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A Spatial Analysis

Potter, A., Southby, C. and Heap, A.D.

Record

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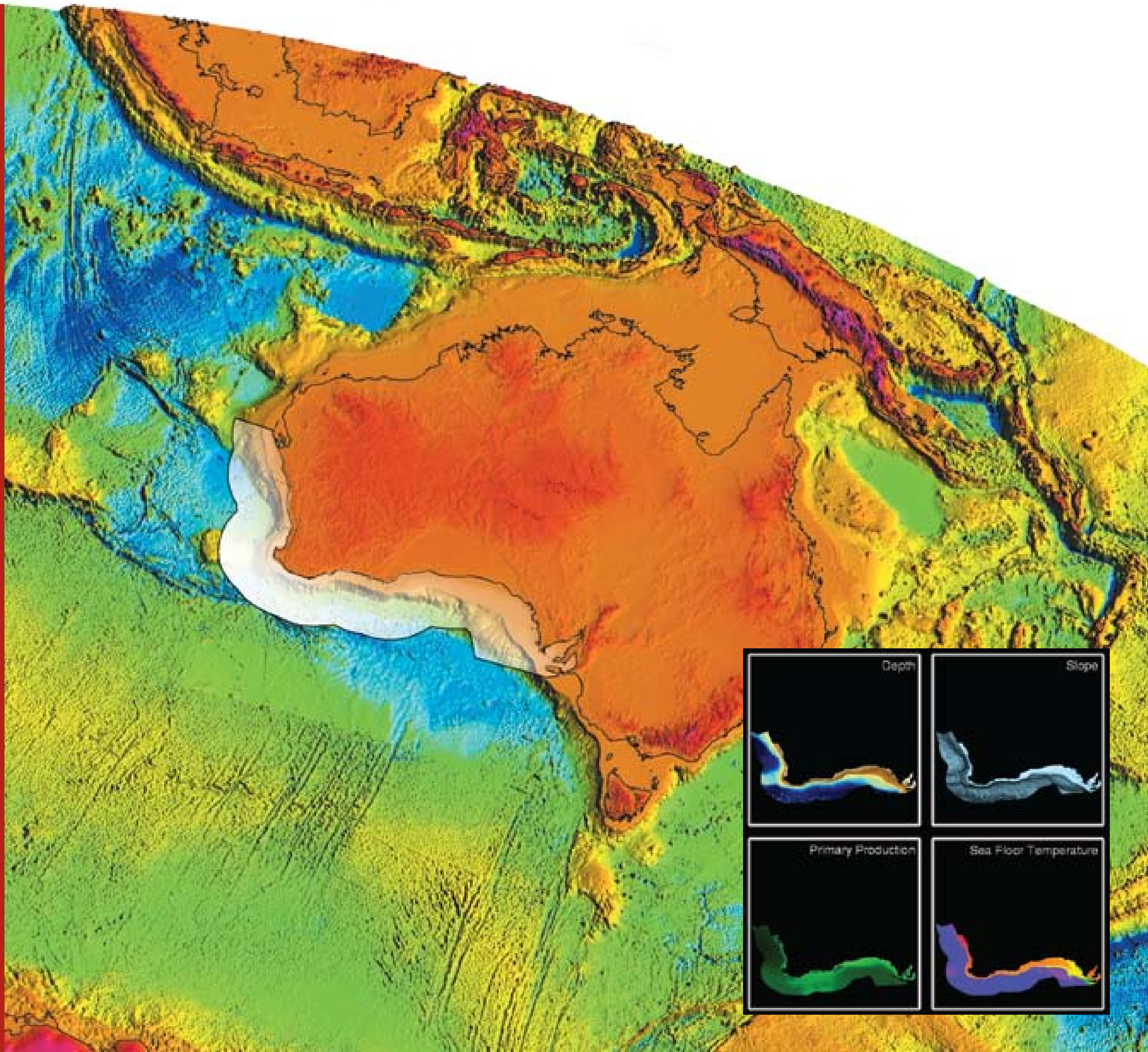

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Geoscience Australia Record 2008/11

Sedimentology and Geomorphology of the South West Planning Region of Australia:

A Spatial Analysis

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Australian Government

Geoscience Australia

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Executive Summary

This report contains the substantive results from a sedimentological study of the seabed in the South West Planning Region (SWPR) of Australia. The study formed a collaboration between Geoscience Australia and the Department of Environment and Heritage (National Oceans Office). Data generated by this study expands the national fundamental marine samples dataset for Australia's marine jurisdiction, with analyses consistent with those completed on samples from the rest of the margin. Information contained in this report will contribute to Geoscience Australia's national work program through the creation of seascapes (surrogates for seabed habitats) for the SWPR, and may be used by the Department of the Environment and Heritage to assist in the selection of candidate marine protected areas.

Geoscience Australia is the national repository and custodian of marine sediment data and has developed a National Marine Samples Database (MARS; http://www.ga.gov.au/oracle/mars) that is a fundamental marine dataset for the Australian margin. Prior to this study, the SWPR was the most data poor region of the Australian Exclusive Economic Zone (Australian EEZ). The principal aim of this study was to generate high-quality quantitative texture and composition data for the seabed in the SWPR to achieve data coverage similar to that of the other margins. To realise the principal aim of the study the following four objectives were devised:

1. Analyse seabed sediment samples (nominally 1,000) for quantitative grainsize distribution and carbonate content;
2. Identify sources of marine sediment sample information to be entered into MARS;
3. Populate MARS with the data; and
4. Produce a report synthesizing and summarizing the sedimentology of the SWPR based on this data.

The results of the analyses are presented as a regional synthesis and also within the framework of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4), which comprises provincial bioregions of both the IMCRA 3 and National Marine Bioregionalisation of Australia 2005. Reporting the results in this way provides both an up-dated and quantitative analysis of the regional sedimentology from previous workers, and characterises the broad-scale management zones designed to support regional marine planning in a way that allows quantitative comparisons to be made between them.

Major physiographic characteristics of the SWPR that distinguish it from other Australian margins include:

- An extensive cool-water carbonate shelf that contains two large, restricted embayments (Spencer and St Vincent Gulfs), and low-latitude coral reefs (Houtman Albrolhos reefs);
- A narrow and relatively steep slope that occurs across the entire region. The slope comprises numerous broad mid-slope terraces, a single submerged marginal plateau (Naturaliste Plateau), as well numerous submarine canyons that have deeply incised the margin; and
- Large areas of rise and abyssal plain/deep ocean floor, which contain unique deep water environments that are not found elsewhere on the Australian margin (e.g., Diamantina Zone).

The regional sedimentology reveals that the seabed of the southwest margin is dominated by marine carbonates. Non-carbonate sediments from terrigenous and biogenic

sources are present mainly on the shallow inner shelf and extensive deep water areas. Main sedimentological trends identified in the SWPR include:

- A cool-water carbonate shelf dominated by sand. The spatial distribution of the major grainsize fractions reveal that the sedimentology of the shelf is relatively uniform, but complex distributions occur locally where large differences in the texture and composition occur over relatively short distances (10's km). These complex regions are characterised relatively high gravel and mud contents;
- A complex slope dominated by mud. The spatial distribution of the major grainsize fractions varies considerably, and is associated with a complex arrangement of geomorphic features including the numerous submarine canyons. Generally, mean grainsize and carbonate content decrease with increasing water depth; and
- A relatively homogenous rise and abyssal plain/deep ocean floor dominated by non-carbonate mud. The variability of the principal grainsize fractions is relatively small and occurs over relative large spatial scales (1000's km).

A total of four IMCRA bioregions occur on the continental shelf in the SWPR. These bioregions occur in water depths of <200 m and comprise 24% of the total area. Together, the IMCRA bioregions contain 57% of the samples collected and the assays add reliable quantitative information to many local- and regional-scale studies completed for the shelf. A total of three National Benthic Marine Bioregionalisation provincial bioregions occur on the slope, rise and abyssal plain/deep ocean floor in the SWPR. These bioregions occur in water depths from 200 m to over 7,000 m and comprise 76% of the total area. Together, the provincial bioregions contain 43% of the samples collected and the assays are the first quantitative data generated for much of southwest Australian margin beyond the shelf.

The significant outcomes of this sedimentological study include:

- Production of the most up-to-date and comprehensive representation of the seabed sedimentology for the southwest Australian margin, building on the existing regional sediment model for the shelf by previous workers;
- Quantification of the regional seabed sediment characteristics and their distribution in the SWPR for the first time, and assessment of the sediment variability at relatively small spatial scales using a robust and consistent dataset;
- Production of a robust, consistent quantitative dataset that permits defensible quantitative comparisons of the seabed sedimentology to be made between the southwest margin and the rest of the Australian margin; and
- Recognition and quantification of the spatial heterogeneity of seabed sedimentology within the SWPR that can be linked to seabed habitat complexity. Capturing the spatial heterogeneity of the seabed sedimentology will allow more accurate and precise mapping of seabed habitats (seascapes) and aids in more effective future sampling strategies.

A principal application of the study is to support research into the associations between seabed physical properties such as sediment texture and composition and the distribution of benthic marine habitats and biota. This research enables Geoscience Australia to spatially represent benthic marine habitats and biota for Australia's vast marine jurisdiction. This approach is crucial for developing robust, defensible methods of mapping habitats using spatially abundant physical data combined with site-specific biological data and over thousands of kilometres.

1. Introduction

This report presents the results of a study of seabed sediment texture and composition in the South West Planning Region (SWPR) of Australia. The study was a collaboration between Geoscience Australia and the Department of the Environment and Heritage. Seabed sediment data for the SWPR is scarce, and the most incomplete of any region in Australia. This study aimed to address this lack of data by generating quantitative texture and composition data from (nominally) 1,000 seabed samples. The data collected expands the national fundamental marine dataset for Australia's marine jurisdiction, with analyses consistent with those completed on samples from the rest of the margin. Information contained within this report will contribute to the Department of the Environment and Heritage's national work program and will also assist in the selection of candidate marine protected areas for the SWPR.

1.1. AUSTRALIA'S MARINE JURISDICTION

Australia's marine jurisdiction (including the Australian Antarctic Territory) covers a total area of >11 million km^2. Australia's marine jurisdiction spans all climatic zones, spanning >40° of latitude and occurring in three of the worlds oceans (i.e., the Indian, Southern and Pacific Oceans). Most of this vast area has been little studied and our knowledge of all but the broadest geomorphic and sedimentary characteristics is relatively poor. The marine jurisdiction is composed of the four basic geomorphic provinces, namely: shelf, slope, rise and abyssal plain/deep ocean floor. The most well-studied region of the Australian continental margin is the shelf, which covers an area of >1.9 million km^2 (not including Antarctica and Heard Island) (Harris et al. 2005). The slope is the most extensive geomorphic province at >4 million km^2, followed by the abyssal plain/deep ocean floor which covers an area of >2.8 million km^2. At only 97,070 km^2, the rise is relatively small compared with the other provinces and is smallest of all other continents.

Dominant sediment types on the shelf are detrital and biogenic sands and gravels, with relict and palimpsest sediments locally present (Harris et al. 1991). Cores and seismic profiling studies reveal that the post-glacial sediments on the outer Australian shelf (>100 m) are generally <1 m thick (Harris, 1995). Generally, on the middle and outer shelves, carbonate concentrations typically exceed 50% and reflect the relatively low terrigenous sediment input from land sources (Harris, 1995). Inner shelf (<60 m) sediments are generally thicker (<4 m) and comprise >50% siliciclastic grains (Harris, 1995; Orpin et al., 2004; Roberts and Boyd, 2004). These sediments comprise of about 50% detrital, relict and palimpsest sediments and the remaining 50% being of biological origin (Harris, 1995). On the middle shelf (60-100 m) sediments are generally coarse sands usually comprised of >60% carbonate (Conolly and Von der Borch, 1967; James et al., 1994; Passlow et al., 2005).

The texture and composition of sediments on the slope, rise and abyssal plain/deep ocean floor are poorly documented. Where data are available sediments of the continental slope of the southern margin are comprised of spiculitic carbonate silt of 20-50% clay sized carbonate, 50% silt and up to 30% fine sand (James et al., 1999). On the relatively steep slope, these sediments form turbidites and other gravity flows (Boyd et al., 2004). These mass flow deposits can extend on to the rise and abyssal plain/deep ocean floor close to the continental margin. The relatively few samples for the abyssal plain/deep ocean floor show it is dominated by pelagic fine-grained mud, aerial-born dust and manganese micro-nodules (James et al., 1992; Sayers et al., 2002). Extensive pavements of manganese nodules are also present on the rise of the Tasman Sea and the abyssal plain/deep ocean floor of the Indian and Pacific Oceans (Exon, 1979; Bolton et al., 1988; Exon, 1997).

1.2. SEDIMENT-HABITAT RELATIONSHIPS

Spatial variations in benthic (seabed) habitats and biota may be ascribed to the spatial variation in the texture and composition of seabed sediments (Levinton, 1982; Kostylev et al., 2001; Remey and Snelgrove, 2003; Beaman et al., 2005; Post et al., 2006). Substrate type is a first-order determinant of the distribution and nature of marine biota over a wide range of spatial and temporal scales (Ward et al., 1999; Day and Roff, 2000; Bax and Williams, 2001). Sessile organisms principally occur on hard, immobile substrates and burrowing organisms in soft sediments. Species diversity is highest in rocky environments and in muddy environments because fine-grained sediments contain a relatively high proportion of organic matter (Snelgrove and Butman, 1994; Long et al., 1995). Substrate or sediment particle size is a dominant influence on benthic and demersal communities (Remey and Snelgrove, 2003). The nature of the benthic community and the types of organisms that can live within or on the substrate may be determined by particle size along a spectrum from solid rock to mud (Levinton, 1982; Day and Roff, 2000). Sediment type can have a significant control on species richness, with studies showing markedly higher average number of species on gravel lags, and lowest species numbers in sandy sediments (Kostylev et al., 2001).

To conserve marine biodiversity the physical environment must also be characterised and preserved (Day and Roff, 2000; Bax and Williams, 2001; Solan et al., 2006). Despite these studies recognising that the physical environment plays a key role in influencing marine biodiversity, the influence of the texture and composition of seabed sediments on benthic biota over different spatial scales is largely unstudied. The degree to which variations in carbonate concentrations affect the spatial distribution and the character of benthic habitats and biota is not known.

Geoscience Australia is researching the associations between seabed physical properties such as sediment texture and composition and the distribution of benthic marine habitats and biota (Post, 2006). This research is helping to spatially represent benthic marine habitats and biota for Australia's vast marine jurisdiction. This approach is crucial for developing robust, defensible methods of mapping habitats using spatially abundant physical data combined with biological data and over thousands of kilometres.

1.3. GOVERNANCE AND LEGISLATION

1.3.1. National Fundamental Marine Data

In 2002 Geoscience Australia, in its role of national repository and custodian of Australia's marine geoscience data, and the Department of the Environment and Heritage (National Oceans Office) commenced a collaborative project to develop a national marine samples database (MARS; www.ga.gov.au/oracle/mars) (Passlow et al., 2005). The principal aim of the project was to create a national fundamental marine dataset by locating, identifying and collating all existing information on the nature and distribution of marine sediments within the Australian marine jurisdiction. Through the MARS database, seabed sediment data collected across Australia's entire marine jurisdiction can be accessed from one location. MARS continues to provide the framework for the ongoing collection and maintenance of marine sediment data in Australia and has been developed in line with ANZLIC data standards.

At the beginning of the present project MARS contained >40,000 sample and sub-sample records, and approximately 200,000 records describing the characteristics of these samples. While coverage of seabed sediment data has been improved across Australia's marine jurisdiction, the south and west Australian margins (as covered by the SWPR) still contain (by far) the least data of any region.

1.3.2. Oceans Policy and Regional Marine Planning

Australia's Oceans Policy was introduced in 1998 to establish an integrated ecosystem-based approach for planning and management of Australia's marine jurisdiction. This approach requires that planning and management in marine environment is based on habitat and biodiversity distributions rather that on sectoral or jurisdictional boundaries (Department of Environment and Heritage, 2005b). The primary aim of the Oceans Policy is the protection and maintenance of biodiversity in Australia.

In order to protect and maintain Australia's biodiversity, the Federal Parliament passed the Environmental Protection and Biodiversity Conservation (EPBC) Act in 1999. One of the key mechanisms being implemented by the Department of the Environment and Heritage to conserve marine biodiversity is the selection of a network of marine protected areas (MPA's). In 2006, a set of 13 new MPA's covering >226,000 km^2 were nominated for the South East Planning Area, which represented the first stage in a strategy under the EPBC Act to establish a national representative system of MPA's. The network includes newly declared MPA's in the Territorial Sea (i.e., within 3 nautical miles of the coast) and those already in existence (e.g., Macquarie Island; Norfolk Island; Ashmore Reef). As with all the planning areas around Australia, a new series of MPA's will be designed and nominated for the SWPR as a part of this strategy.

1.3.3. National Marine Bioregionalisation of Australia 2005

In 2004, as part of a collaborative agreement between Geoscience Australia, CSIRO – Marine and Atmospheric Research, and the Department of the Environment and Heritage (National Oceans Office) a scientific panel of experts from a range of institutions created a National Marine Bioregionalisation of Australia (NMB2005). The NMB2005 provides an over-arching management framework for a large part of Australia's marine jurisdiction, and is based on the most up-to-date knowledge of the biophysical properties of Australia's ocean environment, including seabed geomorphology and sedimentology.

For the benthic marine environment this national framework consists of a hierarchical set of geographic management units. Below the scale of the major ocean basins that comprise Australia's marine jurisdiction (i.e., the Indian, Southern and Pacific Oceans), the continental shelf, slope, rise and abyssal plain/deep ocean floor are each separated into Primary Bathymetric Units that represent the broadest-scale planning unit, and have areas of several million km^2. Within each of the Primary Bathymetric Units are Provincial Bioregions, which have been defined mainly by the distribution of demersal fish, bathymetry, and geomorphology, and have areas of hundreds of thousands of km^2. The Provincial Bioregions are the principal planning unit for Marine Bioregional Planning.

Since the introduction of Australia's Ocean Policy, Geoscience Australia has provided geoscientific data and knowledge in support of the regional marine plans and identification and selection of MPA's. A key component of the marine environment program is to research the degree to which the physical character of the seabed (e.g., geomorphology, texture and composition) can be used to represent benthic marine habitats. The development of a comprehensive and consistent dataset of texture and composition of the seabed provides one of the fundamental datasets used in this research.

1.4. STUDY BACKGROUND AND RATIONALE

1.4.1. Analysis of Seabed Samples for the SWPR

In February 2006, Geoscience Australia and the Department of the Environment and Heritage agreed to undertake a collaborative project to identify, analyse and collate existing information on the texture and composition of the seabed in the SWPR. The main objectives of this project were to:

- analyse sediment samples (nominally 1,000) from the SWPR, currently held by Geoscience Australia and associated marine science institutions, for grain size and carbonate concentrations;
- identify as far as possible, sources of marine sediment sample information for the SWPR held by Australian and international research groups and private, corporate entities;
- provide data on the texture and composition of the seabed for the SWPR and to populate Geoscience Australia's national marine samples database (MARS) with the data; and
- produce a report synthesising and summarising the sedimentology of the seabed for the SWPR in support of regional marine planning and national representative system of marine protected areas.

The texture and composition data generated from this project will be incorporated with other physical data (i.e., depth, geomorphology, sediment mobility, etc) held by Geoscience Australia to create "seascapes" that represent major ecological units based on measurable, recurrent and predictable features of the marine environment.

1.4.2. Expected Project Outcomes

The expected outcomes of this project are:

- a better understanding of the nature of the seabed for the south west and west continental margins of Australia;
- improved information on the sedimentology of the SWPR for the scientific and planning communities, leading to the development of more effective plans for marine conservation sustainable development; and
- improved access to data on the nature of the seabed by further population of the MARS database as a national fundamental marine dataset with data from a data poor region.

1.4.3. Scope and Relevance

This report covers the presentation and synthesis of seabed texture and composition data for the SWPR. Geomorphic, sedimentary and biological information has already been used to develop a bioregionalisation of the SWPR (Department of the Environment and Heritage, 2005b), and the substantive geomorphic features of the west and south continental margins have already been identified and mapped (Harris et al., 2005). This report adds significantly to these previous studies by incorporating this information in the sedimentology synthesis which includes a discussion of the implications for marine conservation in the SWPR.

The physical characteristics of the seabed in the SWPR, as described by the sediment texture and composition data, can assist in determining the broad-scale diversity of benthic habitats in the SWPR. These data represent "enduring features" which are elements of the physical environment that do not change considerably (in human life spans) and they are known to influence the diversity of biological systems. This is important for marine conservation and can be applied to better define and characterise benthic habitats. Seabed texture and composition are observable and measurable parameters that along with other physical features can be used to create "seascapes" that serve as broad surrogates for benthic habitats and biota. Seascapes have the potential to be used in informing the planning process and the design of MPA's.

2. South West Planning Region

Section 2 presents an overview of the South West Planning Region (SWPR). The broad-scale sedimentology of the SWPR is described, followed by the previous work that has been undertaken in the area.

2.1. DEFINITION

The SWPR covers commonwealth waters from the eastern most tip of Kangaroo Island in South Australia to Kalbarri in Western Australia (Fig. 2.1). This region comprises 1.4 million km^2 of ocean and seabed and abuts the coastal waters of both South Australia and Western Australia. The area extends 3 nautical miles from the territorial sea baseline out to 200 nautical miles.

Broadly, the SWPR can be divided into four major physiographic regions: 1) Rottnest; 2) South West (SW); 3) Great Australian Bight (GAB); and 4) Spencer and St Vincent Gulfs (Richardson et al., 2005). These regions are defined based on major geomorphic and sedimentary characteristics that distinguish the SWPR, including: the longitude-parallel continental shelf, slope and rise in the Rottnest region; 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.

2.2. SEDIMENTOLOGY

2.2.1. Rottnest Region

Broadly, the seabed sediments in the SWPR change from tropical carbonate sediments in the north to cool temperate carbonate sediments in the south (James et al., 1999). Surface sediments along the north western margin of the SWPR from Kalbarri to Cape Naturaliste are dominated by carbonate bioclasts. On the Rottnest Shelf recent sediments have attributes of both warm and cool water carbonates that are composed of mud-, sand- and gravel-sized skeletal remains of coralline algae, bryozoans, molluscs and foraminifers (James et al., 1999). These sediments occur as thin, discontinuous sheets over rocky or algal substrates (Collins et al., 1997; James et al., 1999). The Houtman-Abrolhos shelf is in a biotic transition zone between warm northern tropical and cool southern temperate environments with conditions close to the limits for coral reef development (Collins et al., 1997). On the Houtman-Abrolhos reefs themselves tropical reef biota are dominant while across the shelf temperate cool-water species are dominant (Collins et al., 1997).

2.2.2. Southwest Region

Seabed sediments in the southwest region are generally bioclastic carbonate sands composed of the skeletal remains of bryozoans, molluscs, foraminifers and corals (Carrigy and Faribridge, 1954; Carrigy, 1956). Calcareous fragments make up >80% of the sediment fraction on the shelf, with minor amounts of quartz and faecal pellets (Carrigy, 1956). Sediments from the western area contain terrigenous material such as quartz and feldspar, which may represent the supply of material from onshore (Carrigy, 1956; Conolly and Von der Borch, 1967).

