Sciences*, 41 (4), 353-363.

Gage, J.D., Lamont, P.A., Kroeger, K., Paterson, G.L.J. and Vecino, J.L.G., 2000. Patterns in deep-sea macrobenthos at the continental margin: standing crop, diversity and faunal change on the continental slope off Scotland. *Hydrobiologia*, 440, 261-271

Gage, J.D., 2004. Diversity in deep-sea benthic macrofauna: the importance of local ecology, the larger scale, history and the Antarctic. *Deep-Sea Research II*, 51, 1689-1708.

Geoscience Australia, (2005). MARS - National Marine Sediments database (http://www.ga.gov.au/oracle/mars), Canberra, Geoscience Australia, accessed: 09/08/2005.

Gersbach, G.H., Pattiaratchi, C.B., Ivey, G.N. and Cresswell, G.R., 1999. Upwelling on the south-west coast of Australia: source of the Capes Current? *Continental Shelf Research*, 19, 363-400.

Gili, J.-M., Bouillon, J., Pages, F., Palanques, A. and Puig, P., 1999. Submarine canyons as habitats of prolific plankton populations: three new deep-sea Hydroidomedusae in the western Mediterranean. *Zoological Journal of the Linnean Society*, 125, 313-329.

Gili, J.-M., Bouillon, J., Pages, F., Palanques, A., Puig, P. and Heussner, S., 1998. Origin and biogeography of the deep-water Mediterranean Hydromedusae including the description of two new species collected in submarine canyons of Northwestern Mediterranean. *Scientia Marina*, 62 (1-2), 113-134.

Godfrey, J.S. and Ridgway, K., 1985. The large-scale environment of the poleward flowing Leeuwin Current, Western Australia: Longshore steric height gradients, wind stresses and geostrophic flow. *Journal of Physical Oceanography*, 15, 481-508.

Goldberg, N.A. and Kendrick, G.A., 2004. Effects of island groups, depth, and exposure to ocean waves on subtidal macroalgal assemblages in the Recherché Archipelago, Western Australia. *Journal of Phycology*, 40, 631-641.

Gofas, S., 2002. An Endemic Radiation of Trituba (Mollusca, Gastropoda) on the North Atlantic Seamounts. *American Malacological Bulletin*, 17 (1-2), 45-63.

Gostin, V.A., Hails, J.R., and Belperio, A.P., 1984a. The sedimentary framework of northern Spencer Gulf, South Australia. *Marine Geology*, 61 (2-4), 111-138.

Gostin, V.A., Sargent, G.E.G. and Hails, J.R., 1984b. Quaternary seismic stratigraphy of northern Spencer Gulf, South Australia. *Marine Geology*, 61 (2-4), 167-179.

Gostin, V.A., Belperio, A.P. and Cann, J.H., 1988. The Holocene non-tropical coastal and shelf carbonate province of southern Australia. *Sedimentary Geology*, 60, 51-70.

Gray, J.S., 2002. Species richness of marine soft sediments. *Marine Ecology Progress Series*, 244, 285-297.

Gray, J.S., Poore, G.C.B., Ugland, K.I., Wilson, R.S., Olsgard, F. and Johannessen, Ø., 1997. Coastal and deep-sea benthic diversities compared. *Marine Ecology Progress Series*, 159, 97-103.

Green, H.S., 1984. Fluid transport processes in Upper Spencer Gulf. *Marine Geology*, 61 (2-4), 181-195.

Greenpeace, 2005. *From the small islands to the deep-sea mountains: taking action to conserve deep sea biodiversity sustainable and equitably now and for the future*, Briefing Paper, 2005. Internet document from: http://www.savethehighseas.org/publicdocs/GP_SIDS_briefing.pdf, accessed 05/09/05.

Griffin, D.A., Thompson, P.A., Bax, N.J. and Bradford, R.W., 1997. The mass mortality of pilchard: no role found for physical or biological oceanographic factors in Australia. *Australian Journal of Marine and Freshwater Research*, 48, 27-42.

Hageman, S.J., James, N.P. and Bone, Y., 2000. Cool-water Carbonate Production from Epizoic Bryozoans on Ephemeral Substrates. *Palaios*, 15 (1), 33-48.