The deep water regions of the Naturaliste Plateau are covered by ~30 m of pelagic

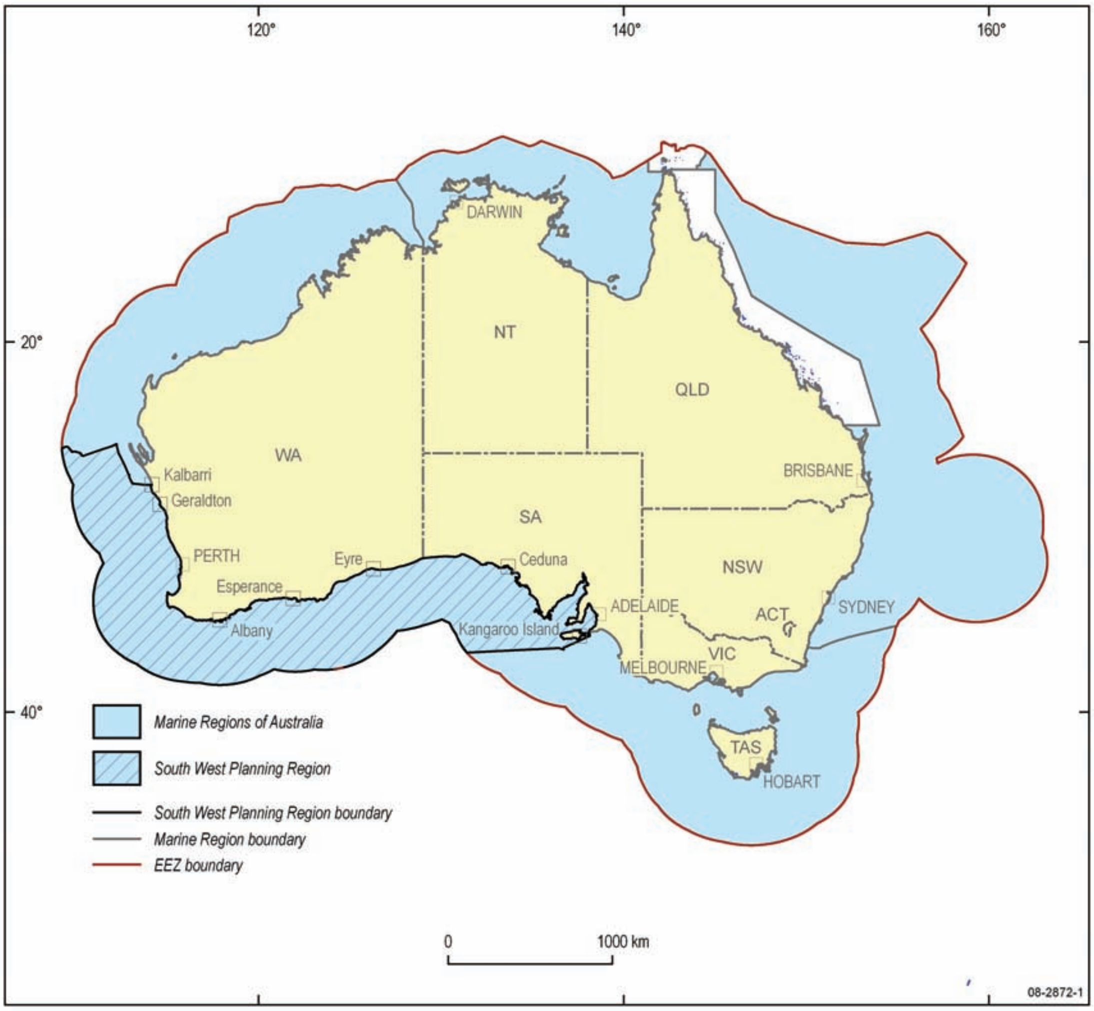

Figure 2.1. Map showing the location of the SWPR in relation to Regional Marine Planning areas.

foraminiferal-nannofossil ooze (Kennett, 1975; Borissova, 2002). The single core recovered from the northern margin of the plateau by Burckle et al. (1967) contained coarse-grained foraminiferal sand (Borissova, 2002). The Diamantina Zone covers an area of >100,000 km^2 and is thought to be a zone of continent to ocean transition with closely spaced E-W trending ridges and troughs with relief of up to 4,000 m (Borissova, 2002). Where sampled, sediments present in the Diamantina Zone are primarily composed of spiculitic nannofossil ooze (Borissova, 2002; Hill and De Deckker, 2004).

2.2.3. Great Australian Bight (GAB) Region

The shelf of the southern region including the Great Australian Bight (GAB) is the largest area of cool-water carbonate sedimentation in the modern world (James et al., 2001). Seabed sediments are generally a mixture of modern skeletal carbonate grains and older (Late Pleistocene) relict carbonate intra-clasts. Carbonate fragments are primarily from bryozoans, molluscs, sponges, coralline algae, and benthic foraminifers (Conolly and Von der Borch, 1967; James et al., 1994; 2001). The grain size distribution reflects the high energy environment, with coarse sands present to 90 m water depth, and with fine-grained sand and mud present below 90 m. Below 500 m the slope is characterised by pelagic calcareous ooze

(James et al., 1994). The Eyre and Ceduna Terraces are covered by a thin layer of pelagic calcareous ooze and mixed terrigenous-carbonate sand, silt and mud (Davies et al., 1989).

There are numerous submarine canyons cut into the outer shelf and continental slope. The largest of these extend up to 90 km offshore and reach the base of the slope, and onto the abyssal plain. The largest canyons have incised the margin up to 1,500-2,000 m (Conolly and Von der Borch, 1967; Von der Borch, 1968; Conolly, 1976; Exon et al., 2005). Extensive carbonate production on the continental shelf since the Eocene has supplied abundant abrasive carbonate grains that have helped to cut the canyons, forming a very wide rise (Exon et al., 2005). Seabed sediments in the Albany Canyons principally consist of siliceous and calcareous mud and ooze, with minor amounts of glauconitic sandstone and mudstone, calcareous marl, and bioclastic, foraminifera rich calcarenite (Blevin, 2005). Analyses from core samples from the Murray Canyons shows that recent seabed sediments contain little terrigenous matter and consist of pelagic carbonate particles and minor amounts of aeolian dust (Hill and De Deckker, 2004).

Significant variations in the texture and composition of shelf sediments are broadly zoned parallel to the coast. These distinct zones reflect the dominance of long-period ocean swell waves and large storm waves, which regularly rework and sort the seabed sediments down to 140 m water depth (Collins, 1988; James et al., 1992; Sanderson et al., 2000). Modelling studies have revealed that sediment mobilisation from swell waves on the southern margin annually occurs over ~31% of the seabed below 200 m water depth, and over ~41% of the seabed by tidal currents (Porter-Smith et al., 2004).

2.2.4. Spencer & St. Vincent Gulfs

The Spencer and St. Vincent Gulfs are shallow restricted embayments overlying basins formed by Tertiary tectonic activity. The Gulfs contain extensive intertidal zones, particularly in the north. The shallow areas support seagrass meadows, mangrove woodlands and samphire-algal marshes (Barnett et al., 1997). Sandwaves are present in the northern Spencer Gulf. Deeper channels link the Gulfs to the Investigator Strait and Lincoln Shelf to the south.

The sedimentology of the Gulfs has been studied on various scales. Seabed sediments are dominated by biogenic carbonate sands sourced from within the gulfs and on the shelf (Waters, 1982). A significant terrigenous component is present locally, particularly in the northern Spencer Gulf (Burne and Colwell, 1982; Fuller et al., 1994). Sediments of the carbonate sands rich in bivalves and bryozoans cover most of the area of Investigator Strait and the Lincoln Shelf (James et al., 1997).

2.3. PREVIOUS WORK

2.3.1. Marine Samples Database (MARS)

Prior to the present study, MARS contained sediment texture and composition data for 196 seabed samples from the SWPR or approximately 1.5% of the total number of samples collected in Australia's marine jurisdiction (Fig. 2.2; Table 2.1).

MARS also contained spatial and sample details for an additional 339 samples in the SWPR held at Geoscience Australia, although these samples had not been analysed for quantitative grain size or carbonate concentrations and were not part of the fundamental national marine dataset. These samples have been included in the present study.

2.3.2. Great Australian Bight Marine Park

The Great Australian Bight Marine Park (GABMP) is located in the GAB and covers 21,400 km^2. The boundaries extend from 200 km west of Ceduna in South Australia, following the coast to the Western Australian border (Fig. 2.3). The GABMP includes a 20 nautical wide strip extending offshore to the seaward limit of the EEZ at 200 nautical miles (Department of the Environment and Heritage, 2005a).

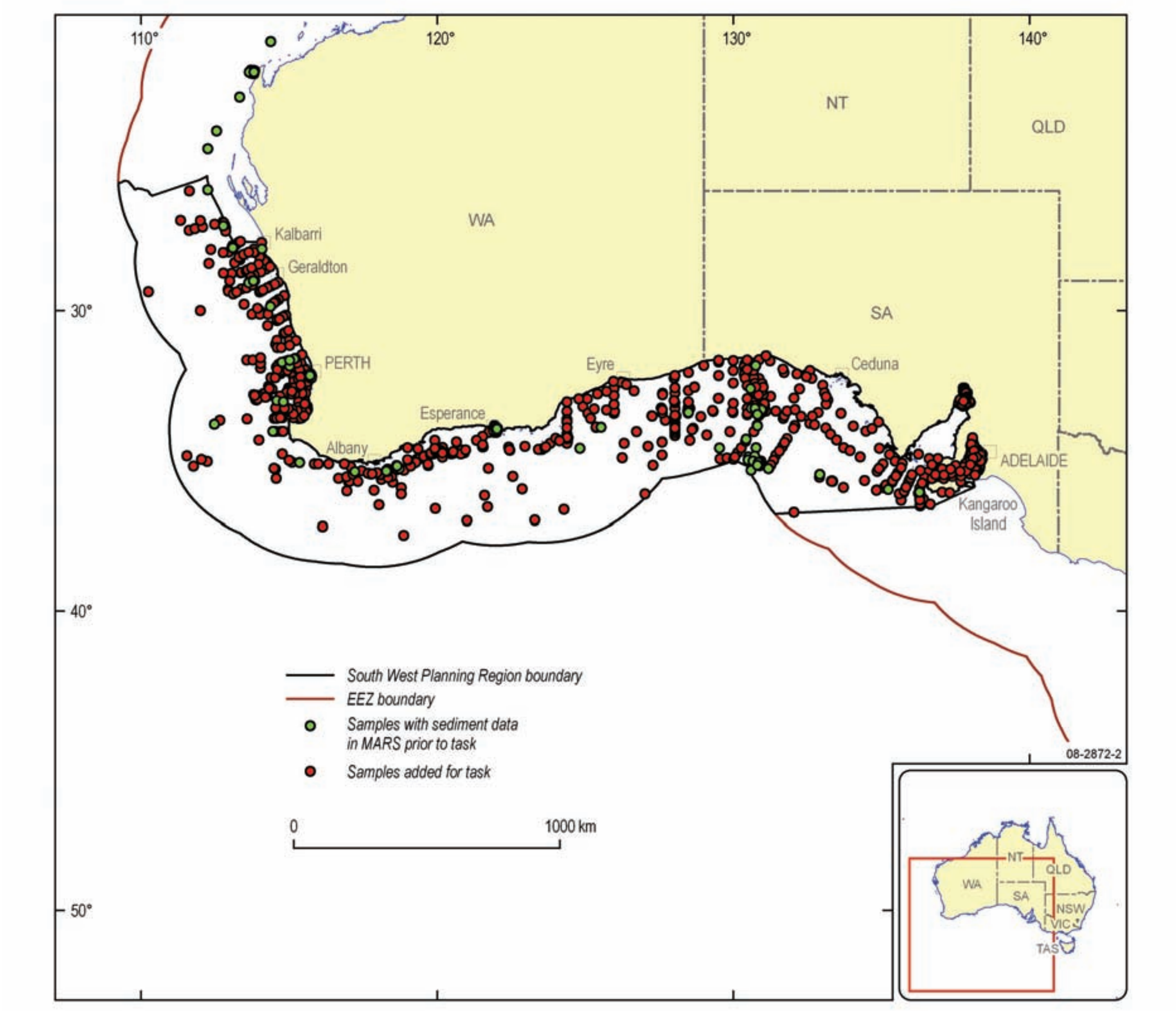

Figure 2.2. Location of all quantitative textural and compositional data for the SWPR stored in MARS prior to this project.

Table 2.1. Metadata for sediment samples in the SWPR prior to the task.

Survey Name	Date	Number of samples	Survey description
Eastern Bass Strait and GAB	Apr.-May 2000	26	GAB Marine Protected Area demersal fish and benthic invertebrates study
GAB 2	Nov.-Dec. 1986	5	Heat flow and geological sample collection
Cockburn Sound	Mar.-Apr. 2004	63	Coastal research and management
Coastal Geomorphology and Classification – Esperence (Recherche) #2	May 2005	54	Coastal research and management

GAB Warm Seeps	Jan.-Feb. 2001	15	Heat flow and geological sample collection
Mapping benthic ecosystems on the deep continental shelf and slope (GAB)	Jul.-Aug. 2005	32	Mapping benthic ecosystems on the deep continental shelf and slope in Australia's "South West Region".
Deep Sea Drilling Program Leg 26	Sept.-Oct .1972	1	Deep sea floor survey
Total (prior to Jan'06)		196	

The GABMP is made up of two overlapping zones and is directly adjacent to the South Australian Marine Park (SAMP), which covers an area of 1,683 km^2 and includes the territorial sea extending from the Western Australian border (129°00'E) to just west of Cape Adieu (132°00'E) (Fig. 2.3). The GABMP comprises of the Marine Mammal Protection Zone that extends from three nautical miles to approximately 31° 47'S. This area is primarily intended to provide for undisturbed calving for the Southern Right Whale and protection of Australian Sea-lion colonies. To the west of the head of the bight is the benthic protection zone, a 20 nautical mile-wide representative strip of the seabed between 130° 28'E and 130°

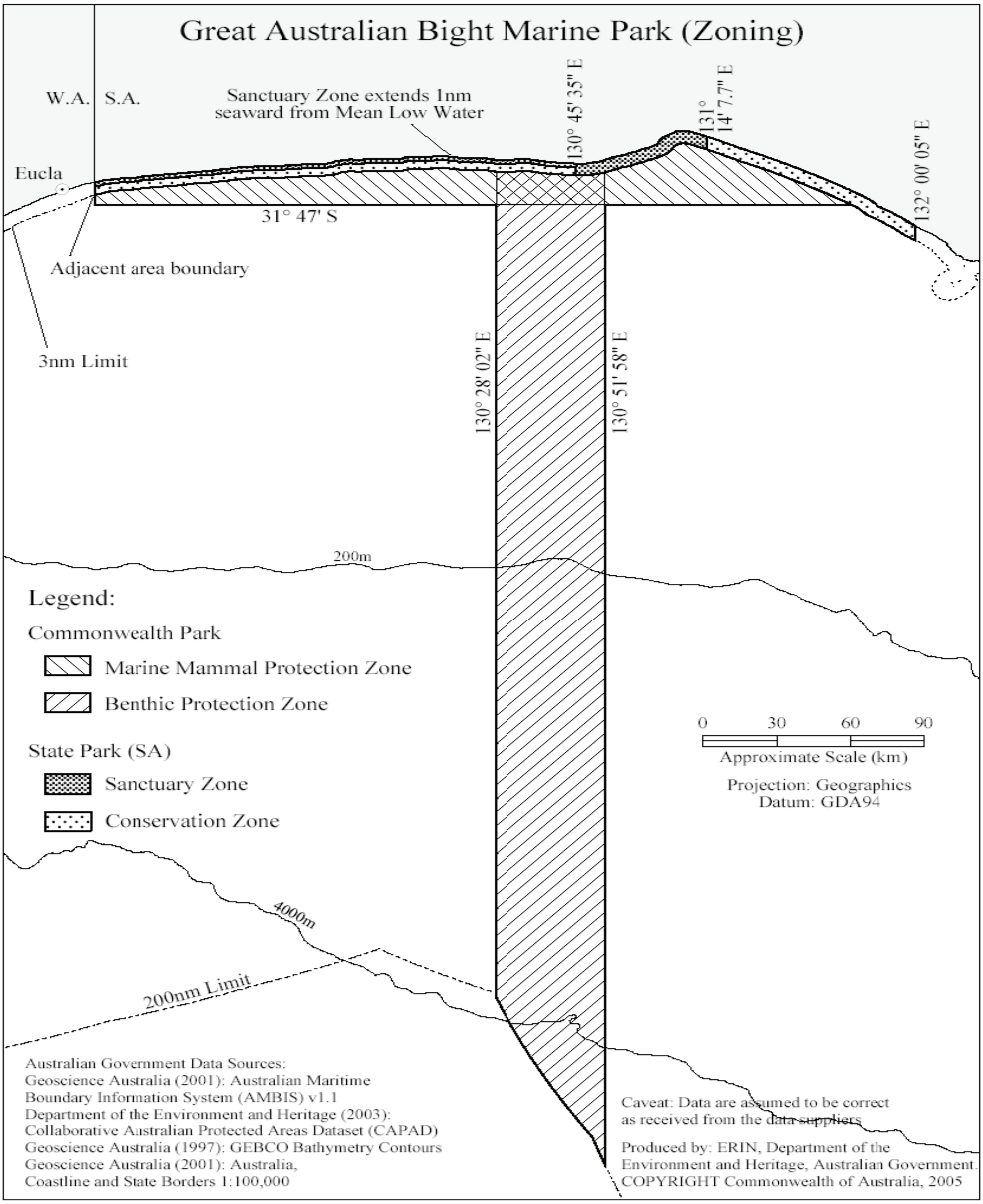

Figure 2.3. Location and zoning of the Great Australian Bight Marine Park (Source: Department of the Environment and Heritage, 2005a).

51′E, and extending from the seaward boundary of the SAMP (Fig. 2.3). This area is intended to protect the unique and diverse plants and animals that live on, and are associated with, the seabed (Department of the Environment and Heritage, 2005a). Samples from two surveys to eastern Bass Strait and GAB (Fig. 2.2) were collected as part of a project to determine the GABMP (Fig. 2.2). These data have been included in the present analysis.

The aim of the marine protected area is to contribute to the long-term ecological viability of marine and coastal systems, to maintain ecological processes and systems, and to protect Australia's biological diversity in the GAB region. The GABMP helps to conserve ecosystems that are characteristic of the GAB (Department of the Environment and Heritage, 2005a), as well as being an important reference area for scientific study and long-term environmental monitoring.

2.3.3. Geomorphology and Sedimentology Literature Review

A recent synthesis of the scientific literature describing the geomorphic, sedimentary, tectonic and oceanographic information and knowledge on the SWPR has been completed by Geoscience Australia specifically for the SWPR (Richardson et al., 2005). While this synthesis provides baseline scientific information for the SWPR, our understanding of the sedimentology remains biased as a rigorous analysis of seabed samples had not been undertaken due to the small amount of quantitative data available (see above). The present study aims to fill this crucial data gap by providing a detailed regional synthesis of the seabed sedimentology for the SWPR.

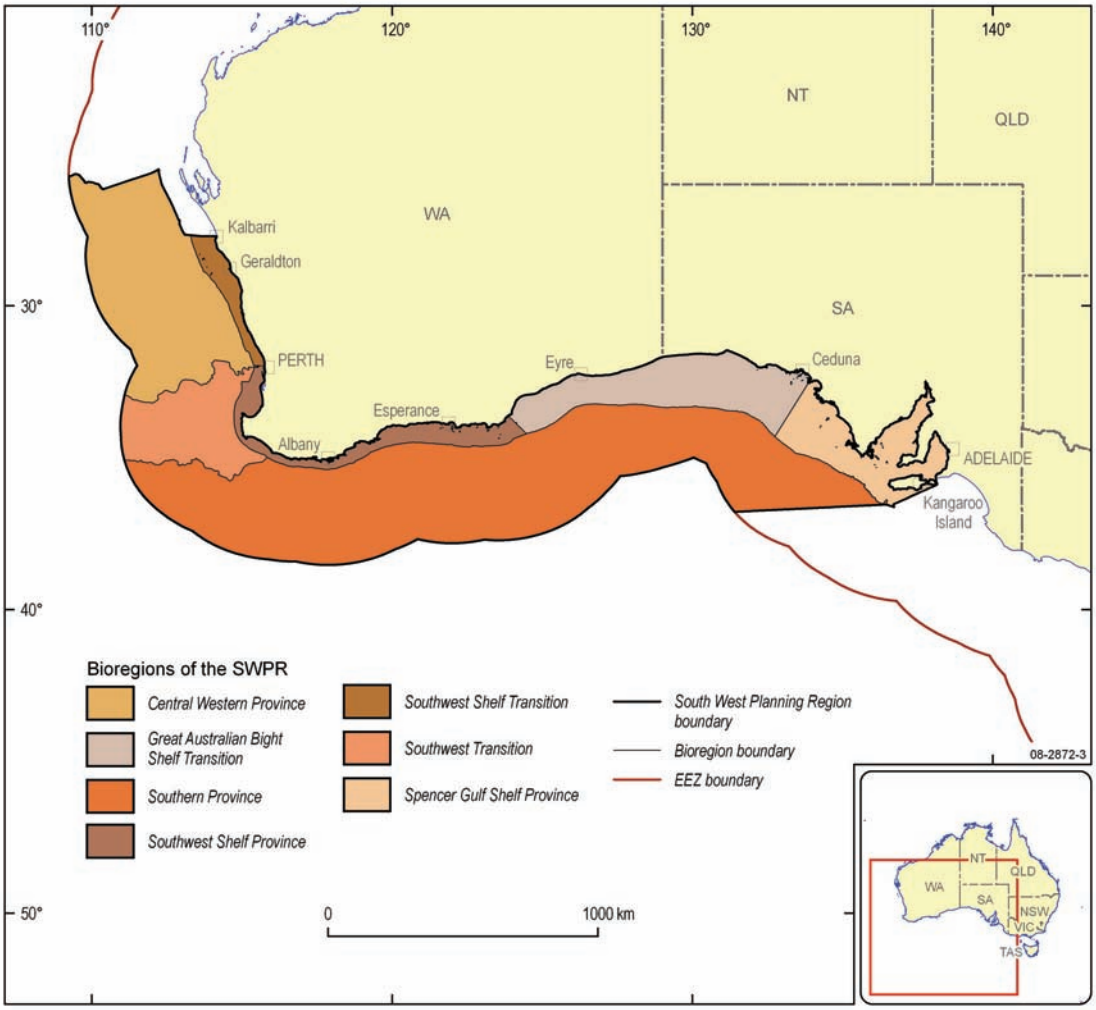

Figure 2.4. Map showing the bioregions of the South West Planning Regions as defined by the Department of the Environment and Heritage.

Table 2.2. Summary details of the provincial Bioregions contained in the SWPR.

Province	Description	% in SWPR
Spencer Gulf IMCRA	Warm Temperate Waters	76
Southern Province	Warm Temperate Waters	85
Great Australian Bight IMCRA Transition	Transition	100
Southwest IMCRA	Warm Temperate Waters	100
Southwest Transition	Transition	100
Southwest IMCRA Transition	Transition	100
Central Western Province	Subtropical Waters	96

2.3.4. National Benthic Marine Bioregionalisation 2005 Provincial Bioregions

A total of 7 of the NMB2005 Provincial Bioregions occur either wholly or partly within the SWPR. The SWPR contains all of the South West Transition, South West IMCRA Province, South West IMCRA Transition, and the Great Australian Bight IMCRA Transition (Table 2.2). The SWPR also partially contains the Spencer Gulf IMCRA Province, the Central Western Province and the Southern Province. Full details of the bioregions are presented in Section 5. To support regional marine planning in the SWPR, the results of this study are discussed in the context of the Provincial Bioregions, and data are presented for each bioregion.

3. Methodology

This section describes the procedures for identifying and procuring the samples for the SWPR and the analysis techniques used to determine the texture (grain size) and composition (carbonate concentration) data. All of the metadata and assays from the procurement and analysis of the samples are contained in Geoscience Australia's marine samples database, MARS (http://www.ga.gov.au/oracle/mars).

3.1. DATA COLLECTION AND COLLATION

3.1.1. Sample Identification

Samples held at Geoscience Australia and in external archives were initially identified through a database search of Australian and overseas marine research institutions and museums. This search resulted in the identification of 1,194 samples for the SWPR, comprising 336 in Geoscience Australia's archives, and 858 samples in the archives of 10 external agencies (Table 3.1). Sample searches were completed for the following:

- Geoscience Australia's marine samples database, MARS;
- Australian state government repositories;
- Australian academic institutions with current or past marine geology programs
- Australian marine research survey reports;
- Australian national facility survey database (http://www.marine.csiro.au/marlin);
- Research papers documenting work in the SWPR in scientific journal articles and technical reports;
- International seabed sediment databases (EuSeased); and
- Overseas marine research institutions (ARFFSU, IODP, Geomar).

Samples procured for this project were collected by research agencies on 25 surveys between 1960 and 2006 (Table 3.2). Acquiring samples from their holdings ensures that a consistent data set is derived from as many samples collected in Australia as possible and that Australia retains an archive sample if it resides in overseas agencies. This is a much more cost effective option of acquiring large amounts of sediment samples and data compared to collecting new samples. With samples spanning 46 years of study enables an assessment of the temporal changes in sediment distribution.

3.1.2. Sample Procurement

Initially, all sample holdings were assessed to confirm that: 1) enough material was available for analysis; 2) that the material was in appropriate condition for analysis; and 3) that appropriate metadata existed for each sample. Data agreements were then negotiated with all external sample providers covering sub-sampling procedures, freight and metadata requirements. Samples obtained from Australian research institutions and state agencies were obtained via direct contact with the principal researcher. Geoscience Australia staff conducted sub-sampling of the material and transported the samples back to Canberra for analysis. Samples from overseas data providers were obtained via an on-line request and they sub-sampled their own material and air-freighted the samples to Geoscience Australia.

Table 3.1. External sample providers with number of samples provided for task.

Institution	Previous supplier	Number of samples provided for this study
Australian-based holdings		
Geoscience Australia	-	336
South Australian Research and Development Institute	No	64
Department of Primary Industries and Resources of South Australia	No	150
Adelaide University	No	467
Australian National University	Yes	47
Curtin University	No	77
Overseas holdings		
Lamont Doherty Geophysical Observatory (USA)	No	42
Deep Sea Drilling Project (USA)	Yes	6
Antarctic Research Facility, Florida State University (USA)	No	10
Ocean Drilling Program (USA)	Yes	9
Geomar, (Germany)	No	15

Table 3.2. Source organisations, surveys and chief scientists' of samples procured for this study.

Source	Survey	Chief Scientist	No of Samples
South Australian Research and Development Institute (SARDI)	Epifaunal assemblages of the eastern Great Australian Bight	T. M. Ward	64
Curtin University	Postglacial sediments and history, Southern Rottnest Shelf, WA.	L. Collins	77
Deep Sea Drilling Project (USA)	Deep Sea Drilling Project, Legs 26 & 28 1972	Unknown	6
Australian National University	Franklin 10/1995 & Franklin 02/1996 – Australian Marine Quaternary Programs 1 & 2	P. De Deckker	25
	AUSCAN Leg 2 / MD13, 2003		3
	AUSCAN 2006 – Geological and biological investigation of the Murray Canyons Group		19
Lamont Doherty Earth Observatory, (USA)	Vema 16, 1960	R. Houtz	3
	Vema 18, 1962	L. Oblinger	4
	Vema 33, 1976	R. Sheridan	25
	Robert Conrad 8 & 9	G. Bryan	10
Geomar, (Germany)	Sonne 8, 1979	U. von Stackelberg	15
Ocean Drilling Program (USA)	Great Australian Bight: Cenozoic Cool-Water Carbonates. Sites: 1126-1134, 1998	D. A. Feary	9
Antarctic Research Facility, Florida State University (USA)	Eltanin 35	R. Houtz	4
	Eltanin 45	T. Aitkin	6
	Eltanin 55	P. Hendershot	26

Adelaide University	Holocene Biogenic Sedimentation, Northern Rottnest Shelf, Western Australia: Franklin 01/1996	L. Collins	78
	Cool Water Carbonate Sedimentation, Bonny and Lacepede Shelves and Eastern Great Australian Bight: Franklin 03/1998	Y. Bone	41
	Cool-water Carbonate Sedimentation, Great Australian Bight and Phytoplankton Productivity: Franklin 07/1995	Y. Bone	120
	Southern Margins 2: Franklin 06/1994	D. A. Feary	57
	Sedimentation and Quaternary Geological history of the South Australian Continental Shelf: Franklin 03/1989	V. A. Gostin	53
	Bass Strait Interdisciplinary Study: Franklin 01/1991	P. Nichols	63
Department of Primary Industries and Resources of South Australia (PIRSA)	Northern Spencer Gulf Vibrocoring 1985-91	V. A. Gostin	118
	Adelaide Offshore Sands Investigation 1977-79	V. A. Gostin	31
	Beach Petroleum Survey, 1963	Unknown	1

A total of 280 samples identified in the SWPR (23% of the total) were not procured due to insufficient material for analysis or limited time available, and 64 samples (5%) of reduced volume were supplied. A total of 587 (49%) samples were obtained from Adelaide University, South Australian Research and Development Institute, Curtin University and Department of Primary Industries and Resources of South Australia. These contained enough material to be archived separately at Geoscience Australia, where they can be accessed by request. A total of 308 additional samples identified in external repositories and the scientific literature were found to no longer exist. Where previous analyses for grain size and carbonate concentrations had been performed on the sediment samples, and the metadata was of suitable quality, the results were added to the MARS database.

3.2. METADATA

Metadata for samples held at Geoscience Australia was already contained in the MARS database. However, the quality of the metadata for samples obtained from the external providers varied. Samples contained in international marine sediment databases (i.e., EU-SEASED, Report of Observations/Samples collected by Oceanographic Programmes (ROSCOP) and National Geophysical Data Center (NGDC) and from international repositories (e.g., Leibniz Institute of Marine Sciences (Geomar), International Ocean Drilling Program, and Lamont Doherty Earth Observatory) had the highest quality metadata, which required minimal manipulation for entry into the MARS database. Samples obtained from Australian universities generally contained no electronic metadata, and the metadata was entered into the MARS database manually. A total of 650 samples (54%) came with minimal metadata beyond survey name and sample number. The missing metadata for these samples was obtained from relevant survey reports, ship's logs, and the scientific literature. Metadata could not be found for 63 samples received from the Bass Strait Interdisciplinary Study (Franklin 01/1991), and these samples were not used in our study.

3.3. SAMPLE ANALYSIS

Sub-samples of between 12 and 50 g were required to complete all of the grain size and carbonate analyses undertaken for this study. Further information on the data analysis is available in Appendix C. Where possible, each sample was analysed for grain size and carbonate concentration, as follows:

- Mean grain size (Vol%; µm): The grain size distribution of the 0.01–2,000 µm fraction of the bulk sediment was determined with a Malvern Mastersizer 2000 laser particle analyser. All samples were wet sieved through a 2,000 µm mesh to remove the coarse fraction. A minimum of 1 g was used for relatively fine material and between 2–3 g for relatively coarse material. Samples are ultrasonically treated to ensure that good dispersion of the particles occurs. Distributions represent the average of three runs of 30,000 measurement snaps that are divided into 100 particle size bins of equal size.
- Grain size (Wt%): Gravel, sand, and mud concentrations were determined by passing 10–20 g of bulk sediment through standard mesh sizes (>2,000 µm; Gravel; 63 µm-2,000 µm; Sand; <63 µm Mud). The resulting gravel, sand, and mud concentrations represent dry weight proportions.
- Carbonate content (Wt%): Bulk, sand and mud carbonate concentrations were determined on 2–5 g of material using the 'Carbonate bomb' method of (Muller and Gastner, 1971). Carbonate gravel concentrations were determined by visual inspection.

All analyses were conducted by the Palaeontology and Sedimentology Laboratory at Geoscience Australia. For samples of <12 g preference was given to analyse laser grain size and bulk carbonate content.

3.4. MAP PRODUCTION

3.4.1. Gravel/Sand/Mud% and Folk Sediment Type Classification and Carbonate content

Maps for %Gravel, %Sand, %Mud, Folk Class, and %Carbonate were produced by:

- Querying the MARS database to obtain all numeric grain size and carbonate content information in the SWPR;
- Compiling the results into gravel, sand and mud fractions (%), mean grain size (µm) and carbonate (%);
- Checking that gravel, sand and mud for each sample had all three fractions reported, and that these fractions were in the appropriate range when summed (98-102%); and then
- Checking for and resolving cases of duplication.

The sediment classification proposed by Folk (1954) has been used to present information on sediment type. Mean grain size data was entered into the GRADISTAT sediments statistics computer program to provide the folk classification for each sample. This method produces a single value and corresponding Folk classification, which is then presented on a map.

4. Quantitative Description of the SWPR

4.1. GEOMORPHOLOGY

The SWPR covers an area of 1,375,000 km² which represents around 15% of the Australian EEZ. Four geomorphic provinces are represented in the SWPR (Figs. 4.1 and 4.2; Table 4.1). Slope makes up the largest area (41%, 574,500 km²), followed by the abyssal plain/deep ocean floor (30%, 413,000 km), shelf (24%, 334,600 km), and rise (4%, 52,200 km). Relative to the rest of Australia's EEZ the SWPR has a significantly larger percentage of slope and rise (Table 4.1). The SWPR contains approximately 54% of area of rise in the entire EEZ (Fig. 4.2; Table 4.1).

Of the 21 geomorphic features defined on the Australian margin, 19 are represented in the SWPR. A total of 18 are included in our study. Seamount/guyots and sills are not represented. In addition, saddles cover <1 km², and therefore they have been excluded from the analysis (Table 4.1).

Large areas of the shelf, slope and abyssal plain in the SWPR have no geomorphic features identified within them. These areas form 69% of the total SWPR area (shelf = 22%, slope = 25%, and abyssal plain/deep ocean floor = 22%). Geomorphic features covering significant areas of these provinces include terraces on the shelf and slope which comprise 185,700 km² (14%) of the SWPR area and knoll/abyssal hills/hills/mountain/peak found on the shelf, slope and abyssal plain/deep ocean floor (66,800 km²; 5% SWPR area). No geomorphic features are identified on the rise (Table 4.1).

The SWPR contains a large proportion of the total area of several geomorphic features over the EEZ (Fig. 4.3). Relative to the entire EEZ, the SWPR contains a relatively large area of canyons, knoll/abyssal hills/hills/mountain/peaks, ridges, and terraces. Terraces in the SWPR cover 185,660 km² or 32% of the total area of terraces in the EEZ, followed by ridges (39,660 km²; 36%); knoll/abyssal hills/hills/mountain/peaks (66,800 km²; 56%), submarine canyons (29,200 km²; 27%), and rise (52,200 km²; 54%) (Fig. 4.4; Table 4.1).

4.2. BATHYMETRY

Water depths in the SWPR range from 0 – 7,390 m (Fig. 4.5). The boundaries of the SWPR also include areas where water depths are <10 m. These include intertidal zones and areas of land on islands. These areas have not been included in the analyses.

The SWPR is dominated by shallow water and deep water areas with >25% of the total area occurring in water depths of <150 m and almost 50% of the SWPR occurring in water depths >4,000 m. Compared with the entire EEZ, the SWPR contains a very large proportion of deep water areas. Water depths of >4,000 m form only 35% of the area of the Australian EEZ (Fig. 4.6).

More than 99% of the area of the rise and abyssal plain/deep ocean floor in the SWPR occurs in waters depths of >4,000 m. These depths are deeper than those typically found for these provinces across the entire EEZ (Fig. 4.8). The difference between the depth distributions for these provinces in the SWPR and EEZ reflect differences in the gross geomorphology within these provinces. Across the entire EEZ, geomorphic features such as seamounts/guyot and pinnacles extend into shallower water on these provinces. In the SWPR these features are rare or absent, and almost 75% of the abyssal plain/deep ocean floor contains no identified geomorphic features due to sparse data coverage (Appendix A).

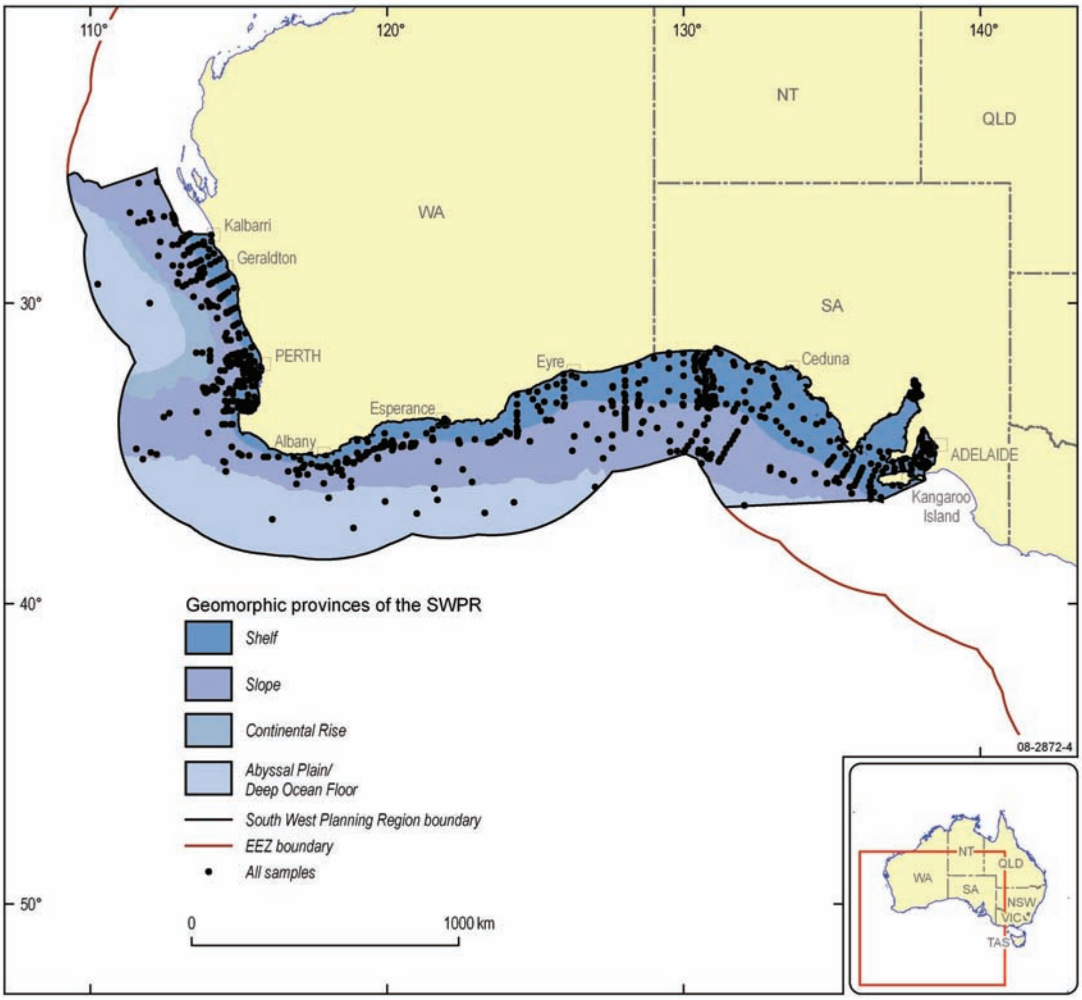

Figure 4.1. Map showing the geomorphic provinces of the SWPR.

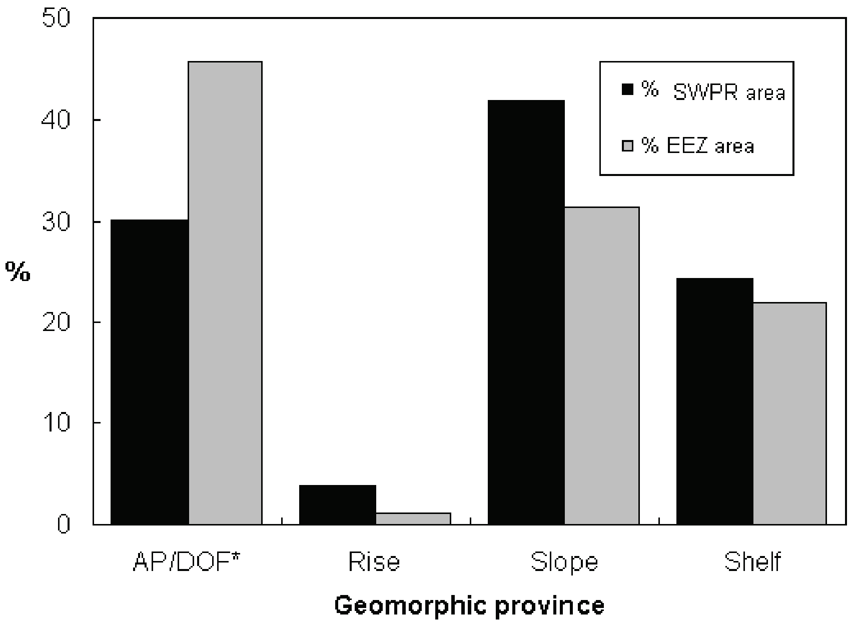

Figure 4.2. Graph showing the area of the geomorphic provinces for the SWPR (black bars) and EEZ (grey bars) expressed as percent.

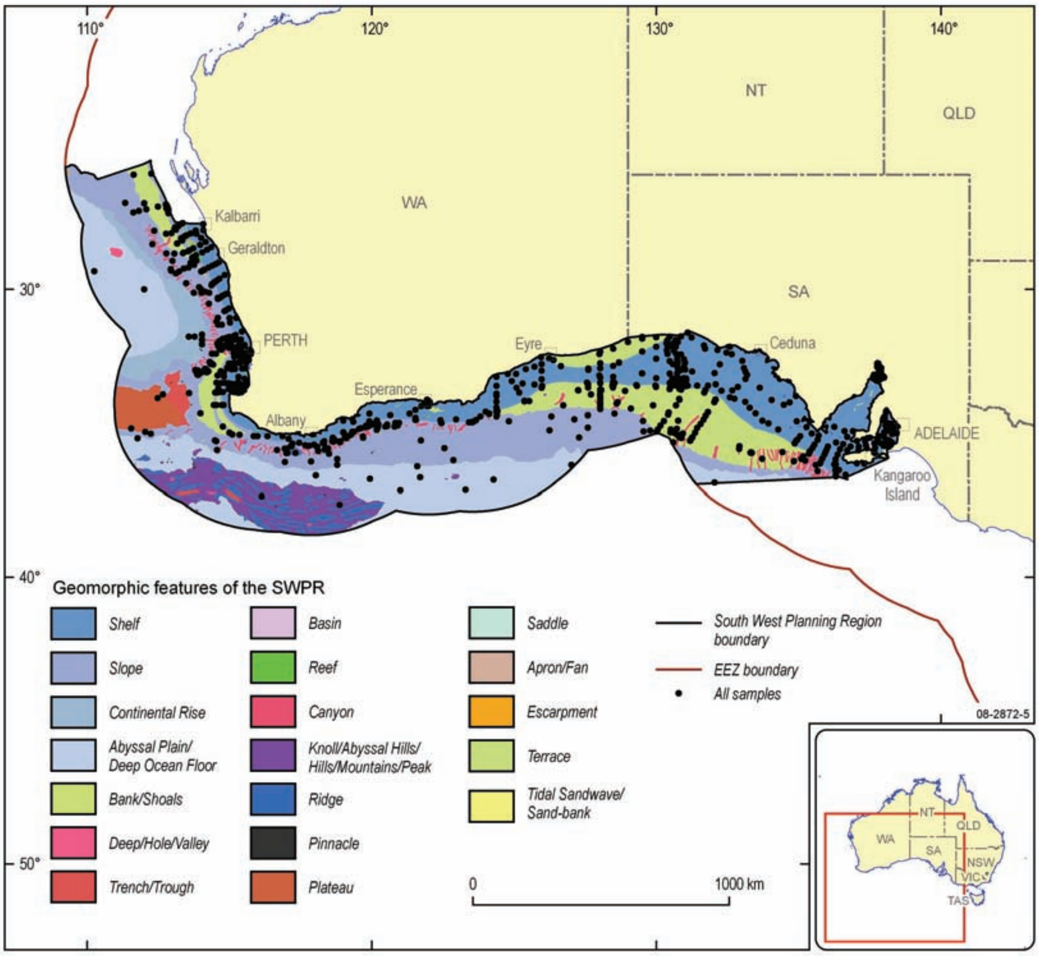

Figure 4.1. Map showing the geomorphic features of the SWPR (after Harris et al., 2005)

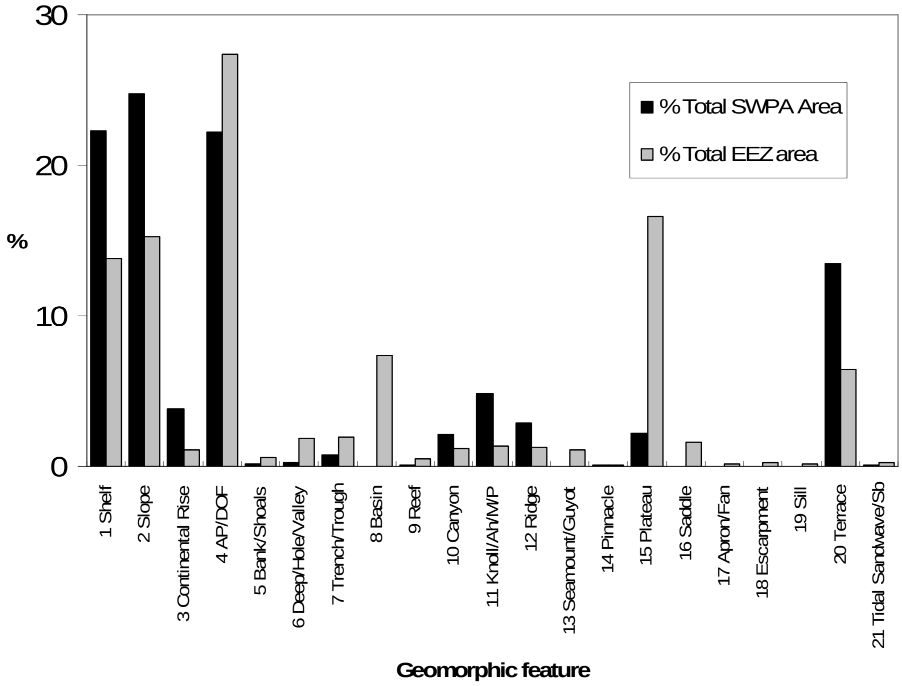

Figure 4.2. Graph showing the area of geomorphic features for the SWPR (black bars) and EEZ (grey bars) expressed as percent.