Hails, J.R., Gostin, V.A. and Sargent, G.E., 1980. The significance of the submarine geology of Upper Spencer Gulf, South Australia, to environmental decision-making. *Search*, 11 (4), 115-116.

Hails, J.R. and Gostin V.A. (Eds.), 1984. The Spencer Gulf Region. *Marine Geology*, 61, 111-424.

Hails, J.R., Belperio, A.P. and Gostin, V.A., 1984a. Quaternary sea levels, Northern Spencer Gulf, Australia. *Marine Geology*, 61 (2-4), 373-389.

Hails, J.R., Belperio, A.P., Gostin, V.A. and Sargent, G.E.G., 1984b. The submarine Quaternary stratigraphy of northern Spencer Gulf, South Australia. *Marine Geology*, 61 (2-4), 345-372.

Harris, L.B., 1994a. Structural and tectonic synthesis for the Perth Basin, Western Australia, *Journal of Petroleum Geology*, 17(2), 129-156.

Harris, P.T., 1994b. Comparison of tropical, carbonate and temperate, siliciclastic tidally dominated sedimentary deposits: examples from the Australian continental shelf. *Australian Journal of Earth Sciences*, 41, 241-254.

Harris, P.T., Baker, E.K. and Cole, A.R., 1991. *Physical sedimentology of the Australian continental shelf, with emphasis on Late Quaternary deposits in major shipping channels, port approaches and choke points.* Ocean Sciences Institute, University of Sydney, Report No. 51. 505pp.

Harris, P., Heap, A., Passlow, V., Sbaffi, L., Fellows, M., Porter-Smith, R., Buchanan, C. and Daniell, J., 2005. *Geomorphic Features of the Continental Margin of Australia*. Geoscience Australia, Record 2003/30.

Hatcher, B.G., 1985. Ecological research at the Houtman Abrolhos: high latitude reefs of Western Australia. *Proceedings of 5th International Coral Reef Symposium*, v.6, pp. 115-127.

Hatcher, B.G., 1991. Coral reefs in the Leeuwin Current—an ecological perspective. *Journal of the Royal Society of Western Australia*, 74, 115-127.

Heap, A., Daniell, J., Mazen, D., Harris, P., Sbaffi, L., Fellows, M. and Passlow, V., 2004. *Geomorphology and Sedimentology of the Northern Marine Planning Area of Australia: review and synthesis of relevant literature in support of Regional Marine Planning*. Geoscience Australia, Record 2004/11.

Heap, A.D., Harris, P.T., Last, P. and Lyne, V., 2005. *Benthic Bioregionalisation of the Australian Exclusive Economic Zone: Report to the National Oceans Office on the Development of a National Benthic Bioregionalisation in support of Regional Marine Planning.* Geoscience Australia, Record, in press.

Hegarty, K.A., Weissel., J.K. and Mutter. J.C., 1988. Subsidence history of Australia's southern margin; constraints on basin models. *AAPG Bulletin*, 72 (5), 615-633.

Heinz, P., Ruepp, D. and Hemleben, C., 2004. Benthic foraminifera assemblages at Great Meteor Seamount. *Marine Biology*, 144, 985-998.

Herzfeld, M., 1997. The annual cycle of sea surface temperature in the Great Australian Bight. *Progress in Oceanography*, 39 (1), 1-27.

Hessler, R.R. and Sanders, H.L., 1967. Faunal diversity in the deep-sea. *Deep-Sea Research*, 14, 65-78.

Hill, P.J., Rollet, N., Rowland, D., Calver, C. and Bathgate, J., 2000. *Seafloor mapping of the South-east Region and adjacent waters - AUSTREA-1 AGSO report: Lord Howe Island, south-east Australian margin and central Great Australian Bight*, Survey 222, AGSO Record 2000/6.

Hill, P., Rollet, N. and Symonds, P., 2001. *AUSTREA final report: Lord Howe Island, south-east Australian margin (includes Tasmanian and South Tasman Rise) and central Great Australian Bight*. AGSO, Record 2001/08.

Hill, P. and De Deckker, P., 2004. *AUSCAN Seafloor Mapping and Geological Sampling Survey on the Australian Southern Margin by RV* Marion Dufresne *in 2003*. Geoscience Australia, Record 2004/04.

Hine, A.C., Feary, D.A., Malone, M.J. et al., 1999. Research in Great Australian Bight yields exciting early results. *Eos, Transactions, American Geophysical Union*, 80 (44), 521, 525-526.