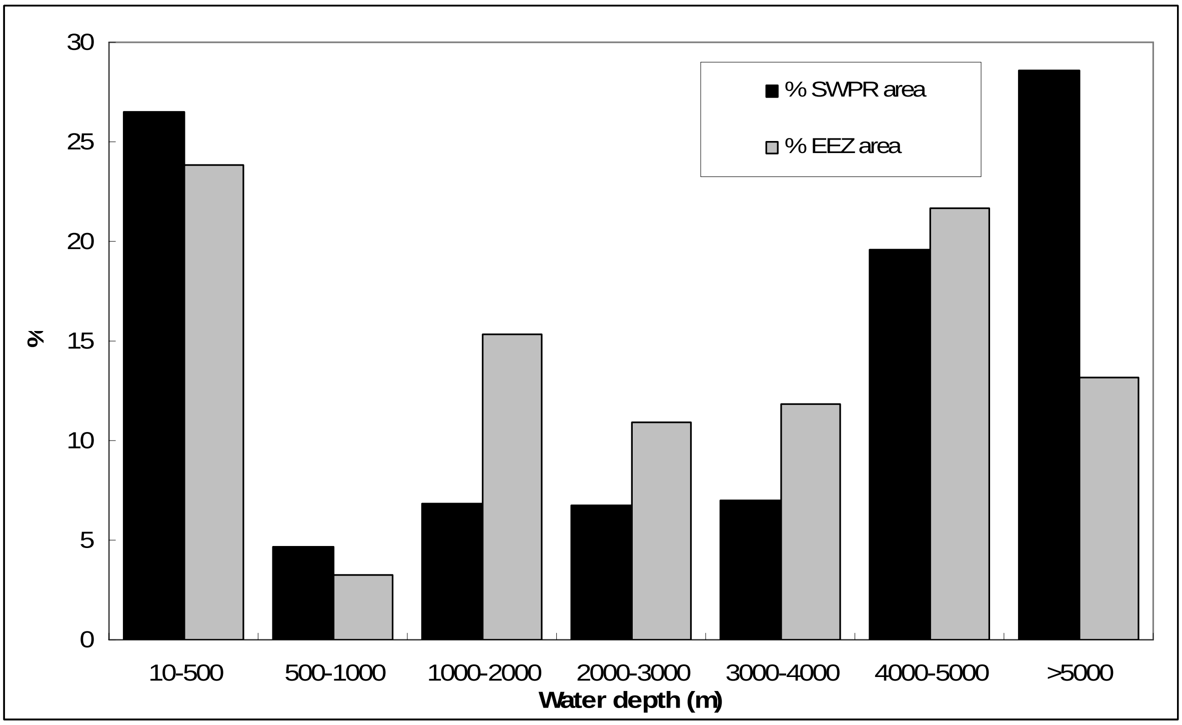

Figure 4.5 Graph showing the area covered by each water depth class for the SWPR (black bars) and EEZ (grey bars) expressed as percent.

Table 4.1. Statistics of geomorphic provinces and features of the SWPR

Feature	Area in SWPR	% total* SWPR Area	% EEZ Area	% Total EEZ area located in SWPR	Water Depth Range* in SWPR (m)
Geomorphic Provinces					
Shelf	334,600	24.35	21.91	16.93	10 – 2,390
Slope	574,500	41.80	31.31	20.35	10 – 5,890
Rise	52,200	3.80	1.08	53.81	2,830 – 5,940
AP/DOF*	413,000	30.05	45.71	10.02	840 – 7,390
Geomorphic Features					
Shelf (unassigned)	306,700	22.32	13.79	24.65	10 – 2,390
Slope (unassigned)	340,100	24.74	15.23	24.75	10 – 5,840
Rise (unassigned)	52,200	3.78	1.06	54.49	3,840 – 5,940
AP/DOF* (unassigned)	304,600	22.16	27.34	12.35	1,650 – 6,440
Apron/fan	200	0.018	0.13	2.08	10 – 40
Bank/shoal	1,800	0.13	0.56	3.65	10 – 5,890
Basin	500	0.037	7.36	0.08	20 – 40
Deep/hole/valley	3,400	0.25	1.93	2.04	30 – 6,170
Canyon	29,200	2.12	1.18	27.33	50 – 5,290
Knoll/abyssal-hills/hills/ peak	66,800	4.86	1.32	56.35	10 – 7,250
Escarpment	200	0.018	0.23	1.19	4,000 – 4,270
Pinnacle	700	0.051	0.06	13.73	10 – 5,950
Plateau	29,800	2.17	16.59	1.99	1,970 – 3,130

Reef	1,400	0.10	0.52	3.09	10 – 100
Ridge	39,700	2.89	1.24	35.56	840 – 6,970
Terrace	185,700	13.51	6.43	32.03	10 – 5,020
Tidal-sandwave/sand-bank	800	0.058	0.27	3.34	10 – 60
Trench/trough	10,500	0.76	1.93	6.03	2,780 – 7,390
TOTAL	1,374,900*				

* AP/DOF = Abyssal plain/deep ocean floor.
^ Does not include areas designated as land and water shallower than 10 m totalling 640 km².
Areas for EEZ geomorphic provinces calculated in GIS from geofeatures file (2005); areas for features in EEZ and provinces and features in SWPR calculated using polygon shapefile and boundaries current as at 09/06.

The SWPR includes deep water banks/shoals, with 320 km² or 20% of the total SWPR area for this feature occurring in water depths of >3000 m. By contrast, more than 95% of the area of these features across the EEZ occurs in water shallower than 500 m. Deep/holes/valleys in the SWPR occur in both very deep (>5,000 m) or shallow (<500 m) water. Across the entire EEZ more than 99,090 km² or 60% of the total area of these features occurs in water depths of <500 m, and less than 10% of the total area occurs in water depths of >4,000 m.

Basins and apron/fans in the SWPR occur only in water shallower than 500 m. Across the entire EEZ more than 50% of the area of basins and around 40% of the area of apron/fans occurs at water depths >3000 m. As such, basins and apron/fans in the SWPR may not include all habitats occurring in these geomorphic features across the entire EEZ.

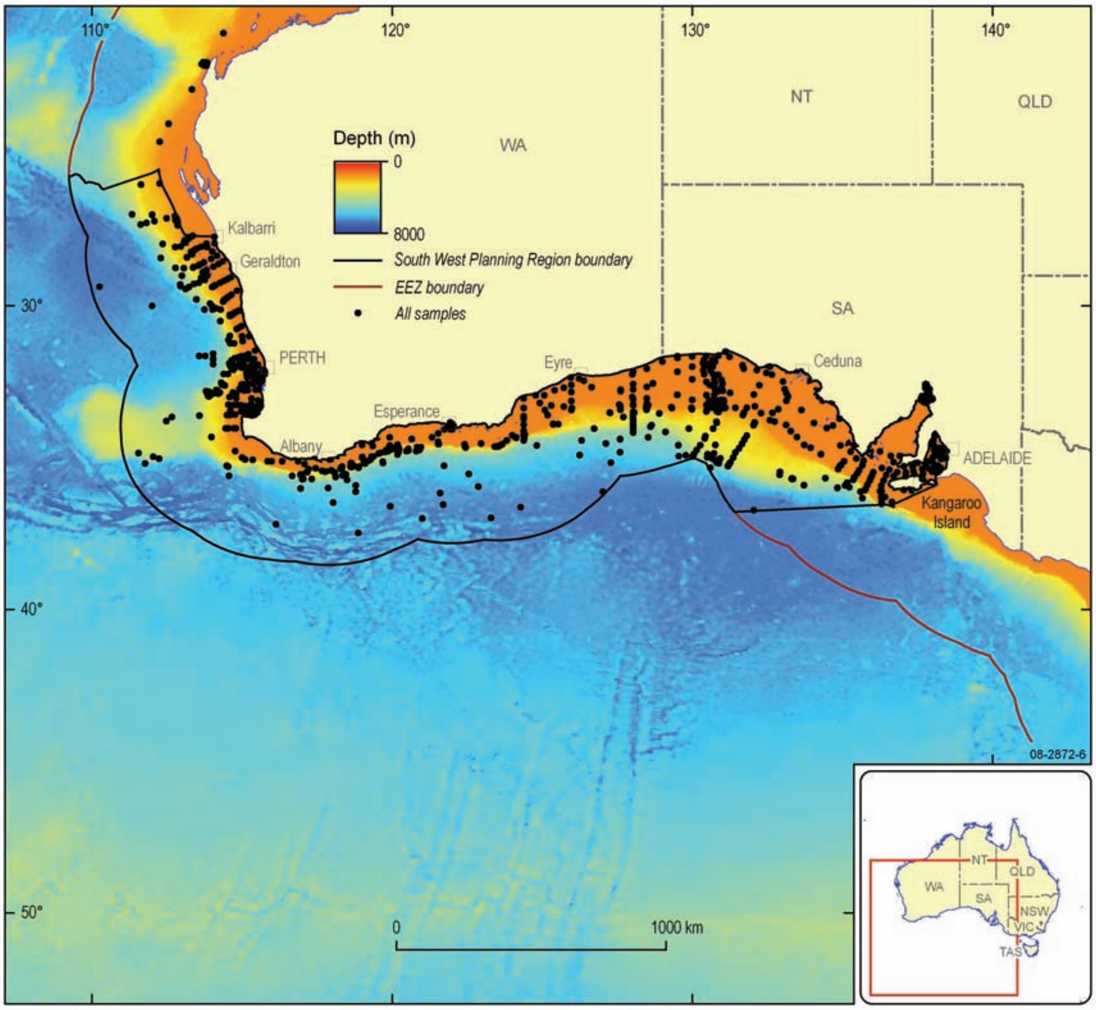

Figure 4.6. Map showing the bathymetry for the SWPR and the sample points used in this study.

4.3. SEDIMENT DATA COVERAGE

Sample density varies significantly across the SWPR (Fig. 4.7). More than 35% of the total area of the SWPR is within 25 km of a sample, 50% of the total area is within 100 km of nearest samples, and 15% of the total area remains at a distance of >100 km from the nearest sample (Fig. 4.8). Samples are clustered as a result of collection on surveys of local areas or targeting specific seabed features. In general, sample coverage is denser in shallower water and in proximity to the coastline where the seabed is more accessible.

A total of 703 (60%) samples occur on the shelf, which covers 334,600 km^2 or 24% of the total SWPR area, which results in an average sample density of ~1:500 km^2 (Figs. 4.9 and 4.11; Table 4.2). A total of 474 (40%) samples occur on the slope, which covers 574,460 km^2 (40%) of the SWPR area, giving a sample density of 1:1,200 km^2 (Figs. 4.9 and 4.11; Table 4.2). Only 21 (<5%) samples occur on the rise and abyssal plain/deep ocean floor, although these cover a total of 465,240 km^2 (34%) of the SWPR, giving an average sample density of ~1:27,500 km^2 and 1:8,700 km^2 for the abyssal plain/deep ocean floor and rise, respectively (Fig. 4.11; Table 4.2).

Samples cover 13 of the 18 geomorphic features present in the SWPR. No samples were collected from basin, reef, escarpment, apron/fan and trench/trough features. Together, these features cover approximately 14,000 km^2 (1%) of the SWPR (Fig. 4.11; Table 4.2).

Highest sample densities were achieved on banks (~1:50 km), followed by deep/holes (~1:350), canyons (~1:400), terraces (1:1,100), shelf (1:500), and tidal sand waves/sand banks (~1:50km). Poorer coverage was obtained for the abyssal plain/deep ocean floor (1:23,500), rise (1:1000), plateaus (1:7,500), knoll/abyssal hills/hills/peak (1:33,400), and ridge (1:19,800) (Table 4.2).

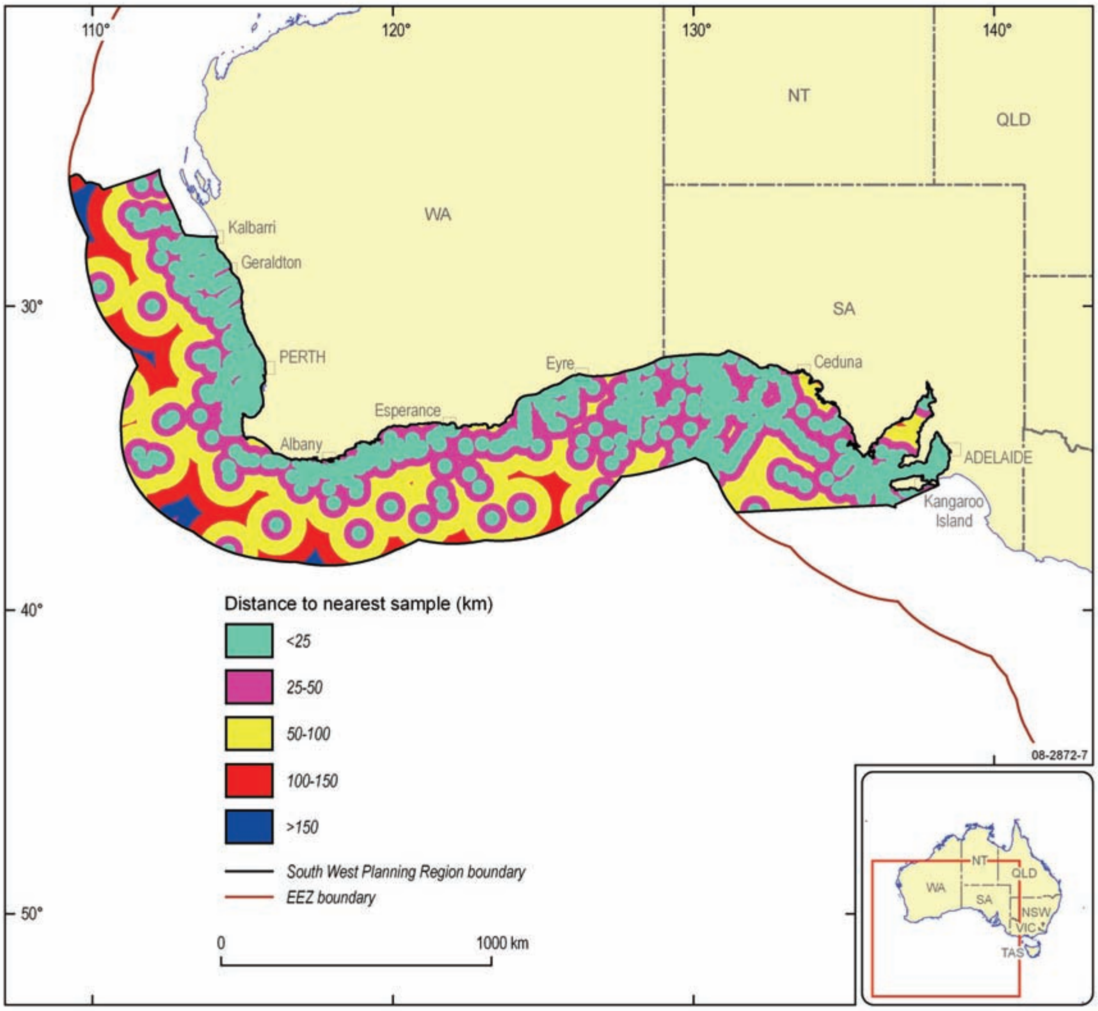

Figure 4.7. Map showing the sample density distribution across the SWPR.

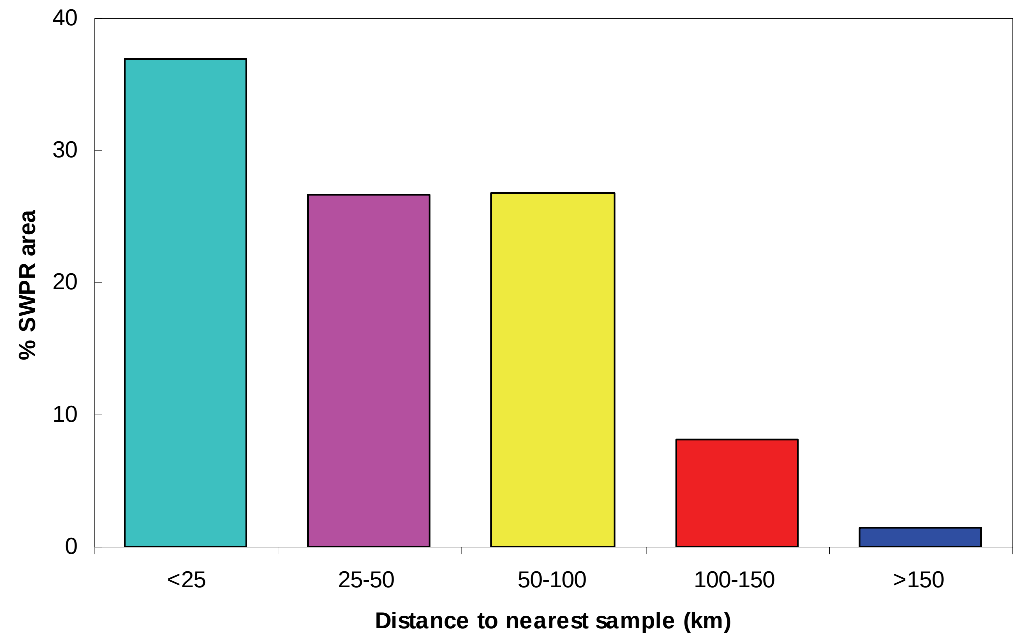

Figure 4.8. Graph showing the frequency distributions of sample density within the SWPR.

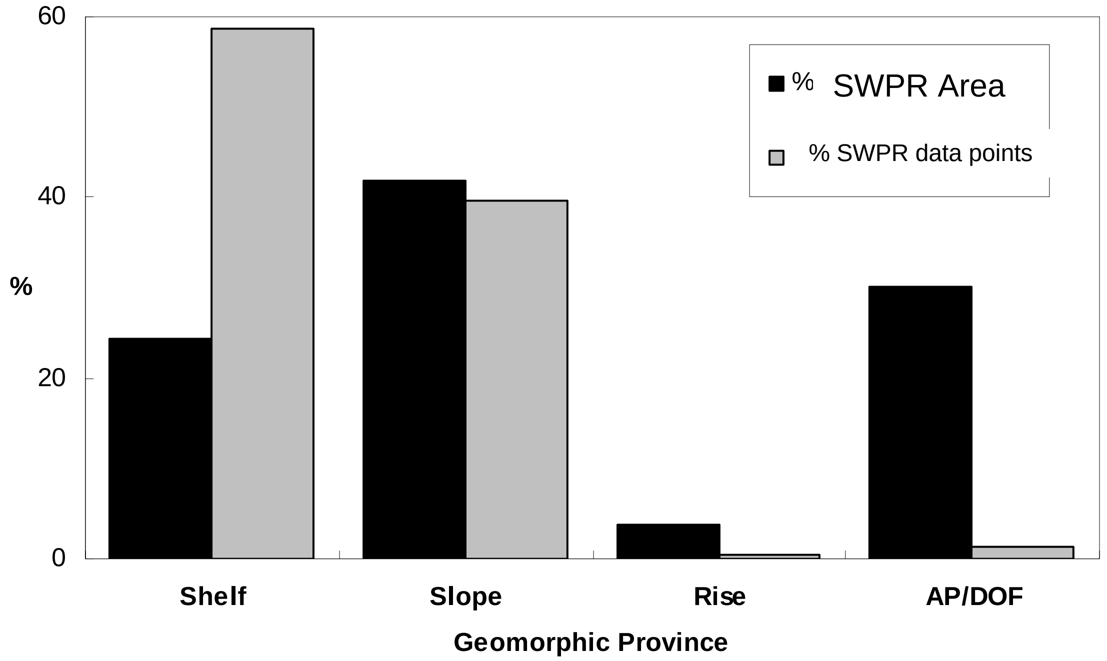

Figure 4.9. Graph showing coverage of geomorphic province covered by sample points expressed as percent (grey bars) and total geomorphic province area expressed as percent (black bars) for SWPR.

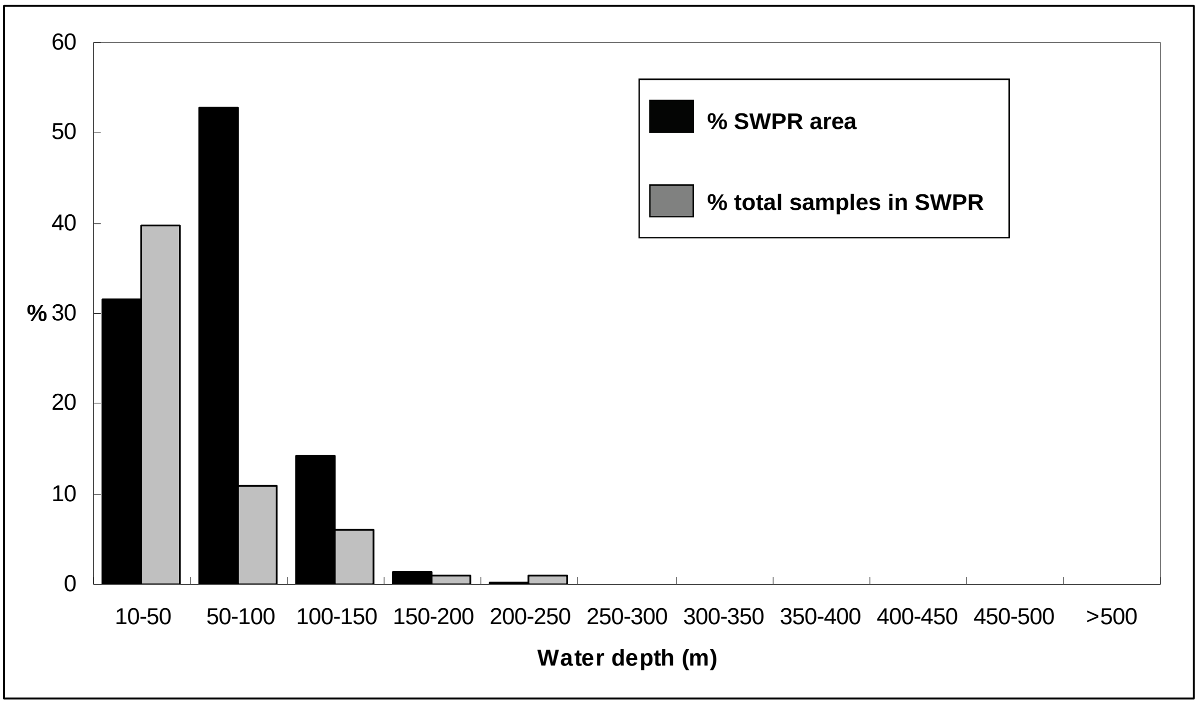

Figure 4.10. Graph showing percent sample coverage by water depth for the continental shelf in the SWPR. Percent total area of the SWPR (black bars) is compared to percent total samples in the SWPR (grey bars).

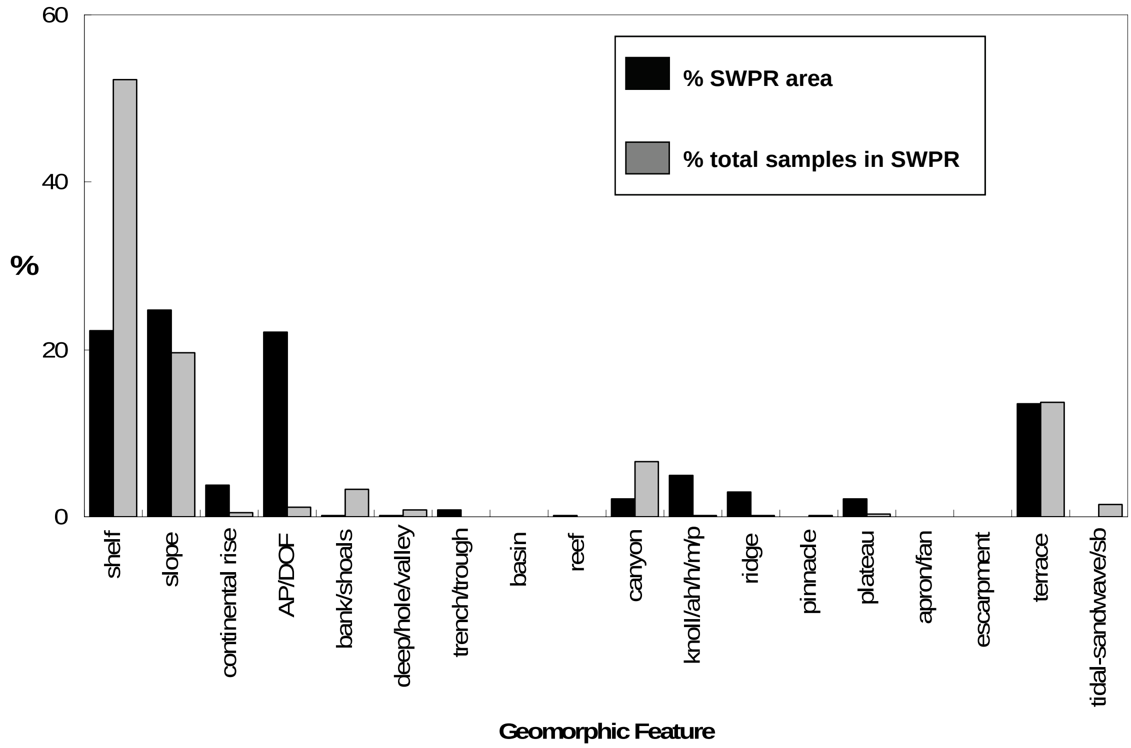

Figure 4.11. Graph showing sample coverage of geomorphic features expressed as percent total samples in the SWPR (grey bars) and total SWPR area of geomorphic features expressed as percent (black bars) for SWPR.

Table 4.2. Data density statistics for geomorphic provinces and features.

Feature	Total number of samples	Average density (samples per km²)	Adequate coverage to assess sedimentology in these bioregions
Geomorphic Provinces			
Shelf	703	~1:500	Bioregion level in SWIT,SWI,SG, GAB
Slope	474	~1:1,200	Bioregion level in SWT, CW, SP
Rise	6	~1:8,700	Bioregion level in CW
AP/DOF*	15	~1:27,500	Bioregion level in SWI, CW, SP
Geomorphic Features			
Shelf (unassigned)	626	~1:500	Bioregion level in SWIT, SWI, SG, GAB
Slope (unassigned)	235	~1:1500	Bioregion level in SWT, CW, SP
Rise (unassigned)	6	~1:1000	Bioregion level in CW
AP/DOF* (unassigned)	13	~1:23,500	Bioregion level in SWI, CW, SP
Bank/shoal	40	~1:50	Bioregion level in SWI, SG
Deep/hole/valley	10	~1:350	Bioregion level in SWI
Canyon	79	~1:400	Bioregion level in SP, CW
Knoll/abyssal-hills/hills/ peak	2	~1:33,400	Only at SWPR level
Pinnacle	1	~1:700	Only at SWPR level
Plateau	4	~1:7,500	Bioregion level in SWT
Ridge	2	~1:19,800	Only at SWPR level
Terrace	163	~1:1100	At bioregion level in SWT, CW, SP, GAB
Tidal sandwave/sand bank	17	~1:50	At bioregion level in SG

There were no data points located in basin, reef, escarpment, apron/fan and trench/trough features.

4.4. QUANTITATIVE REGIONAL SEDIMENT DISTRIBUTION FOR THE SWPR

4.4.1. Overview of Distribution and Properties

Sediments in the SWPR are generally either sand or mud dominated, with gravel forming only a minor component at most locations. On average, sand comprises >35% and mud <60% of sediment, but the ratio of these two fractions is highly variable. Gravel contents are generally <10%, although concentrations attain >90 at eight sites sampled.

The spatial distribution of gravel (Fig. 4.12), sand (Fig. 4.14) and mud (Figs. 4.16) has been interpreted by interpolating sediment properties from sample points. Interpolation of the sediment data achieves a total coverage of 825,000 km² or 60% of the SWPR area, including complete coverage of the shelf (Fig. 4.18). As a result, distribution of sediment fractions can only be given as percentages of the total shelf area.

Histograms for sediment fractions (Figs. 4.13, 4.15 & 4.17) highlight the dominance of sand sized sediment on the shelf, evident by the strongly negatively skewed distributions for mud and gravel, and the slightly less extreme positive skew of the sand distribution (Fig.

4.15). The high proportion of samples located in shallow water where sand content is higher and mud content is generally lower means that there results are likely to overstate the abundance of sand.

Maps of interpolated sediment properties highlight regional-scale spatial trends in the distribution of sand, mud and gravel (Fig. 4.21). Interpretations of regional-scale sediment distribution and abundance based on interpolated maps are generally borne out by observation of raw point data. Interpolated maps highlight a strong relationship between sediment texture and water depth. This is supported by statistics generated from point assays and Folk classifications of the seabed sediments, which show an overall fining of sediment texture with increasing water depth (Figs. 4.18 & 4.22). Overall, gravel content is observed to decrease and mud content increase with increasing water depth. Large variations in sediment texture that do not follow these trends occur locally, but are interpreted to be of limited spatial extent.

Sandy sediments generally occur on the shelf; with more than 301,150 km^2 or 90% of the total shelf area estimated to comprise sediments with a sand content exceeding 60%. Gravel is abundant south west of Eyre and Perth and just offshore of Esperance on the inner shelf (Fig. 4.12). However, the total area where the gravel content exceeds 80% is estimated to cover only 13,400 km^2 (<5%) of the total shelf area. Gravel contents of <20% are estimated to cover 301,150 km^2 (90%) of the shelf, but gravel was not detected in samples on most of the slope, rise and abyssal plain/deep ocean floor. Similarly, mud contents of <20% are estimated to cover the same area of the shelf, although mud generally comprises >60% of the sediment on the slope, rise and abyssal plain/deep ocean floor (Fig. 4.16).

Across the SWPR, sediments are dominated by carbonate grains, with bulk carbonate content and mean concentrations in all textural fractions exceeding 80% at 682 sites or 75% of the locations where samples were analysed for carbonate content (Figs. 4.18 & 4.19). Sediments dominated by non-carbonate grains are present particularly in deep water, and are likely to be understated in statistics as few assays are available from these areas.

Mud and sand carbonate content varies across the SWPR, with carbonate sand concentrations ranging between 65 and 100%, and carbonate mud concentrations ranging between 65 and 95% (Fig. 4.20). Carbonate sand and mud concentrations <65% occur locally and form a small percentage of the total sites sampled. Where sampled, gravel is composed almost entirely of carbonate grains, with concentrations of >90% at 570 sites or 80% of locations where gravel was sampled.

At a regional scale, carbonate contents show zoning from high to low with increasing water depth (Fig. 4.19). Sediment with bulk carbonate contents of >80% are estimated to cover a total area of 301,150 km^2 (90%) of the shelf. Carbonate content is most consistently high (80%) on the middle and outer shelves. Very low carbonate contents (<20%) occur on the inner shelf in close proximity to the coast (Fig. 4.19). However, assays in this area suggest these sediments are of limited spatial extent. Their abundance and distribution are interpreted in Figure 4.19 which shows sediment comprising <40% cover 13,000 km^2 or <5% of the shelf area. Carbonate content is more variable on the slope, ranging from 60 to 100%. Carbonate contents is consistently lower on the abyssal plain/deep ocean floor, with 12 (80%) samples containing <50% carbonate.

Low bulk carbonate contents correspond to highs in gravel carbonate contents (inner shelf locations) and mud carbonate contents (abyssal plain/deep ocean floor). Previous studies show that non-carbonate grains in gravels in the SWPR are mainly terrigenous in origin (e.g., Carrigy, 1956; Conolly & Von der Borch, 1967; Gostin et al., 1984; James et al., 2001), while those in deep water mud are most likely biogenic (e.g., diatoms, sponge spicules).

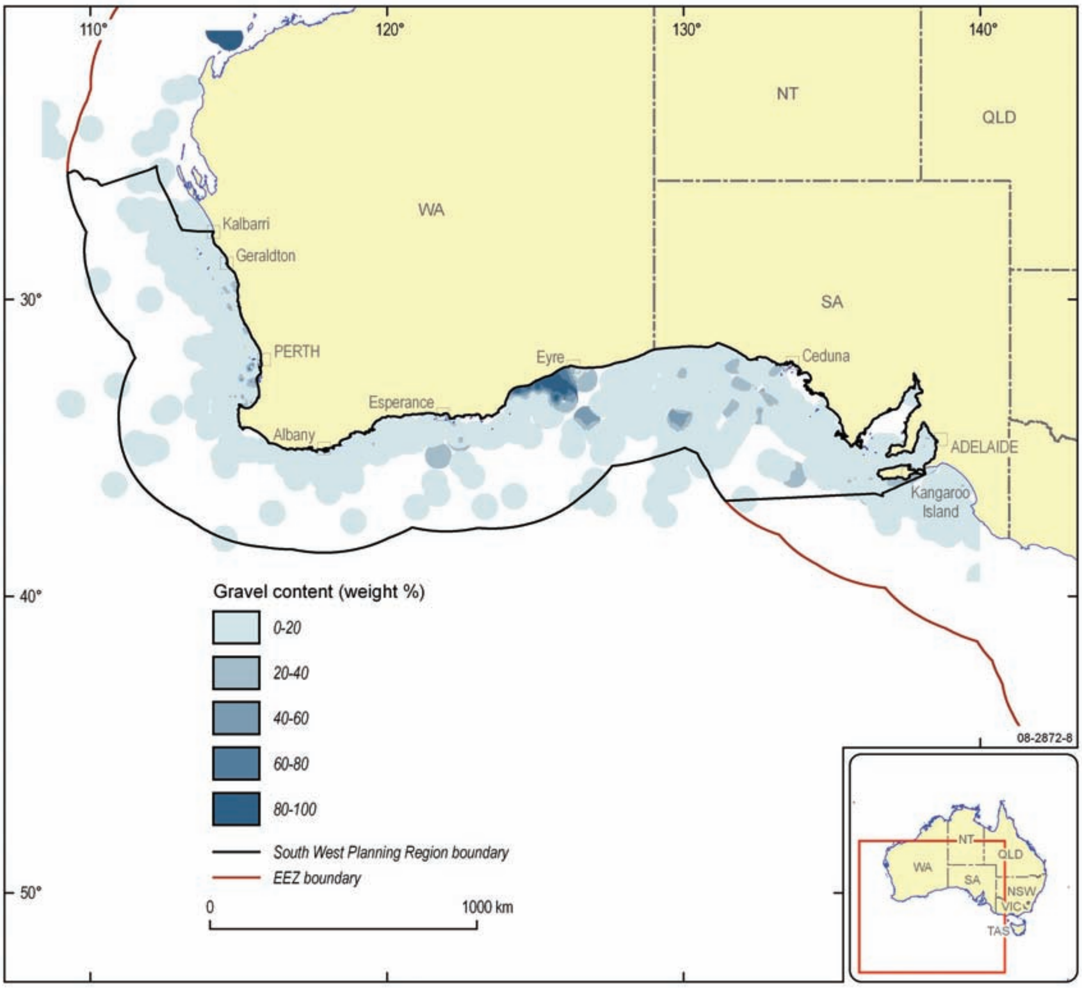

Figure 4.12. Map showing the distribution of gravel in the SWPR derived from interpolated data.

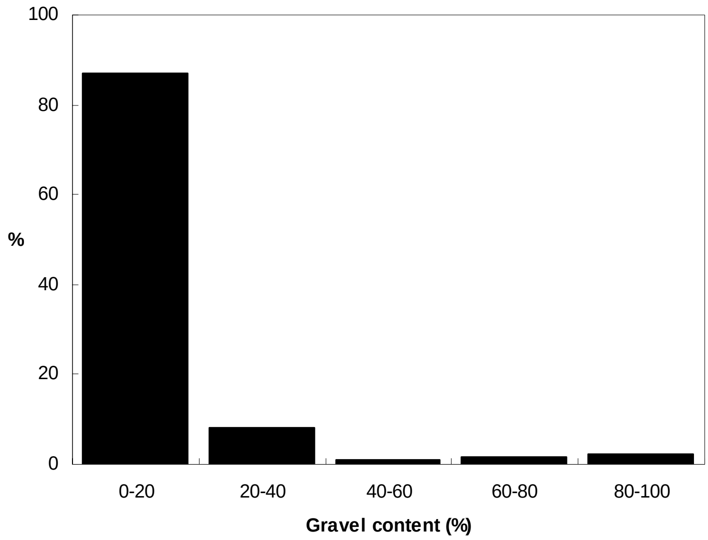

Figure 4.13. Graph showing the distribution of gravel in the SWPR derived from interpolated data (shelf only).

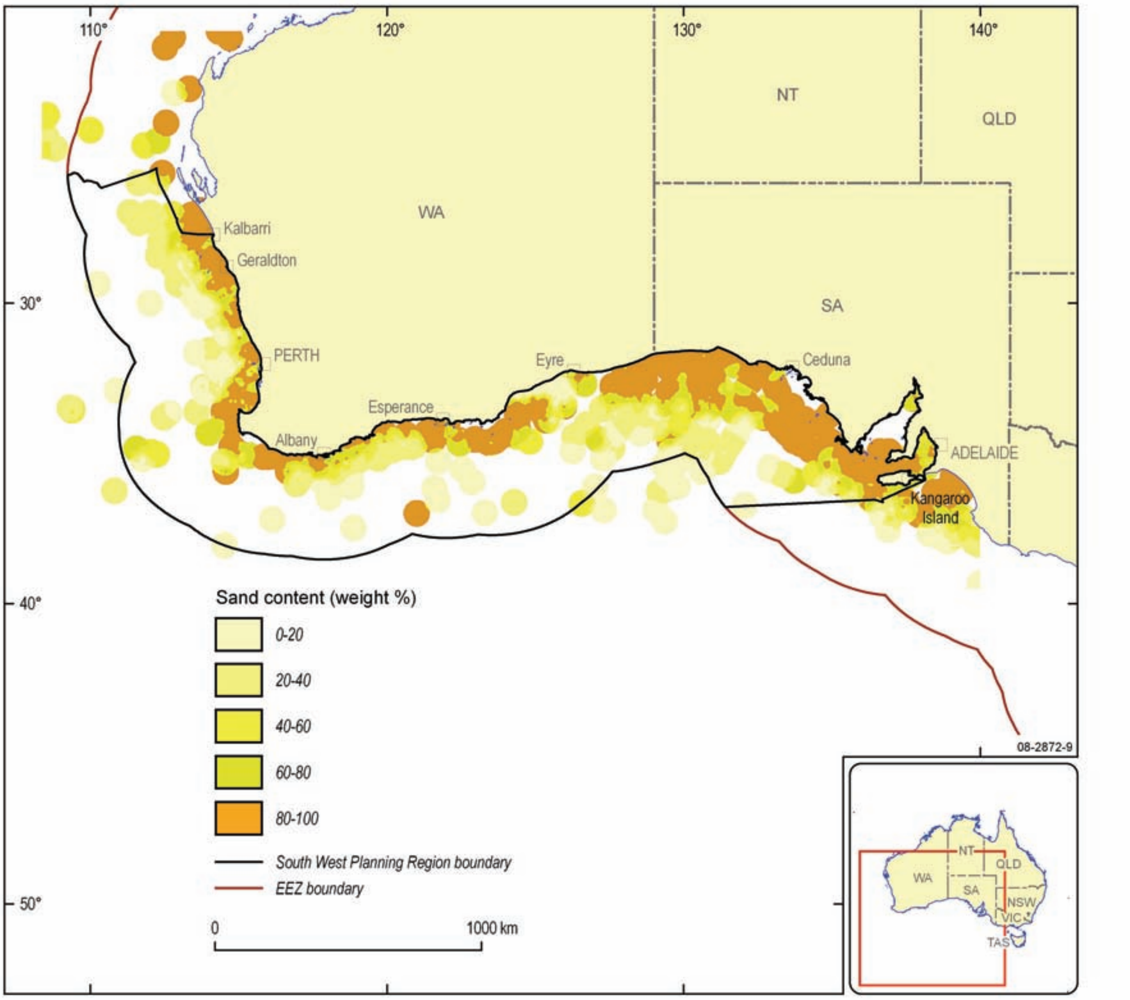

Figure 4.14. Map showing the distribution of sand in the SWPR derived from interpolated data.

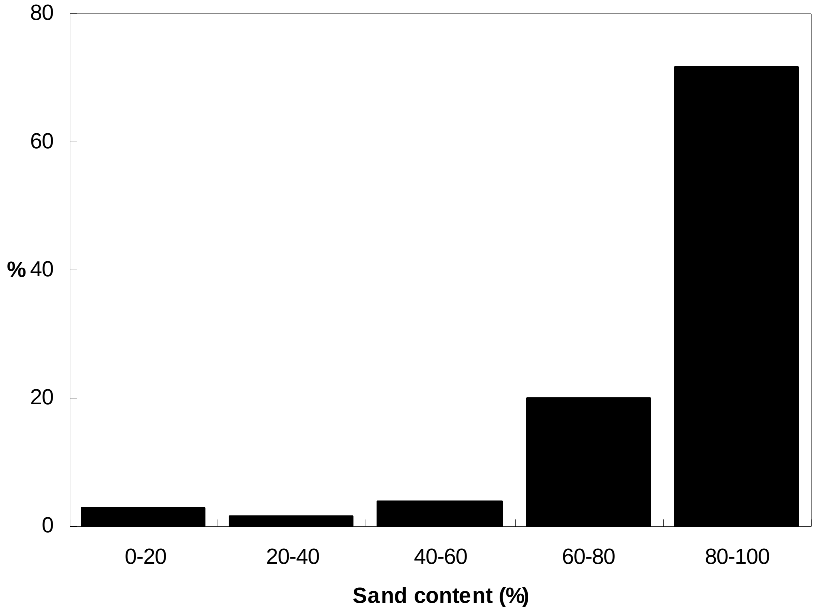

Figure 4.15. Graph showing the distribution of sand in the SWPR derived from interpolated data (shelf only).

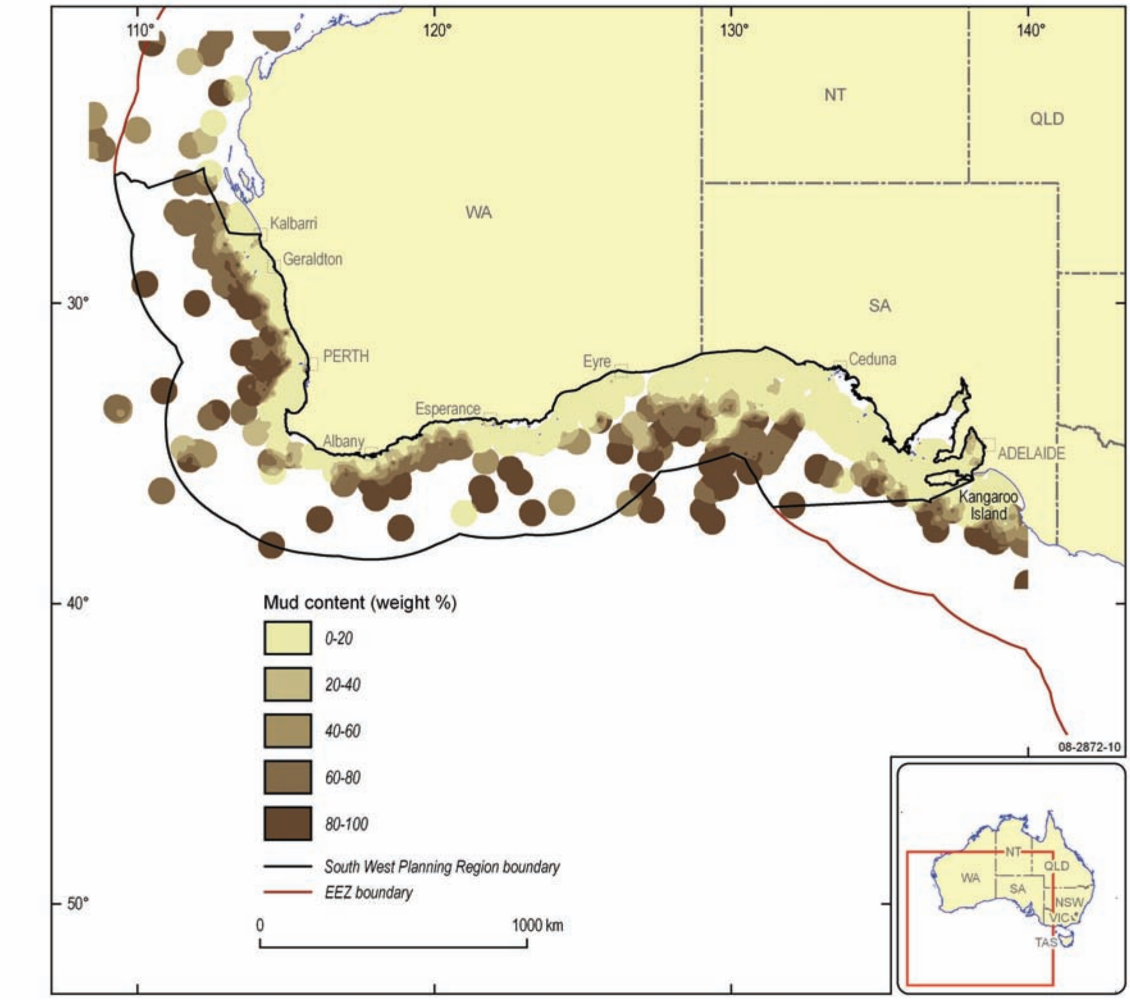

Figure 4.16. Map showing the distribution of mud in the SWPR derived from interpolated data.