Hodgkin, E.P. and Phillips, B.F. 1969. Sea temperatures on the coast of south Western Australia. *Journal of the Royal Society of Western Australia*, 52, 59-62.

Hooker, S.K., Whitehead, H. and Gowans, S., 1999. Marine Protected Area Design and the Spatial and Temporal Distribution of Cetaceans in a Submarine Canyon. *Conservation Biology*, 13 (3), 592-602.

James, N.P., 1997. The cool-water carbonate depositional realm. *In:* James, N.P. and Clarke, J.A.D. (Eds.), *Cool-water carbonates.* SEPM (Society for Sedimentary Geology) special publication No.56, pp 1-20.

James, N.P., 2004. The oceanography of cool-water carbonates: southern Australia. *In:* Dynamic Earth; Past, Present and Future, *Abstracts - Geological Society of Australia*, 73, 236.

James, N.P. and von der Borch, C.C., 1991. Carbonate shelf edge off southern Australia: A prograding open-platform margin. *Geology*, 19, 1005-1008.

James, N.P., Bone, Y., von der Borch, C.C. and Gostin, V.A., 1992. Modern carbonates and terrigenous clastic sediments on a cool water, high energy, mid-latitude shelf: Lacepede, southern Australia. *Sedimentology*, 39, 877-903.

James, N.P., Boreen, T.D., Bone, Y. and Feary, D.A., 1994. Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. *Sedimentary Geology*, 90 (3-4), 161-177.

James, N.P., Bone, Y., Hageman, S.J., Feary, D.A. and Gostin, V.A., 1997. Cool-water carbonate sedimentation during the terminal Quaternary sea-level cycle: Lincoln Shelf, southern Australia. *In:* James, N.P. and Clarke, J.A.D. (Eds.), *Cool-water carbonates.* SEPM (Society for Sedimentary Geology) special publication No.56, pp 53-75.

James, N.P., Collins, L.B., Bone, Y. and Hallock, P., 1999. Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. *Journal of Sedimentary Research*, 69 (6), 1297-1321.

James, N.P., Feary, D.A., Surlyk, F., Simo, J.A.T. et al., 2000. Quaternary bryozoan reef mounds in cool-water, upper slope environments: Great Australian Bight. *Geology*, 28 (7), 647-650.

James, N.P., Bone, Y., Collins, L.B. and Kyser, T.K., 2001. Surficial sediments of the Great Australian Bight: Facies dynamics and oceanography on a vast cool-water carbonate shelf. *Journal of Sedimentary Research, Section B: Stratigraphy and Global Studies*, 71 (4), 549-567.

Jongsma, D. and Petkovic P., 1977. The structure of the Naturaliste Plateau and trough. *The APEA Journal*, Part 1 (17), 3-12.

Jongsma, D. and Johnston, C.R., 1993a. *Albany 1:1000000 scale offshore resource map*. Australian Geological Survey Organisation, Canberra.

Jongsma, D. and Johnston, C.R., 1993b. *Esperance 1:1000000 scale offshore resource map*. Australian Geological Survey Organisation, Canberra.

Kendrick, G.W., Wyrwoll, K.H. and Szabo, B.J., 1991. Pliocene-Pleistocene coastal events and history along the western margin of Australia. *Quaternary Science Reviews*, 10, 419-439.

Kennett, J.P., 1975. Neogene planktonic foraminiferal stratigraphy in deep-sea drilling sites, southeast Indian Ocean. *Initial Reports of Deep Sea Drilling Project 28*; Fremantle, Australia to Christchurch, New Zealand; Leg 28, 705-708.

Kinsey, D.W., 1985. Metabolism, calcification and carbon production I: system level studies. *Proceedings of 5th International Coral Reef Symposium*, v.4, 505-526.

Lee, S. and Bancroft, K.P., 2001. *Review of the existing ecological information for the proposed Recherché Archipelago marine conservation reserve.* Literature Review. MRI/WSA, EUC/SIN, RAR-51/2001. Marine Conservation Branch, CALM.

Legeckis, R. and Cresswell, G., 1981. Satellite observations of sea-surface temperature fronts off the coast of western and southern Australia. *Deep Sea Research Part A. Oceanographic Research Papers*, 28 (3), 297-306.

Lennon, G.W., Bowers, D., Nunes, R.A., Scott, B.D., Ali, M., Boyle, J., Wenju, C., Herzfeld, M., Johansson, G., Nield, S., Petrusevics, P., Stevenson, P., Suskin, A., Wijffles, S.E.A., 1987. Gravity currents and the release of salt from an inverse estuary. *Nature*, 327 (6124), 695-697.

Leonard, M., 2003. Small moves towards a big event in South Australia. *Aus Geo News*, 70, 4-5.

Li, Q. and McGowran, B., 1998. Oceanographic implications of recent planktonic foraminifera along the southern Australian margin. *Marine and Freshwater Research*, 49 (5), 439-445.

Li, Q., McGowran, B., James, N.P. and Bone, Y., 1996. Foraminiferal biofacies on the mid-latitude Lincoln Shelf, South Australia: oceanographic and sedimentological implications. *Marine Geology*, 129, 285-312.

Li, Q., James N.P., McGowran, B., Bone, Y. and Cann, J., 1998. Synergetic influence of water masses and Kangaroo Island barrier on foraminiferal distribution, Lincoln and Lacepede shelves, South Australia: A synthesis. *Alcheringa*, 22 (1-2), 153-176.

Li, Q., James, N.P., Bone, Y. and McGowran, B., 1999. Palaeoceanographic significance of Recent foraminiferal biofacies on the southern shelf of Western Australia; a preliminary study. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 147 (1-2), 101-120.

Maxwell, J.G.H. and Cresswell, G.R., 1981. Dispersal of tropical marine fauna to the Great Australian Bight by the Leeuwin Current. *Australian Journal of Marine and Freshwater Research*, 32, 493-500.

McGowran, B., Li, Q., Cann, J., Padley, D., McKirdy, D.M. and Shafik, S., 1997. Biogeographic impact of the Leeuwin Current in southern Australia since the late middle Eocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 136(1-4), 19-40.

Monaco, A., Biscaye, P., Soyer, J., Pocklington, R., Heussner, S., 1990. Particle fluxes and ecosystem response on a continental margin: the 1985-1988 Mediterranean ECOMARGE experiment. *Continental Shelf Research*, 10, 809-839.

Munschy, M., 1998. The Diamantina Zone as a result of rifting between Australia and Antarctica: Geophysical constraints: La zone de Diamantine, temoin de la separation de l'Australie et de l'Antarctique: arguments geophysiques. *C. R. Acad. Sci. Paris*, 327 (8), 533-540.

Murray-Wallace, C.V. and Belperio, A.P., 1991. The last interglacial shoreline in Australia - a review. *Quaternary Science Review*, 10, 441-461.

National Oceans Office, 2003. Oceans Policy: principles and process. Hobart, National Oceans Office. 28p.

Nicholls, I.A., Ferguson, J., Jones, H., Marks, G.P. and Mutter, J.C., 1981. Ultramafic blocks from the ocean floor southwest of Australia. *Earth and Planetary Science Letters*, 56, 362-374.

NOAA (National Oceanic and Atmospheric Administration), 2003. *Leg II - Reproductive Biology and Population Genetics of Precious Corals in the Hawaiian Archipelago.* Internet document from http://www.noaa.gov/ (Direct link: http://oceanexplorer.noaa.gov/explorations/03nwhi/missions/leg2_summary/leg2_summary.html), accessed 15/09/05.

NOAA (National Oceanic and Atmospheric Administration), 2005. *NOAA Ocean Explorer: Arctic Exploration*. Internet document from http://www.noaa.gov/ (Direct link: http://oceanexplorer.noaa.gov/explorations/02arctic/background/benthos/benthos.html), accessed 05/09/05.

Norvick, M.S., Smith M.A. and Anonymous, 2001. Mapping the plate tectonic reconstruction of southern and southeastern Australia and implications for petroleum systems. *2001 APPEA Conference*, 41 (1), pp 21.

Nunes, R.A. and Lennon, G.W., 1986. Physical Property Distributions and Seasonal Trends in Spencer Gulf, South Australia: an Inverse Estuary. *Australian Journal of Marine and Freshwater Research*, 37, 39-53.

Nunes, R.A. and Lennon, G.W., 1987. Episodic stratification and gravity currents in a marine environment of modulated turbulence. *Journal of Geophysical Research,* 92, 5464-5480.