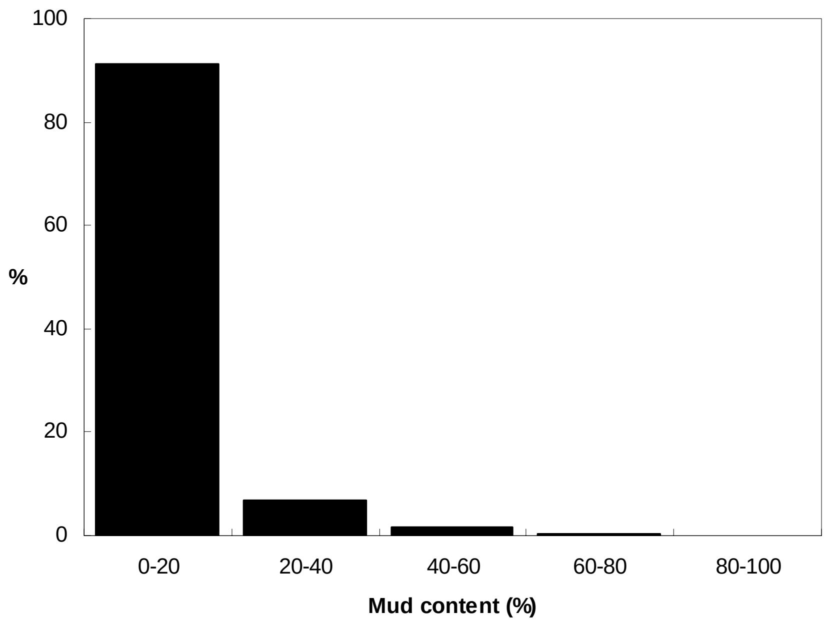

Figure 4.17. Graph showing the distribution of mud in the SWPR derived from interpolated data (shelf only).

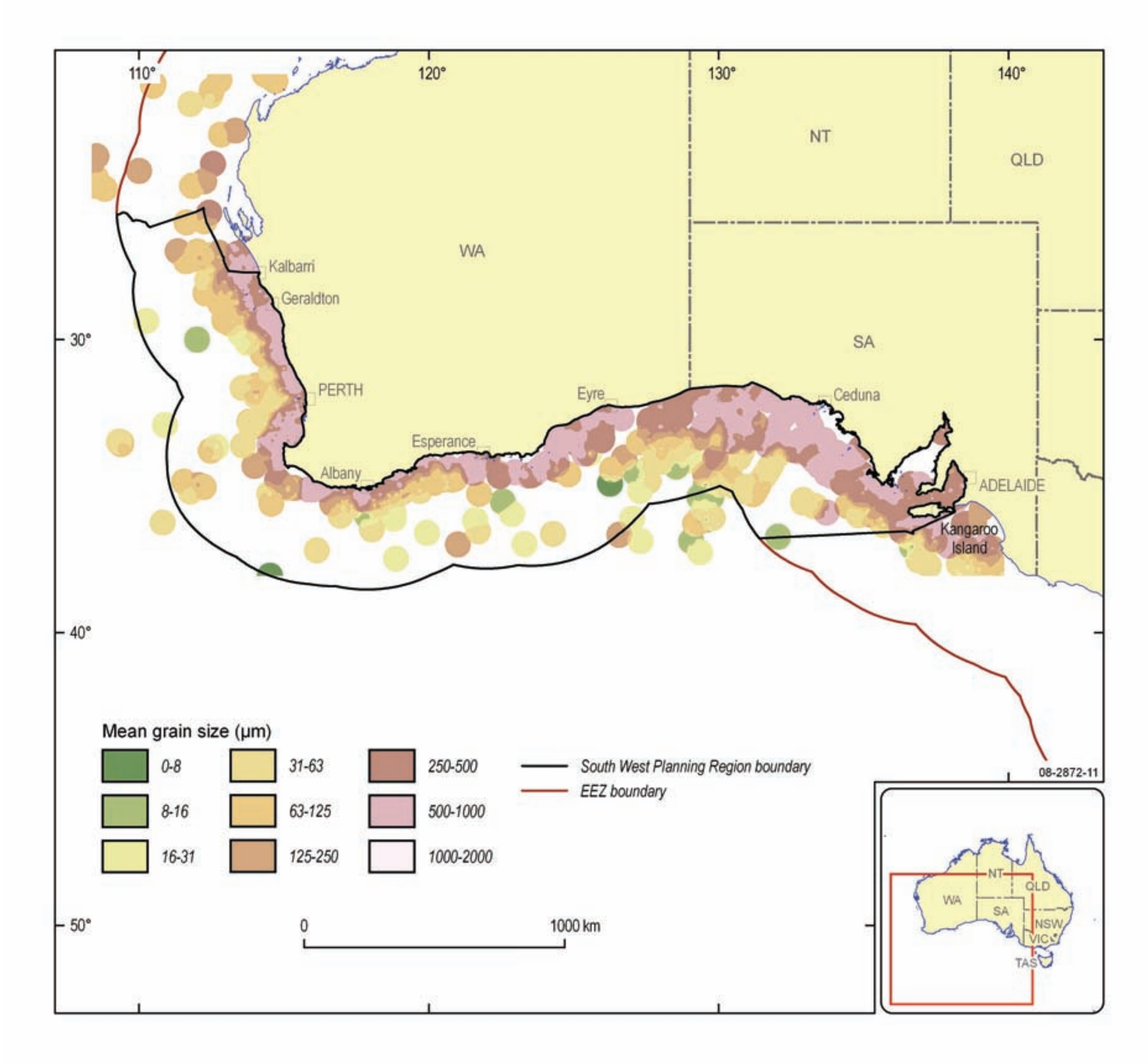

Figure 4.18. Map showing the distribution of mean grain size (µm) in the SWPR derived from interpolated data.

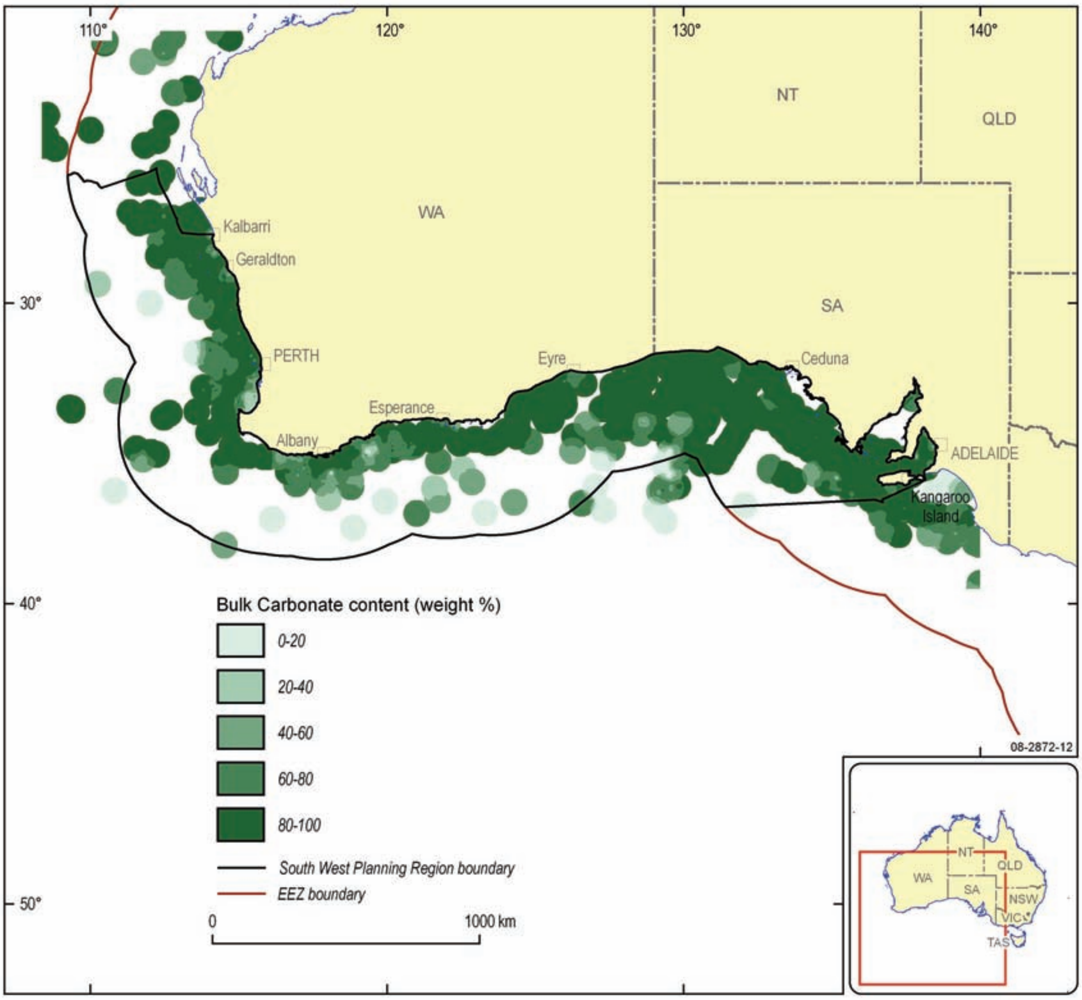

Figure 4.19. Map showing the distribution of bulk carbonate content in the SWPR derived from interpolated data.

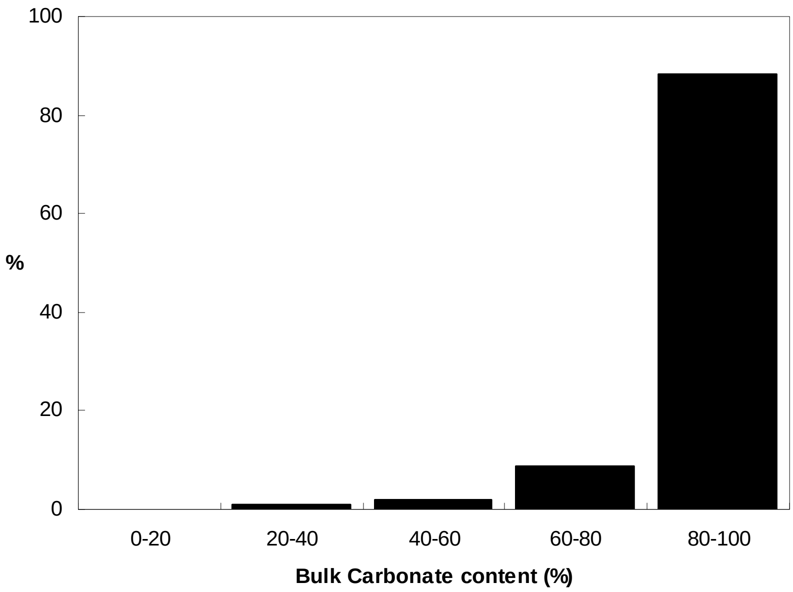

Figure 4.20. Graph showing distribution of bulk carbonate content in the SWPR derived from interpolated data (shelf only).

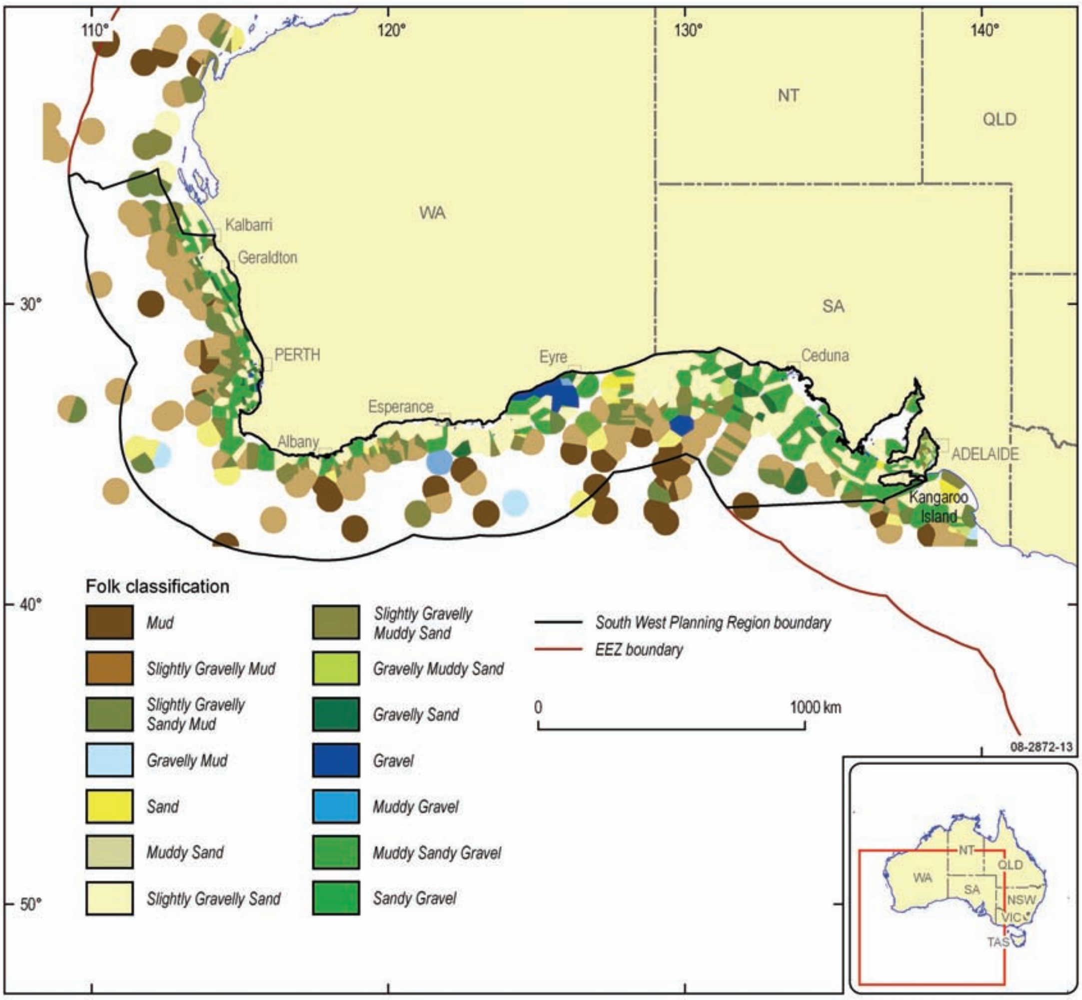

Figure 4.21. Map showing the Folk (1954) classification of seabed sediments across the SWPR.

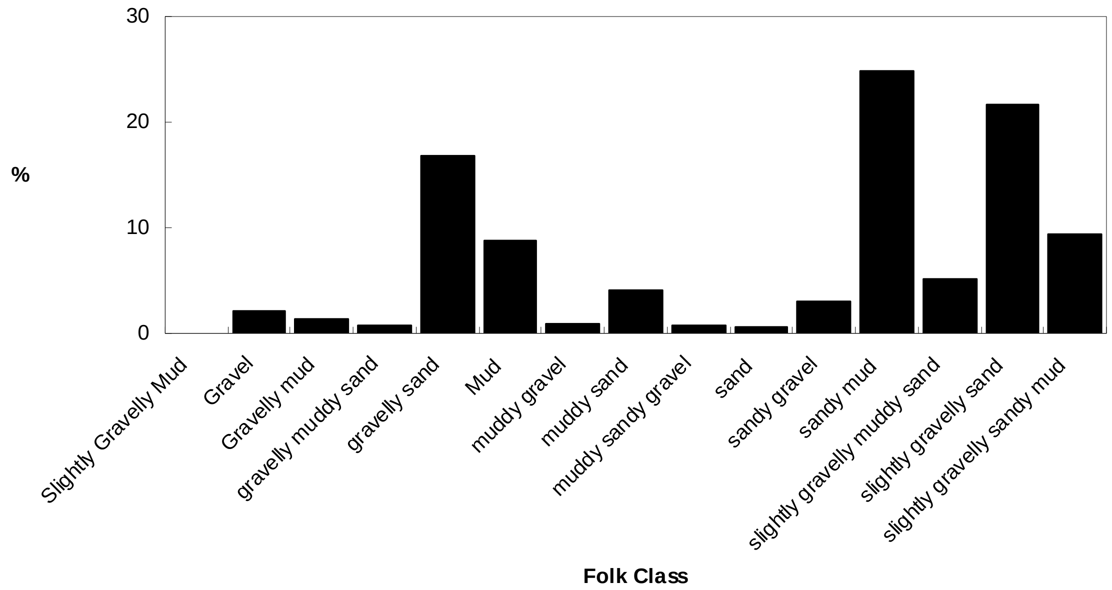

Figure 4.22. Graph showing distribution of Folk (1954) classes across the SWPR.

4.4.2. Sedimentology of Geomorphic Provinces of the SWPR

4.4.2.1. Shelf

Shelf sediments are dominated by sand, with 480 of the 663 samples comprising >70% sand (Fig. 4.14). By contrast, gravel and mud contents are generally low (<20%). However, samples dominated by mud (55 samples) occur mainly clustered on the inner shelf offshore of Perth (35 samples) and in the Spencer and St Vincent Gulfs. Gravel dominated samples (36 samples) are generally restricted to the shelf between Perth and Cape Naturaliste (9 samples), off Esperence (16 samples), and south west of Eyre (11 samples). Data coverage of the shelf is dense enough that we may conclude areas of high gravel content are relatively rare in this province of the SWPR and tend to be of limited spatial extent. The exception to this is a relatively extensive area of gravel in GAB south west of Eyre (Fig. 4.12).

Bulk carbonate content for the shelf sediments generally exceeds 80% (Fig. 4.19). Mud has the lowest carbonate content of all fractions, ranging from around 40-90%, with 60% of samples containing <80% carbonate. Carbonate content of the sand fraction ranges from 0 to 100%, with approximately 70% of samples exceeding 80% carbonate. Carbonate content of gravel ranges from 0 – 100%, and exceeds 80% in 85% of samples and attains 100% in 40% of samples. Gravels with low carbonate contents (<10%) occur at 3 locations in the Spencer Gulf.

4.4.2.2. Slope

On the slope, sand and mud contents range from 0 and 100% (Figs. 4.14 & 4.16, respectively). Sand content is higher on the upper slope, near the shelf break, and generally decreases down slope, corresponding to a relative increase in mud content (Fig. 4.14). Gravel does not attain 5% in >85% of samples from the slope. Exceptions to this trend are localised gravel concentrations of up to 80% that occur off Esperance and in submarine canyons (Fig. 4.12).

4.4.2.3. Rise

The rise covers a relatively small area of the SWPR and contains only 6 data points. Sediments are dominated by mud, with contents ranging from 40 – 95%, and exceeding 90% in 4 of the 6 samples. The remainder of sediment is sand, with gravel not detected at any of sites sampled. Carbonate content of mud ranges from 2 to 82%, and where analysed (2 samples) carbonate content of sand exceeds 80%.

4.4.2.4. Abyssal plain/deep ocean floor

Despite the relatively large area of this province and widely spaced sample locations (15 samples at average sample density of 1:27,500 km^2; Table 4.2) little variability in sediment properties is detected. Results suggest relatively consistent textural properties may be present across the entire province. Mud is the dominant fraction exceeding 80% in 12 (85%) of samples (Fig. 4.16). Sand and gravel fractions did not exceed 15% except in two samples located near the foot of the slope off the western margin where sand attains 80% (Figs. 4.12 & 4.14).

Bulk carbonate content ranges between 0 and 75% (Fig. 4.19). Where analysed (9 samples), mud contained a significant non-carbonate component, with carbonate comprising <50% in 75% of samples, and <10% in 45% of samples. Where analysed (4 samples), carbonate content of gravel varied from 5 – 100%. Sediment volume was not sufficient to assess carbonate content of the sand fraction.

4.4.3. Sedimentology of Geomorphic Features of the SWPR

4.4.3.1. Bank/shoal

A total of 40 samples were obtained from bank/shoal features. Sand is the dominant fraction, comprising between 20 and 100% of sediment, and exceeding 75% in 75% of samples. Gravel content ranges from 0-75%, but does not attain 25% in 75% of samples. Mud content is <5% in 90% of samples, and does not exceed 25%.

Carbonate content was measured for 20 samples. Bulk carbonate and carbonate content of the sand fraction range from 25-97%, and exceed 75% in 80% of samples. Carbonate content of gravel exceeds 95% in 7 out of 9 samples measured. Mud is not present in sufficient quantities to assess carbonate content of this fraction.

Samples occur only in bank/shoals on the shelf, and therefore do not represent sediments present in these features on the slope or abyssal plain/deep ocean floor. More than 75% of samples occur in an area of <1 km^2 on the shelf near Esperence. Samples with lower sand contents (<80%) and high gravel contents (>60%) were collected only in this area, although similar variation in sediment texture is likely to be present elsewhere but not detected due to low sample densities.

Sediments with low (<75%) bulk carbonate content are shown to occur frequently in the Spencer and St Vincent Gulfs, but were not detected in bank/shoals elsewhere on the margin.

4.4.3.2. Deep/hole/valley

A total of 10 samples were obtained from deep/hole/valley features. Sand is the dominant fraction in all but 2 samples, comprising between 25 and 99% of sediment and exceeding 80% in 6 of the 10 of samples. Gravel is the next most abundant fraction ranging from 0-75%, although 8 of the 10 samples contain less than 25% gravel. Mud content is <5% in 8 of the 10 samples, and exceeds 15% only in samples from the Gulf St Vincent. Bulk carbonate content consistently exceeds 80% in all sediment fractions.

Samples only achieve coverage of deep/hole/valley features that occur on the shelf. Sediments occurring in a large feature on the slope in the north of the SWPR are not represented in this dataset.

4.4.3.3. Canyon

A total of 79 samples were obtained from canyon features. Mud is the dominant fraction with contents ranging from 10 and 95%, and exceeding 75% in >70% of samples. The remainder of the sediment is sand, ranging from 5 to 45%. Gravel does not attain 5% except in one sample. This is located near the head of a canyon off the southern margin near Albany. Eight other samples with low mud contents (10-45%) were also recovered from the head of canyons in this area.

Carbonate content was measured for 74 samples. Bulk carbonate content ranged from 0-92%, and exceeded 50% in 85% of samples. Samples with low bulk carbonate contents (0-30%) were restricted to the heads of canyons on the southern margin, and were most abundant in the Albany Canyons at locations where low mud contents were also observed.

Carbonate content of mud ranges from 0-90%, exceeds 50% in 95% samples and exceeds 75% in 80% of samples. Carbonate content of sand ranges from 0 and 95%, but is generally slightly lower than for mud. Sand contains >50% carbonate in 68% of samples, and >75% in 55% of samples. Two samples located in the Albany canyons contained >98% non-carbonate sand and mud. Where present, carbonate content of gravel was variable (0 to 100%).

4.4.3.4. Plateau

Only 4 samples were obtained from the Naturaliste Plateau. Mud is the dominant fraction in 3 out of 4 samples, with contents ranging from 65-88%. The remainder of sediment is sand. Gravel was not detected. Sand was found to dominate (65%) in one sample located on the southern edge of the plateau. This sample shows similar attributes to samples on the adjacent slope. Bulk carbonate content exceeds 85% in all samples and shows similar attributes for both sand and mud fractions.

4.4.3.5. Terrace

A total of 145 grainsize samples were obtained from terrace features. These provide adequate coverage to assess sedimentology of all terraces in the SWPR. Sand and Mud are the dominant size fractions, ranging in content from 10 to 90% and 0 to 90%, respectively. Most samples contain both fractions in substantial quantities - Mud content exceeds 80% in only 17% of samples and sand exceeds 80% in only 20% of samples. Gravel was not detected in 45% of samples, and did not attain 15% in 90% of samples. High gravel contents (30-88%) occur locally but are most common on the Ceduna Terrace.