Nunes Vaz, R.A., Lennon, G.W. and Bowers, D.G., 1990. Physical behaviour of a large, negative or inverse estuary. *Continental Shelf Research*, 10 (3), 277-304.

Passlow, V., Rogis, J., Hancock, A., Hemer, M., Glenn, K. and Habib, A., 2005. *Final Report: National Marine Sediments Database and Seafloor characteristics project.* Geoscience Australia, Record 2005/08.

Paterson, G.L.J. and Lambshead, P.J.D., 1995. Bathymetric patterns of polychaete diversity in the Rockall Trough, northeast Atlantic. *Deep-Sea Research I*, 42, 1199-1214.

Pattiaratchi, C.B. and Buchan, S.J., 1991. Implications of long term climate change for the Leeuwin Current. *Journal of the Royal Society of Western Australia*, 74, 133-140.

Pearce, A.F., 1991. Eastern boundary currents of the southern hemisphere. *In:* Pearce, A.F. and Walker, D.I. (Eds.), The Leeuwin Current. *Royal Society of Western Australia Journal*, 74, 35-46.

Pearce, A. and Pattiaratchi, C., 1997. Applications of satellite remote sensing to the marine environment in Western Australia. *Journal of the Royal Society of Western Australia*, 80, 1-14.

Pearce, A. and Pattiaratchi, C., 1999. The Capes Current: a summer countercurrent flowing past Cape Leeuwin and Cape Naturaliste, Western Australia. *Continental Shelf Research*, 19 (3), 401-420.

Petkovic, P., 1975. Origin of the Naturaliste Plateau. *Nature*, 253 (5486), 30-33.

Petrusevics, P.M., 1993. SST fronts in inverse estuaries, South Australia - indicators of reduced gulf-shelf exchange. *Australian Journal of Marine and Freshwater Research*, 44(2), 305-323.

Powell, C.McA., Roots, S.R. and Veevers, J.J., 1988. Pre-breakup continental extension in East Gondwanaland and the early opening of the eastern Indian Ocean. *Tectonophysics*, 155 (1-4), 261-283.

Preiss, W.V., 2000. The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction. *Precambrian Research*, 100 (1-3), 21-63.

Pritchard, D.W., 1952. Estuarine hydrography. *Advances in Geophysics*, 1, 243-280.

Pritchard, D.W., 1967. What is an Estuary: Physical Viewpoint. *In:* Lauff, G.H. (Ed.), *Estuaries*. The Horn-Shafer Company, US.

Provis, D.G. and Radok, R., 1979. Sea-level oscillations along the Australian coast. *Australian Journal of Marine and Freshwater Research*, 30, 295-301.

Rex, M.A., 1981. Community structure in the deep-sea benthos. *Annual Review of Ecology and Systematics*, 12, 331-353.

Ridgway, K.R. and Condie, S.A., 2004. The 5500-km-long boundary flow off western and southern Australia. *Journal of Geophysical Research C: Oceans*, 109 (4), C04017, 1-18.

Rogers, A.D., 1994. The biology of seamounts. *Advanced Marine Biology*, 30, 305-350.

Rollet, N., Fellows, M.E., Struckmeyer, H.I.M. and Bradshaw, B.E., 2001. *Seabed character mapping in the Great Australian Bight*. Geoscience Australia, Record 2001/42.

Royer, J.Y., Beslier, M.O., Hill, P.J. and MARGAU Scientific Party, 1999. Southwest Australian margin: evidence for mantle exhumation along a wide ocean-continent transition zone. *Abstract Volume, AGU 1999 Spring Meeting,* S321.

Ryan, D., Brooke, B., Collins, L., Baxter, K., Bickers, A. and Siwabessy, J., 2005. The influence of sediments and geomorphology on the distribution of benthic habitats on the Recherche Archipelago Inner Shelf, Western Australia. *In:* H. Hancock and G. Shields (Eds.), *Seventh Australian Marine Geoscience Conference (COGS) - Abstracts Volume*, 33pp.

Sanderson, P. G., Eliot, I., Hegge, B. and Maxwell, S., 2000. Regional variation of coastal morphology in southwestern Australia: a synthesis. *Geomorphology*, 34 (1-2), 73-88.

Sandiford, M., 2003. Neotectonics of southeastern Australia; linking the Quaternary faulting record with seismicity and in situ stress. *Special Paper - Geological Society of America*, 372, 107-119.

SARDI (South Australian Research and Development Institute), 2001. *South Australia's Marine Temperate Environment.* Internet document from http://www.sardi.sa.gov.au/ (Direct link: http://www.sardi.sa.gov.au/pages/aquatics/enviro_eco/ temperateenvironment.htm:sectID=784andtempID=34), accessed 01/09/05.

Sayers, J., Symonds, P.A., Direen, N.G. and Bernardel, G., 2001. Nature of the continent-ocean transition on the non-volcanic rifted margin of the Central Great Australian Bight. *Geological Society Special Publication*, 187, 51-76.

Sayers, J., Borissova, I., Ramsay, D. and Symonds, P.A., 2002. *Geological framework of the Wallaby Plateau and adjacent areas*. Geoscience Australia, Record 2002/21, 85pp.

Sayers, J., Bernardel, G. and Parumns, R., 2003. *Geological framework of the central Great Australian Bight and adjacent areas*. Geoscience Australia, Record 2003/12.

Searle, D.J. and Semeniuk, V., 1985. The natural sectors of the inner Rottnest Shelf coast adjoining the Swan Coastal Plain. *Journal of the Royal Society of Western Australia*, 67 (3-4), 116-136.

Semeniuk, V., 1996. An early Holocene record of rising sea level along a bathymetrically complex coast in southwestern Australia. *Marine Geology*, 131 (3-4), 177-193.

Shepard, F.P., 1961. Submarine canyons of the Gulf of California. *21st International Geological Congress*, Part 26, 11-23.

Shepherd, S.A., 1983. Benthic Communities of Upper Spencer Gulf, South Australia. *Transactions of the Royal Society of South Australia*, 107, 69-85.

Shepherd, S.A. and Hails, J.R., 1984. The dynamics of a megaripple field in northern Spencer Gulf, South Australia. *Marine Geology*, 61 (2-4), 249-263.

Shepherd, S.A. and Sprigg, R.C., 1976. Substrate, sediments and subtidal ecology of Gulf St. Vincent and Investigator Strait. *In:* Twidale, C.R, Tyler, M.J. and Webb, B.P. (Eds.), *Natural History of the Adelaide Region*. *Royal Society of South Australia*, 161-174.

Short, A.D. and Hesp, P., 1982. *Coastal engineering and morphodynamics assessment of the coast within the South East Coast Protection District, South Australia.* Coastal Protection Board, Adelaide, 234 pp.

Simpson, E.S.W. and Heydorn, A.E.F., 1965. Vema Seamount. *Nature*, 207, 249-251.

Skene, D., Ryan, D., Brooke, B., Smith, J. & Radke, L., 2005. The geomorphology and sediments of Cockburn Sound, *Geoscience Australia*, Record 2005/10, 90pp.

Smith, G.C. and Cowley, R.G., 1987. The tectono-stratigraphy and petroleum potential of the northern Abrolhos Sub-basin, Western Australia, *The APEA Journal*, 27, 112-136.

Smith, S.V. and Veeh, H.H., 1989. Mass balance of biogeochemically active materials (C, N, P) in a hypersaline gulf. *Estuarine, Coastal and Shelf Science*, 29 (3), 195-215.

Song, T. and Cawood, P.A., 2000. Structural styles in the Perth Basin associated with the Mesozoic break-up of Greater India and Australia. *Tectonophysics*, 317 (1-2), 55-72.

Stagg, H.M.J. and Exon, N.F., 1981. *Geology of the Scott Plateau and Rowley Terrace, off northwestern Australia.* Bureau of Mineral Resources, Bulletin, 213, 67pp.

Stagg, H.M.J. and Willcox, J.B., 1991. Structure and hydrocarbon potential of the Bremer Basin, southwest Australia. *Journal of Australian Geology and Geophysics*, 12, 327-337.

Stagg, H.M.J. and Willcox, J.B., 1992. A case for Australia-Antarctica separation in the Neocomian (ca. 125 Ma). *Tectonophysics*, 210 (1-2), 21-32.

Stagg, H.M.J. and Willcox, J.B., 1996. The Bremer Basin; evolution from regional tectonic considerations. *Abstracts - Geological Society of Australia*, 41, 417.