Sand and mud content appear to be controlled by water depth and/or proximity to the shoreline, with higher sand contents generally occurring on terraces on the inner shelf, and on the landward side of features. Mud content is highest in areas of terraces located on the lower slope.

Mud content is highly variable with more than 30% of samples containing >75% mud, and a similar percentage containing <25%. Gravel contents do not attain 10% in 85% of samples, and do not attain 1% in >70%. However gravel contents attain 88% locally on the Ceduna Terrace, and frequently exceed 30% on large terraces off the southern margin. Carbonate contents exceed 75% in 97% of samples (all but 4). Where analysed, carbonate content of mud consistently exceeds 70%. Carbonate content of sand exceeds 80% in all but 3 samples. Carbonate content of gravel exceeds 85% in approximately 95% of samples, but does not attain 10% at two locations on the Ceduna Terrace.

4.4.3.6. Tidal sandwave/sand bank

A total of 17 samples were obtained from tidal sandwave/sand bank features (Fig. 4.38). These features in the SWPR show a distinctive sedimentology: Sand and mud are the dominant size fractions of the sediment with contents ranging from 25 to 95% and 2 to 75%, respectively. Around 50% of samples contain >60% sand, while mud contents were generally lower with >85% of samples containing <60% mud. Gravel contents range from 0-40%, and exceed 10% in approximately 50% of samples. Bulk carbonate content of sediments ranges from 50 to 90%. Carbonate contents generally range from 65 to 100% for gravel (mean 92%), 45 to 93% for sand (mean 77%), and 45 to 80% for mud (mean 68% from 13 samples). Samples provide coverage only of tidal sandwave/sand bank features in the northern Spencer Gulf. Results may not be representative of sediments present in other tidal sandwave/sand banks occurring in deeper water elsewhere in the Spencer and St Vincent Gulfs.

Table 4.3. Summary of sediment properties of geomorphic features in the SWPR containing data points.

Geomorphic feature	Total no. of samples	Characteristic sediment properties (Mean sand % +/- SD)
Shelf (unassigned)	626	77.40 +/- 25.25
Slope (unassigned)	235	51.95 +/- 32.06
Rise (unassigned)	6	20.39 +/- 21.74
AP/DOF* (unassigned)	13	8.33 +/- 9.54 (1 outlier removed)
Bank/shoal	40	80.95 +/- 22.33
Deep/hole/valley	10	75.38 +/- 23.13
Canyon	79	22.25 +/- 14.16 (1 outlier removed)
Knoll/abyssal-hills/hills/ peak	2	6.88 +/- 6.23
Pinnacle	1	18.43
Plateau	4	31.39 +/- 24.32
Ridge	2	37.58 +/- 12.14
Terrace	163	46.65 +/- 29.85
Tidal sandwave/sand bank	17	53.50 +/- 24.51

5. Sedimentology and Geomorphology of the SWPR bioregions

5.1. OVERVIEW OF SWPR BIOREGIONS

The SWPR comprises 7 bioregions (Table 5.1; Fig. 5.1). The Southwest IMCRA Transition, Southwest IMCRA Province and Great Australian Bight IMCRA Transition, Southwest Transition and Southern Provinces in their entirety, and the majority of the Spencer Gulf IMCRA Province and Central Western Province.

More than 95% of the four IMCRA Provinces and Transitions combined area is on the shelf, with of the remaining 5% located on the upper slope. Water depths in these bioregions are between 10 and 500 m, but are generally <200 m. Data coverage in these bioregions is greater than in deeper water areas of the SWPR. Samples are concentrated in Spencer and St Vincent Gulfs, on the shelf break at the western end of the Ceduna Terrace, on the coast near Esperance, and at several locations on the rottenest shelf, including Cockburn Sound.

The three offshore provinces are composed mostly of slope, rise, and abyssal plain/deep ocean floor. Their landward boundary occurs at the shelf break and water depths vary from around 200 m to over 7,000 m in deepest trench areas in the Diamantina Zone. Samples are sparsely distributed compared to the shelf, and although a variety of geomorphic features are represented in these bioregions, data coverage of these was insufficient to perform a complete statistical analysis.

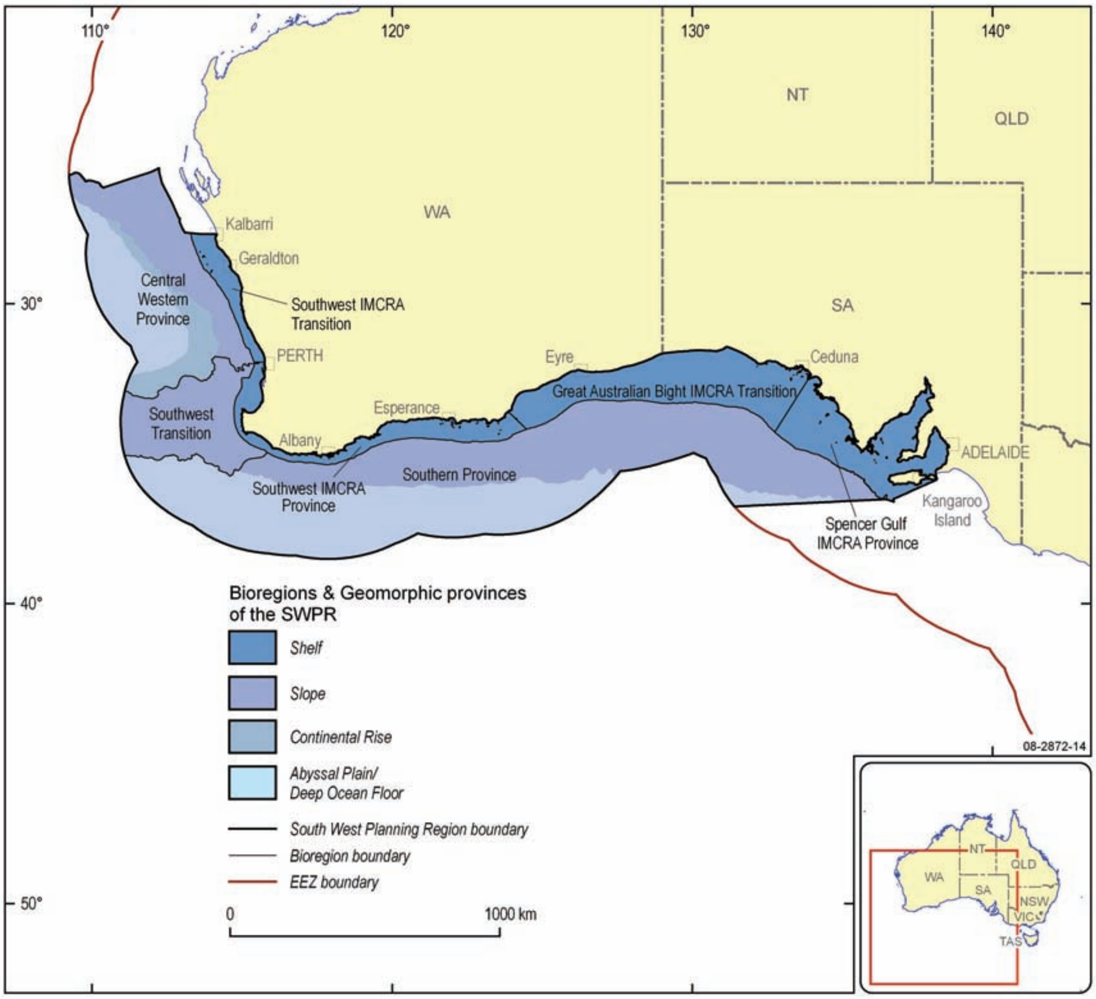

Figure 5.1. Map showing the boundaries of the provincial bioregions overlaid on to the geomorphic provinces for the SWPR.

Table 5.1. Summary details of the provincial bioregions contained in the SWPR.

Bioregion	% bioregion included in SWPR	Water type	% total SWPR area
Central Western Province	96	Subtropical Waters	20
Southwest IMCRA Transition	100	Transition	2
Southwest Transition	100	Transition	8
Southern Province	85	Warm Temperate Waters	48
Southwest IMCRA Province	100	Warm Temperate Waters	4
Great Australian Bight IMCRA Transition	100	Transition	11
Spencer Gulf IMCRA Province	76	Warm Temperate Waters	7

All IMCRA bioregions in the SWPR have broadly similar sedimentology. This is described in Section 4.4.2.1. Sediments in IMCRA bioregions are generally dominated by sand, with less than 20% of the sample comprising mud and gravel. However both mud and gravel dominate sediments locally, particularly on the inner shelf near the coast, and on the outer shelf, though these occurrences are of limited spatial extent. Carbonate content is consistently high, although local lows occur on the inner shelf near the coast.

Some variation occurs between bioregions: The Spencer Gulf IMCRA Province can be distinguished by higher mud contents, reflecting the low energy conditions in the shallow embayments of the Spencer and St Vincent Gulfs. The Great Australian Bight IMCRA Transition is distinguished by areas of gravel with little or no sand and mud, and sediments consistently dominated by carbonate.

In contrast, texture of sediments in offshore bioregions is more variable. Samples are most often mud dominated, although sand remains abundant particularly on the upper slope. Gravel is rarely detected except on the upper slope and in canyons, and where present gravel contents are generally lower than in IMCRA bioregions.

Sediments of the South West Transition can be distinguished from those in other offshore bioregions by a greater proportion of sand dominated rather than mud dominated sediments, the presence of gravels locally, and consistently high carbonate contents. In other offshore bioregions, sediments are more frequently dominated by mud, with the Southern Province having the highest proportion of mud-dominated sediments, reflecting the large areas of abyssal plain/deep ocean floor and extensive deepwater areas of this bioregion.

5.2. SPENCER GULF IMCRA PROVINCE

5.2.1. Geomorphology and Bathymetry

The Spencer Gulf IMCRA Province (SG IMCRA) covers a total area of 132,200 km^2 (Fig. 5.1; Table. 5.1). (This includes areas with water depths <10m, not examined in this study.) All except 31,730 km^2 (24%) of this area lies within the South West Planning Region (SWPR). The Spencer Gulf IMCRA covers 7.1% of the SWPR and 1% of the total EEZ, and is located at the eastern boundary of the SWPR. It is bounded by the Southern Province offshore to the south and the Great Australian Bight IMCRA Province to the west.

More than 99.9% of the Spencer Gulf IMCRA occurs on the shelf (Fig. 5.1; Table 5.2). The province includes the Spencer and St Vincent Gulfs, and Kangaroo Island. Water depths are <10 m over 13,000 km^2 (10%) of the province. The majority of this area lies on the margins of the gulfs and around islands. Areas <10 m water depth have been excluded from statistical analyses. Water depths in the Spencer Gulf IMCRA Province range from 10-595 m. Water depths less than 150 m occur over >90% of the of the Province (Figure 5.3; Table 5.3).

A total of 10 geomorphic features are represented in the Spencer Gulf IMCRA Province (Table 5.2). Approximately 98% of the bioregion is shelf with no other features identified within it. The other geomorphic features each cover less than 1% of the total bioregion area.

Tidal sand waves/ sand banks are found mainly in northern Spencer Gulf and off the eastern end of Kangaroo Island. These cover 1,060 km^2 (0.8%) of the bioregion area and make up 90% of the total area of tidal sandwaves/sand banks in the SWPR. One deep/hole/valley feature is located in water depths of 28-43 m in the St Vincent Gulf (Table 5.2). This feature covers ~700 km^2 (0.5%) of the bioregion area. Deep/hole/valley features are common at these water depths elsewhere in the SWPR and also the EEZ.

5.2.2. Sediment Data Coverage

A total of 216 grainsize and/or carbonate data points occur in the Spencer Gulf IMCRA Province, and all of these are located on the shelf geomorphic province (Figure 5.2; Table 5.4). A total of 81 of these occur in water depths <10 m and were not used in this study. Approximately 80% of remaining samples were collected in water depths <50 m.

Approximately of 60% of samples in the marine area of the bioregion are located in the Spencer Gulf and Gulf St Vincent, with a high concentration of samples in the northern Spencer Gulf. Elsewhere in the bioregion sample coverage is sparse (distance between samples is as great as 50-100 km) but distribution of these gives relatively even coverage of inner and outer shelf (Fig. 5.4).

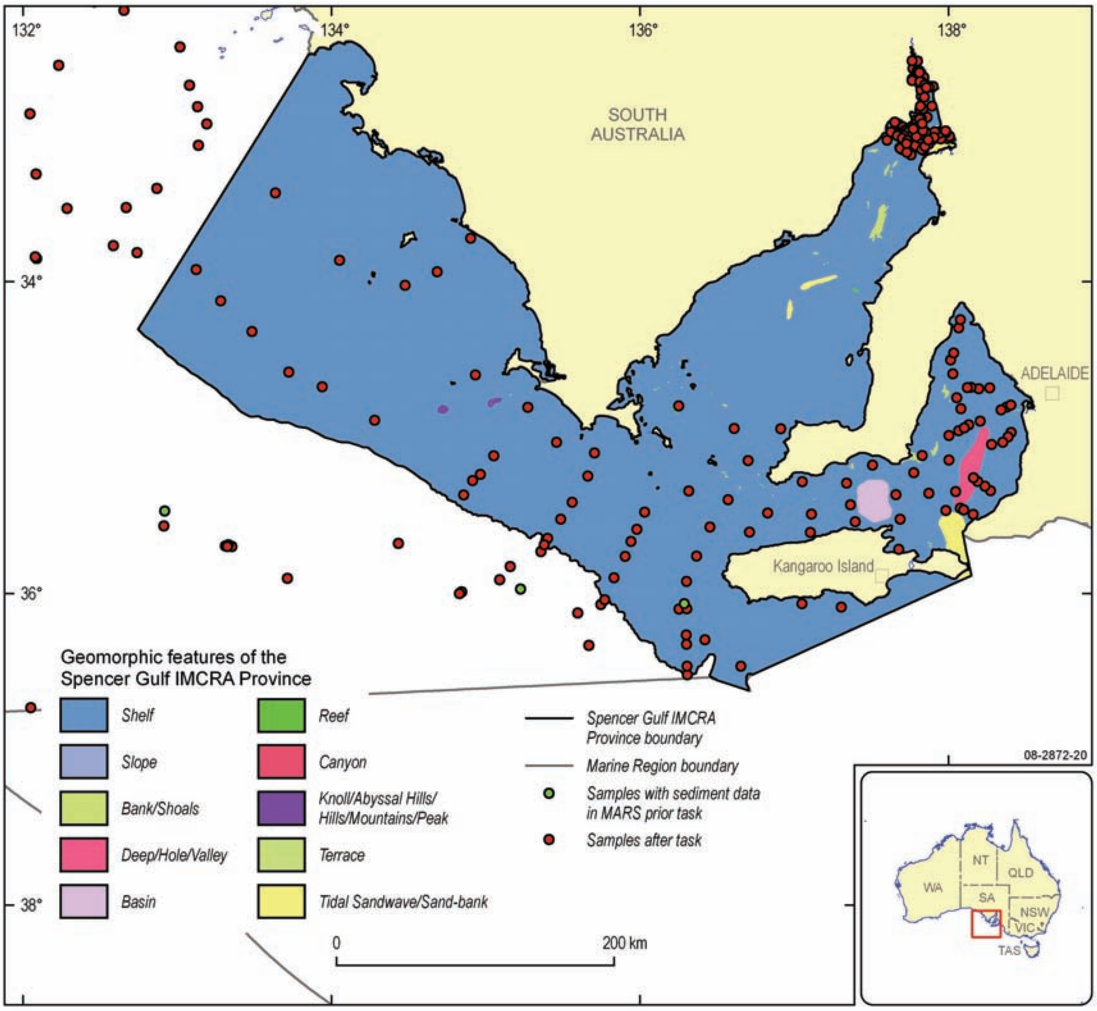

Figure 5.2. Geomorphology of the Spencer Gulf IMCRA Province with location of sediment samples.

Table 5.2. Details of the geomorphology of the Spencer Gulf IMCRA Province.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	99.93	17.48	
Slope	<0.01	<0.01	

Geomorphic Feature			
Shelf (unassigned)	97.76	32.00	7.89
Slope (unassigned)	<0.01	<0.01	<0.01
Bank/shoal	0.34	18.38	0.67
Deep/hole/valley	0.52	15.63	0.32
Basin	0.51	100	0.08
Reef	0.02	1.04	0.03
Canyon	<0.01	<0.01	<0.01
Knoll/abyssal-hills/hills/peak	0.06	0.10	0.05
Terrace	<0.01	<0.01	<0.01
Tidal sandwave/sand bank	0.79	99.00	3.30

*AP/DOF = Abyssal plain/deep ocean floor.

Table 5.3. Distribution of water depths covered by geomorphology in the Spencer Gulf IMCRA Province. Not shown are the slope, canyon and terrace. These features covered areas smaller than the spatial resolution of the bathymetry grid (250 m) and therefore could not be assessed.

Features	**Depth Range (m)**	**Mean Depth (m)**
Geomorphic Province		
Shelf	10 – 600	70
Geomorphic Feature		
Shelf (unassigned)	10 – 600	70
Bank/shoal	10 – 70	20
Deep/hole/valley	30 – 40	40
Basin	30 – 40	30
Reef	10 – 40	20
Knoll/abyssal-hills/hills/peak	10 – 110	60
Tidal sandwave/sand bank	10 – 60	30

Table 5.4. Sample coverage by geomorphic provinces and features for the Spencer Gulf IMCRA Province.

Feature	**No. of Samples**	**Average data density (sample:km^2)**
Geomorphic Province		
Shelf	134	~1:750
Geomorphic Feature		
Shelf (unassigned)	127	~1:700
Bank/shoal	2	~1:150
Deep/hole/valley	2	~ 1:250
Tidal sandwave/sand bank	3	~1:50

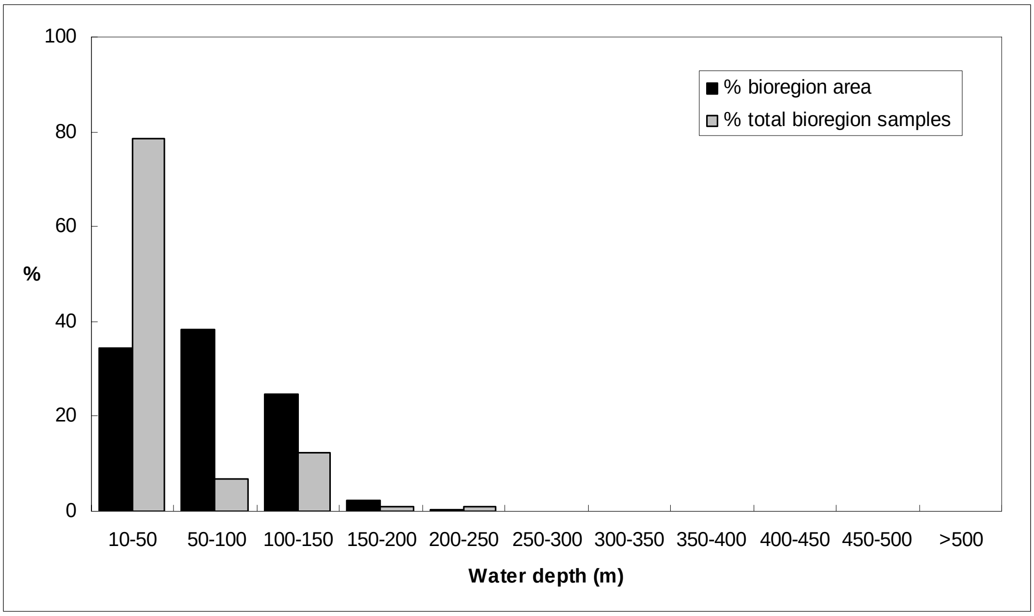

Figure 5.3. Graph of sample coverage distributed by water depth (>10 m) on the shelf in the Spencer Gulf IMCRA Province.

Samples cover 4 of the 10 geomorphic features represented in this bioregion, however more than 85% of samples in the region located on unassigned areas of the shelf (Fig. 5.4; Table 5.4). Bank/shoals and deep/hole/valleys each cover small areas (<500 km²) however contain inadequate samples to assess sedimentology for these features. Tidal sandwaves/sand banks occur in shallow water and contain 3 samples. Samples only occur on the tidal sand waves/sand banks in the northern Spencer Gulf; no samples are located on the tidal sandwaves/sand banks off Kangaroo Island.

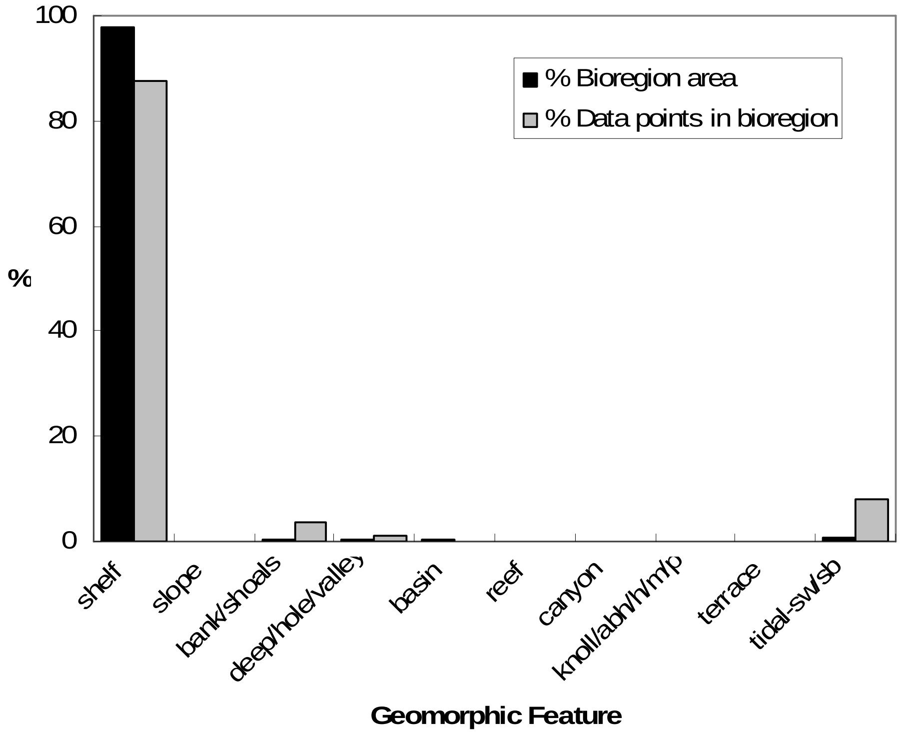

Figure 5.4. Graph of sample coverage distributed by geomorphic features in the Spencer Gulf IMCRA Province.

5.2.3. Quantitative Sediment Distribution for the Spencer Gulf IMCRA Province

Sand is the dominant sediment type across the entire bioregion, with mud and gravel generally comprising <20% of sediment. Of the samples analysed for sand content, 75% contained >60% sand. Sediments containing up to 90% mud and 50% gravel occur locally in the Spencer and St Vincent Gulfs. High mud content (>60%) was also detected in one sample from the outer shelf.

Mud and gravel contents are relatively high on the tidal sandwave/sand banks, and dominate over sand in all samples. Mud content exceeded 25% in all samples and gravel exceeded 35% in 2 out of 3 samples collected from these features.