Stagg, H.H.J., Willcox, J.B., Symonds, P.A., O'Brien, G.W., Colwell, J.B., Hill, P.J., Lee, C.S., Moore, A.M.G. and Struckmeyer, H.I.M., 1999. Architecture and evolution of the Australian continental margin. *AGSO Journal of Australian Geology and Geophysics*, 17 (5-6), 17-33.

Stoian, L.M., 2002. Late Eocene-Early Oligocene sediments in KGD 01 drillhole, offshore Spencer Gulf, South Australia. *Department of Primary Industries and Resources S.A.*, Report Book, 2002/13, 4-7.

Stuart, W.J., 1970. The Cainozoic Stratigraphy of the Eastern coastal area of Yorke Peninsula, South Australia. *Transactions of the Royal Society of South Australia,* 94, 151-178.

Talwani, M., Mutter, J.C., Houtz, R.E., and König, M., 1978. The crustal structure and evolution of the area underlying the magnetic quiet zone on the margin south of Australia. *AAPG Mem.*, 29, 151-175.

Thompson, R.O.R.Y., 1984. Observations of the Leeuwin Current off Western Australia. *Journal of Physical Oceanography,* 14, 623-628.

Tikku, A.A. and Cande, S.C., 2000. On the fit of Broken Ridge and Kerguelen Plateau. *Earth and Planetary Science Letters*, 180, 117-132.

Totterdell, J.M., Blevin, J.E., Struckmeyer, H.I.M., Bradshaw, B.E., Colwell, J.B. and Kennard, J.M., 2000. A new sequence framework for the Great Australian Bight; starting with a clean slate. *APPEA Journal*, 40 (1), 95-117.

Totterdell, J.M. and Krassay, A.A., 2003. The role of shale deformation and growth faulting in the late Cretaceous evolution of the Bight Basin, offshore southern Australia. *Geological Society Special Publication*, 216, 429-442

MBI (Midwest Biodiversity Institute), 2003. *Trends in Biological Integrity, Biodiversity and Aquatic Habitat in the Eastern Corn Belt Plains Ecoregion: Implications for the protection and restoration of streams in the St. Joseph River.* Internet document: http://www.epa.gov/region5/water/wqb/presentations/exec_summary_tnc.pdf, accessed 05/09/05.

Valesini, F.J., Clarke, K.R., Eliot, I. and Potter, I.C., 2003. A user-friendly quantitative approach to classifying nearshore marine habitats along a heterogeneous coast. *Estuarine, Coastal and Shelf Science*, 57 (1-2), 163-177.

Veevers, J.J., 1982. Australian-Antarctic depression from the mid-ocean ridge to adjacent continents. *Nature*, 295, 315-317.

Veevers, J.J., 1986. Breakup of Australia and Antarctica estimated as mid- Cretaceous (95+ or -5 Ma) from magnetic and seismic data at the continental margin. *Earth and Planetary Science Letters*, 77 (1), 91-99.

Veevers, J.J., Stagg, H.M.J., Willcox, J.B. and Davies, H.L. 1990. Pattern of slow seafloor spreading (<4 mm/year) from breakup (96 Ma) to A20 (44.5 Ma) off the southern margin of Australia. *BMR Journal of Australian Geology and Geophysics*, 11 (4), 499-507.

Veron, J.E.N. and Marsh, L.M., 1988. Hermatypic corals of Western Australia: records and annotated species list. *Records of the Western Australian Museum*, Supplement No. 29, 136p.

Vetter, E.W. and Dayton, P.K., 1998. Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system. *Deep-Sea Research II*, 45, 25-54.

von der Borch, C.C., 1968. Southern Australian submarine canyons: Their distribution and ages. *Marine Geology,* 6 (4), 267-279.

Walker, D.I., 1991. The effect of sea temperature on seagrasses and algae on the Western Australia coastline. *Journal of the Royal Society of Western Australia*, 74, 71-77.

Ward, T.J. and Young, P.C., 1984. Effects of metals and sediment particle size on the species composition of the epifauna of Pinna bicolor near a lead smelter, Spencer Gulf, South Australia. *Estuarine, Coastal and Shelf Science*, 18 (1), 79-95.

Wass, R.E., Conolly, J.R. and Macintyre, R.J., 1970. Bryozoan carbonate sand continuous along southern Australia. *Marine Geology*, 9, 63-73.

Waters, C., 1982. Dynamics of Sedimentation in a shallow gulf. Flinders University of South Australia, PhD Thesis.

Webb, D.J. and Morris, R.J., 1984. DSDP Site 258: evidence for recent nutrient-rich upwelling off Western Australia. *Deep Sea Research Part A. Oceanographic Research Papers*, 31 (10), 1265-1272.

Willcox, J.B. and Stagg H.M.J., 1990. Australia's Southern Margin: a product of oblique extension. *Tectonophysics*, 173, 269-281.

Wilson, R.R. and Kaufman, R.S., 1987. Seamount biota and biography. *In:* Keating, B., Fryer, P., Batiza, R., Boehlert, G. (Eds.), Seamounts, islands and atolls. *Geophysical Monograph Series*, 43, 355-377.

Wilson, B.R. and Marsh, L.M., 1979. Coral reef communities at the Houtman-Abrolhos, Western Australia in a zone of biogeographic overlap: Auckland, *Proceedings of International Symposium Marine Biogeography Evolution in Southern Hemisphere*, v.137, 259-278.

Woods, P.J., Webb, M.J. and Elliot, I.G., 1985. Western Australia. *In:* Bird, E.C.F., Schwartz, M.L. (Eds.), *The World's Coastline*. Van Nostrand-Reinhold, New York, pp. 929-947.

Wright, L.D., Guzu, R.T. and Short, A.D., 1982. Dynamics of a high-energy dissipative surfzone. *Marine Geology*, 45, 41-62.

Zhu, J. Q., Zhu, Z. R. & Collins, L. B., 1994. Marine cementation in a Holocene reef complex in a transitional region of carbonate deposition: The Easter Group, Houtman Abrolhos, *Abstracts - Geological Society of Australia*, 37, pp 489.

8. Appendix A
Classification of Acoustic Facies

Echograms from echo-sounders (e.g. depth sounders/side scan sonar) provide useful information on changes in seabed reflectivity, as determined by surface sediment texture and composition (including biota), and micro-topography. Different types of echo-characters are the result of the interaction between the seabed and the echo-pulse. Sediments can affect the echo return by their type, layering, structure and topography (Flood, 1980). As similar echo-types can be returned by different seabed types, additional information from sediment samples, seabed photographs, and/or multibeam sonar is required to define the echo-types in terms of sedimentary processes.

Table 8.1. Seabed echo-types (Damuth, 1980).

Class	Sub-Class	Type	Description
Distinct		IA	Sharp, continuous with no sub-bottom reflectors
		IB	Sharp, continuous with numerous parallel sub-bottom reflectors
		IC	Sharp, continuos with non-conformable sub-bottom reflectors
Indistinct	Prolonged	IIA	Semi-prolonged with intermittent parallel sub-bottom reflectors
		IIB	Prolonged with no sub-bottom reflectors
	Hyperbolae	IIIA	Large, irregular hyperbolae with varying vertex elevation (>100m)
		IIIB	Regular, single hyperbolae with varying vertices and conformable sub-bottom reflectors
		IIIC	Regular overlapping hyperbolae with varying vertex elevation (<100m)
		IIID	Regular overlapping hyperbolae with vertices tangent to the seabed
		IIIE	Type IIID hyperbolae with intermittent zones of distinct (IB) echoes.
		IIIF	Irregular single hyperbolae with non-conformable sub-bottom reflectors

A classification scheme for 3.5 kHz echograms was developed by Damuth (1980). The echo-character of the seabed is classified into three main categories based on the parameters of; echo-clarity, echo-continuity and morphology, as follows:

I. Distinct echoes;

II. Indistinct echoes – prolonged; and

III. Indistinct echoes – hyperbolae.

These three echo-types are further subdivided into sub-types based on the presence or absence of a sub-bottom reflector, prolonged extent, and relationship of hyperbolae to the seabed (Table. 8.1.)

The acoustic character of digital echograms collected during Geoscience Australia surveys to the Great Australian Bight and Gulf St. Vincent were interpreted for the South Western Planning Area. The resultant acoustic maps were substantiated with available sediment, bathymetric and multibeam sonar data, to better determine seabed geology, morphology, and sedimentary processes.