Carbonate content of sediments is relatively high for all fractions, attaining >90% carbonate across most of the shelf area, although terrigenous gravel is present locally in St Vincent Gulf. Carbonate content of sediments in tidal sandwave/ sand banks are lower than elsewhere in the province, ranging from 65-80%. This reflects the presence of a significant terrigenous component in the sand and mud fractions, while gravels are entirely composed of carbonate grains.

5.3. SOUTH WEST IMCRA TRANSITION

5.3.1. Geomorphology and Bathymetry

The South West IMCRA Transition covers a total area of 27,110 km^2 and all of this bioregion lies within the SWPR (Fig. 5.1). It covers approximately 2% of the SWPR area and <1% of the total area of the EEZ. The South West IMCRA Transition is the most northern shallow-water bioregion in the SWPR. It is bounded to the west by the Central Western Province and to the south by the South West IMCRA Province.

The width of the shelf in this bioregion ranges from 30 km in the south to 80 km in the north. More than 99% of the bioregion occurs on the shelf, with around 8% (2,000 km^2) of this area in water depths of <10 m (Fig. 5.5), which has been excluded from the analyses. Water depths in bioregion range from 10-440 m, with almost 70% of this area occurring in water shallower than 50 m (Fig. 5.6).

Eight geomorphic features are represented in the South West IMCRA Transition (Table 5.5). Approximately 92% (~25,000 km^2) of the total area is shelf with no other features identified on it. Bank/shoals (1.6%, 450 km^2), deep/hole/valley (2.1%, 600 km^2) and reefs (3.4%, 90 km^2) dominate the remainder of the bioregion area. These features are concentrated in a small area of the outer shelf along the shelf break in the north of the bioregion. Each feature occurs in multiple patches dispersed over this area. Pinnacles, apron/fans and terraces also cover small areas of the bioregion with each feature covering <1% of the total area. All of these features are found extensively elsewhere in the SWPR and EEZ. The most significant feature in this bioregion is reefs, which cover 64% of the total area allocated to this geomorphic feature in the SWPR. Reefs are abundant elsewhere in the EEZ, however they are rare in the cooler water types found in the SWPR.

5.3.2. Sediment Data Coverage

The South West IMCRA Transition contains 38 grainsize and/or carbonate data points (Table 5.7). These occur over three geomorphic features and cover significant areas of shelf, bank/shoals and deep/hole/valleys. A total of 21 (55%) of these were collected in water shallower than 50 m. The remainder were collected in water depths of 50-100 m, resulting in the highest sample density in this bioregion occurring in waters of this depth (Fig. 5.6; Table 5.6).

Although samples are distributed evenly across the bioregion, many geomorphic features cover relatively small areas and contain few data (Fig. 5.6). Bank/shoals achieve an average sample density of 1 sample per 400 km² which represents coverage of only 1 of 11 discrete patches of this feature in the bioregion. Deep/hole/valley features achieve relatively high average data density (~1:300 km²) but poor coverage of polygons with data covering only two of the seven that occur in the bioregion (Table 5.7). Owing to the close proximity and similar bathymetry, all seven of these geomorphic features are likely to contain similar environments. No samples were available from reefs.

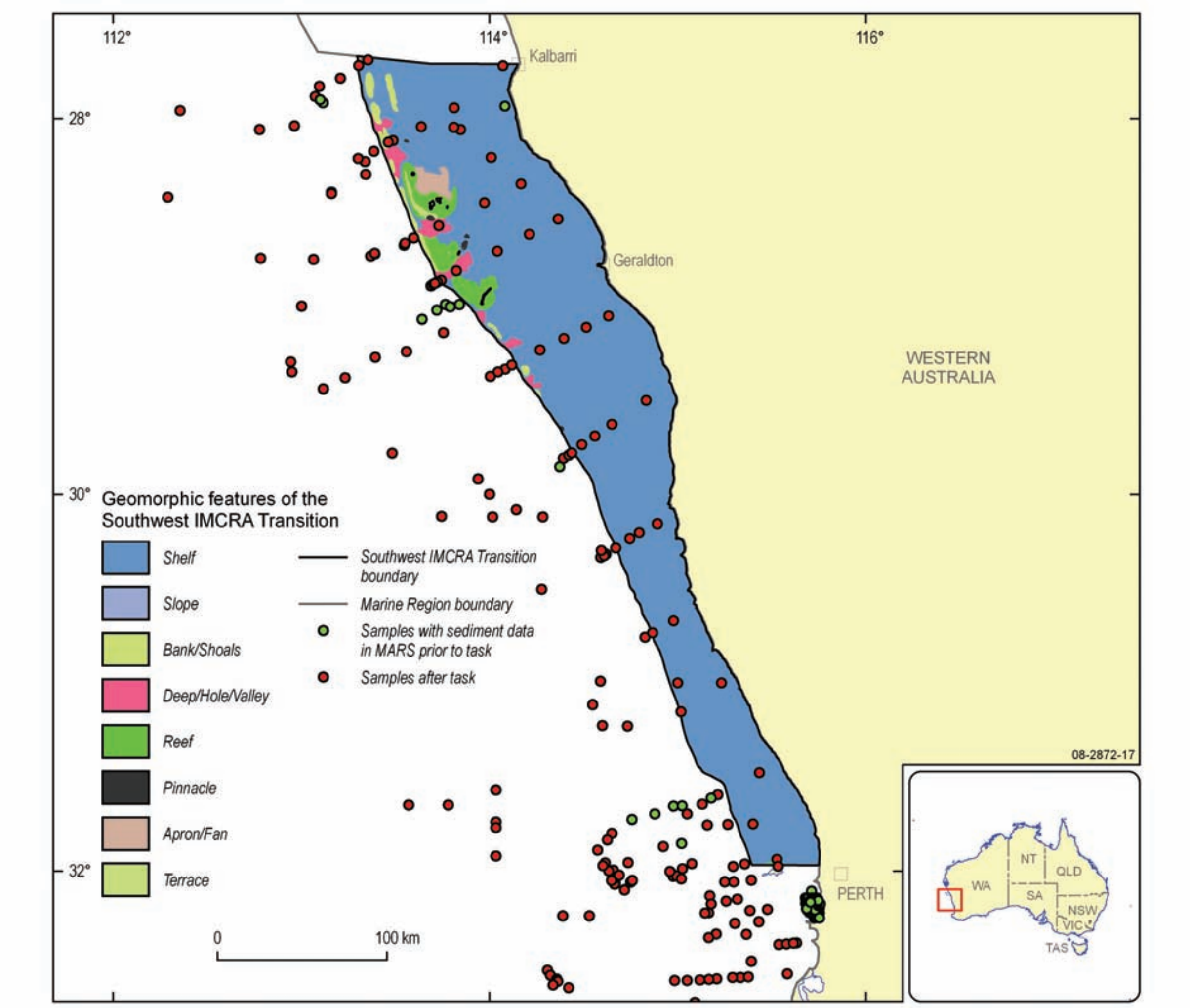

Figure 5.5. Geomorphology of the South West IMCRA Transition with location of sediment samples.

Table 5.5. Details of the geomorphology of the South West IMCRA Transition.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	99.74	8.08	1.37
Slope	0.26	0.01	<0.01
Geomorphic Feature			
Shelf (unassigned)	91.61	8.10	2.0
Slope (unassigned)	<0.01	<0.01	<0.01
Bank/shoals	1.62	23.86	0.87
Deep/hole/valley	2.06	16.58	0.34
Reef	3.39	63.80	1.97
Pinnacle	0.15	5.83	0.80
Apron/fan	0.90	0.08	<0.01
Terrace	0.26	0.04	0.01

Table 5.6. Distribution of water depths covered by geomorphology in the South West IMCRA Transition.

Feature	Depth Range (m)	Mean Depth (m)
Geomorphic Province		
Shelf	10 – 440	40
Slope	20 – 50	30
Geomorphic Feature		
Shelf (unassigned)	10 – 400	40
bank/shoals	10 – 90	50
deep/hole/valley	20 – 100	60
Reef	10 – 60	30
Pinnacle	10 – 440	50
Apron/fan	10 – 40	30
Terrace	20 – 50	30

Table 5.7. Sample coverage by geomorphic provinces and features for the South West IMCRA Transition.

Feature	No. of Samples	Average data density (sample:km^2)
Shelf	38	~1:700
Shelf (unassigned)	35	~1:700
Bank/shoal	1	~1:400
Deep/hole/valley	2	~1:300

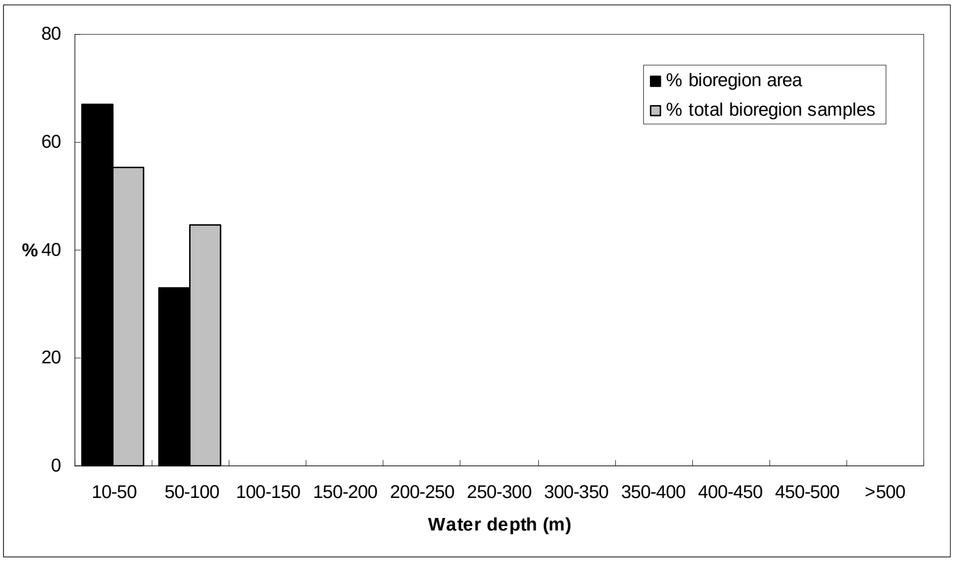

Figure 5.6. Graph of sample coverage distributed by water depth on the shelf in the South West IMCRA Transition.

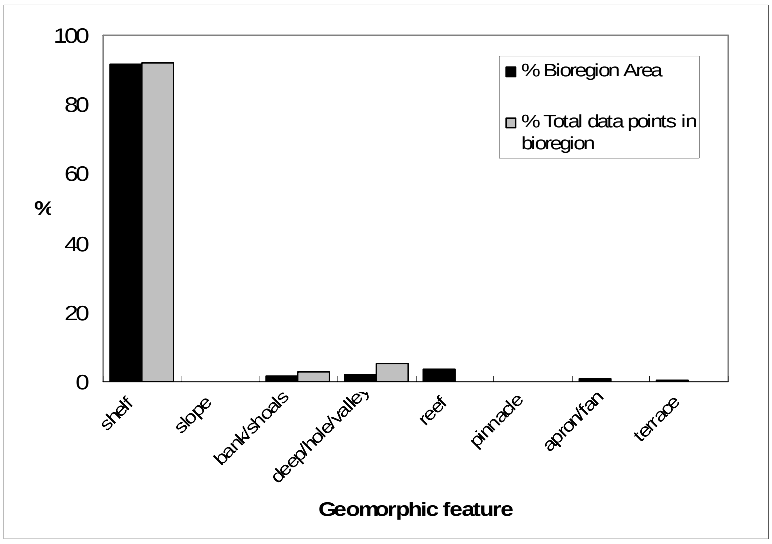

Figure 5.7. Graph of sample coverage distributed by geomorphic features in the South West IMCRA Transition.

5.3.3. Quantitative Sediment Distribution for the South West IMCRA Transition

Sample coverage is only adequate to assess the sedimentology of the bioregion as a whole, and the area of shelf that contains no other geomorphic features (Fig. 5.6; Table 5.7).

Sediments in this bioregion are dominated by sand (>75% in 33 of 38 samples) with <15% gravel in 32 of 38 samples. Mud was generally detected only in trace amounts (<1% in 35 of 38 samples). Sediments dominated (>50%) by mud occur at 2 locations: on the inner shelf in the north of the bioregion and on the outer shelf near the shelf break. Sediments with significant gravel content (>25%) are sparsely distributed on the shelf. Carbonate content of all fractions is consistently >80%, although sand and gravel has a non-carbonate component of 40-70% at a total of four separate locations on the inner shelf.

5.4. SOUTH WEST IMCRA PROVINCE

5.4.1. Geomorphology and Bathymetry

The South West IMCRA Province covers a total area of 61,190 km²; all of the bioregion lies within the SWPR (Fig. 5.1). This bioregion covers 4% of the SWPR and 1% of the EEZ. The SWIP extends from the lower west coast, around the south western corner of the Australian continent and across the Great Australian Bight. It is bounded on its offshore edge by the Southern Province and the South West Transition, and to the east and north by the Great Australian Bight IMCRA Transition and South West IMCRA Transition, respectively.

The continental shelf narrows in width from around 200 km in the Great Australian Bight to <20 km on the south western corner of the mainland (Fig. 5.8). More than 99% of the province lies on the shelf, and around 10% (~6,000 km²) of this is in water shallower than 10 m. Water depths in the marine area of the bioregion range from 10 to 1,901 m (Fig. 5.9). Water depths across 60% of this area are 50-100 m, with 35% of the area in 10-50 m water depth (Fig. 5.9; Table 5.9).

A total of 7 geomorphic features have been mapped in this bioregion (Table 5.8). Shelf covers 59,360 km² (97%) of the bioregion area and represents 19% of the total area allocated to this feature in the SWPR. Other features forming significant areas are banks/shoals, Deep/hole/valleys and reefs. Bank/shoals and reefs occur in water depths of <100 m (mean = <50 m) in this bioregion (Table 5.9), and are found at similar water depths elsewhere in the SWPR. A single deep/hole/valley covers ~600 km² (1%) of the bioregion area at the shelf break in the north of the bioregion in 80 m water depth, which represents 17% of the SWPR area for this feature. Deep/holes/valleys are found at similar depths elsewhere in the SWPR.
Banks/shoals cover only a relatively small area of this bioregion (1%) (Table 5.8). However, this represents 45% of the total area for this feature in the SWPR. Reefs are present in small patches, with each patch generally <20 km². Most of the reefs lie close to the coastline however a few patches in the extreme east and north of the bioregion are located in water depths of up to 100 m near the shelf break. Reefs cover ~500 km² (<1%) of this bioregion, with represents 33% of the total area of reefs in the SWPR

5.4.2. Sediment Data Coverage

The SWIP contains 296 grainsize and/or carbonate data points (Table 5.10). A total of 114 of the samples occur in water of <10 m and have been excluded from the analysis (Fig. 5.8). More than 95% of the remaining data points (177) lie within the shelf geomorphic feature (average data density=~1:300 km²). Data also achieved coverage of deep/hole/valleys with 6 samples located in these features (average density=1:100 km²) (Fig. 5.10; Table 5.10).

The majority of data points are clustered in two small areas on the inner shelf near the coastline in the north and the east of the bioregion (Fig. 5.8). There is relatively sparse coverage of the outer shelf in the north of the bioregion, and of the inner shelf in the east. Data is particularly sparse around the south western corner of the continent. This results in average sample density of 1:100 km² for water depths of <50m and 1:1,500 km² for water depths of >50 m (Fig. 5.9).

5.4.3. Quantitative Sediment Distribution for the South West IMCRA Province

Sample coverage is adequate to assess sedimentology for shelf and deep/hole/valley features (Fig. 5.8).

Sediment composition varies significantly across the bioregion. Sand dominates with approximately 65% of samples containing >80% sand. Sand is most abundant in shallower water on the inner shelf. Gravel is more common in sediments than mud with >35% of samples containing >10% gravel, and approximately 15% containing >50% gravel. Mud contents range from 0-40%, but only attain 10% in 5% of samples.

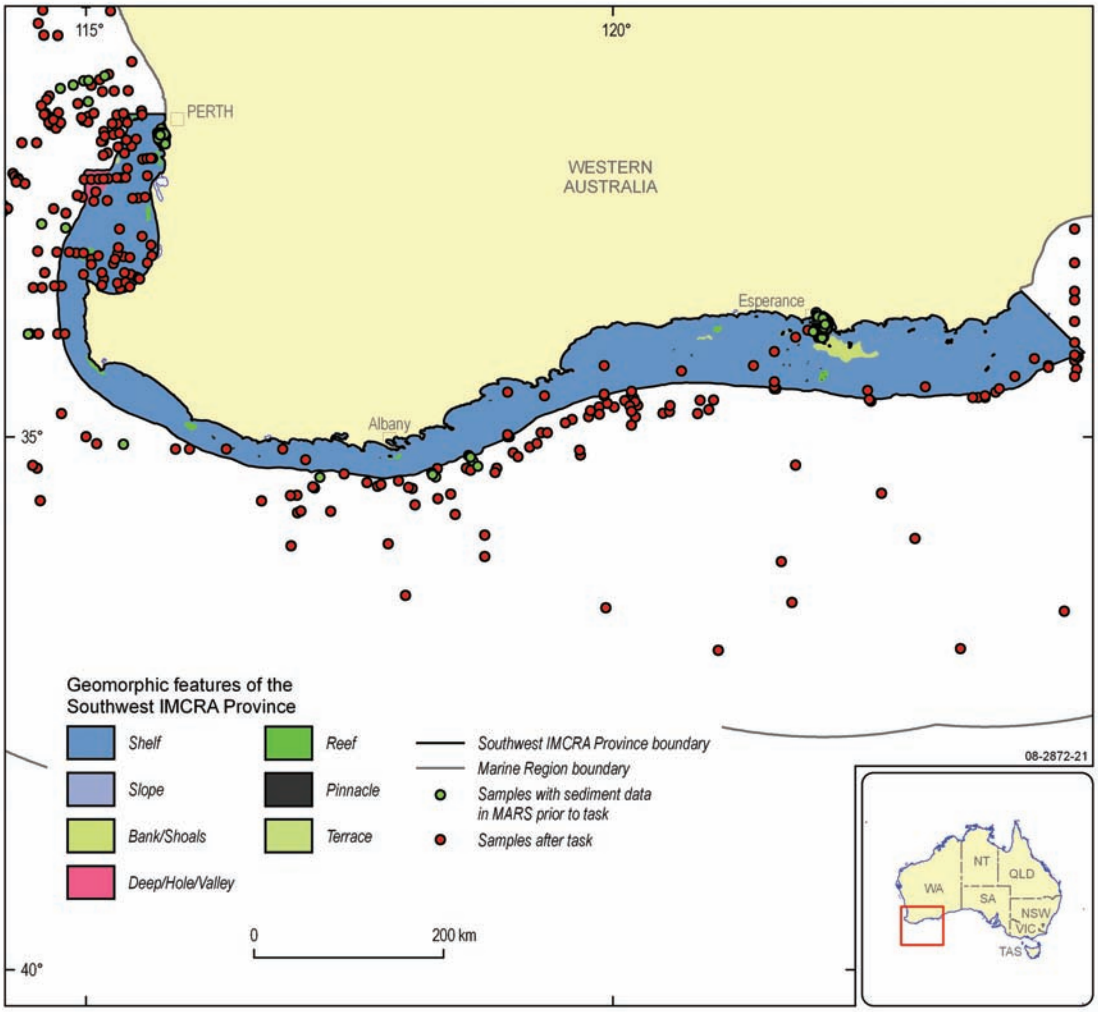

Figure 5.8. Geomorphology of the South West IMCRA Province with location of sediment samples.

Table 5.8. Details of the geomorphology of the South West IMCRA Province.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	99.82	10.64	-
Slope	<0.01	<0.01	-
Geomorphic Feature			

Shelf (unassigned)	96.77	19.28	4.75
Slope (unassigned)	<0.01	<0.01	<0.01
Bank/shoal	1.37	45.34	1.66
Deep/hole/valley	0.95	17.23	0.35
Reef	0.78	33.22	1.03
Pinnacle	0.13	10.95	1.5
Terrace	<0.01	<0.01	<0.01

Table 5.9. Distribution of water depths covered by geomorphology in the South West IMCRA Province. Not shown are slope and terraces. These covered smaller areas than the resolution of the bathymetry grid (250 m) and therefore could not be assessed.

Feature	Depth Range (m)	Mean Depth (m)
Geomorphic Province		
Shelf	10 – 1,900	60
Geomorphic Feature		
Shelf (unassigned)	10 – 1,900	60
Bank/shoal	10 – 80	30
Deep/hole/valley	30 – 220	80
Reef	10 – 100	50
Pinnacle	10 – 730	60

Table 5.10. Sample coverage by geomorphic provinces and features for the South West IMCRA Province. One data point was found to fall in water shallower than 10 m and has therefore not been included in the analyses.

Feature	No. of Samples	Average data density (sample:km^2)
Shelf	183	~1:300
Shelf (unassigned)	177	~1:300
Deep/hole/valley	6	~1:100

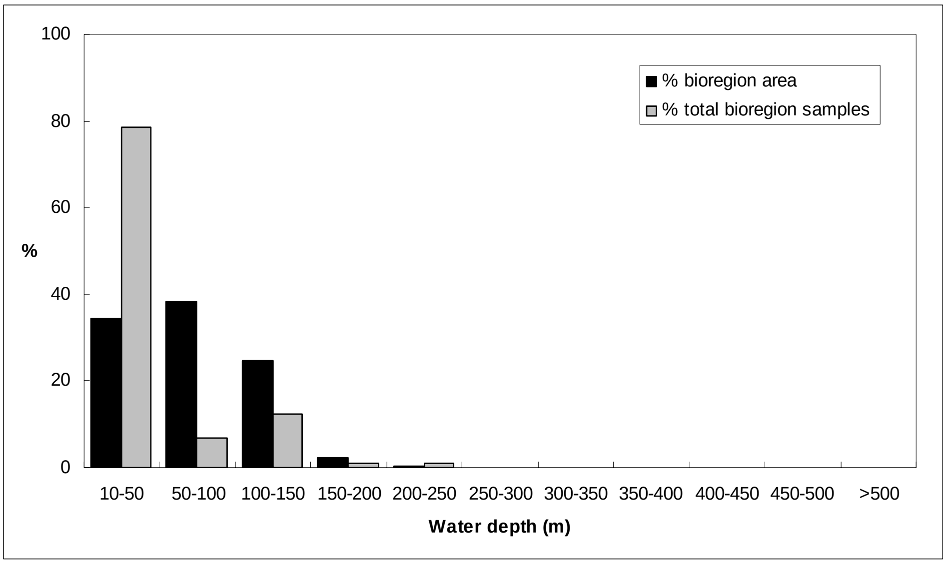

Figure 5.9. Graph of sample coverage distributed by water depth on the shelf in the South West IMCRA Province.

Muddy sediment (>20% mud) occurs on the outer shelf near the shelf break. Gravel, occurs in water depths of <50 m on the inner shelf north of Casurina Point and on the inner Recherche Shelf near Esperance.

Bulk carbonate content is also highly variable. Carbonate content is generally zoned with water depth. Sediments with high (>80%) bulk carbonate contents occur across all areas of the shelf, but were most abundant on the outer shelf. Low bulk carbonate contents (<40%) generally occur in close proximity to the coast, particularly in Geographe Bay to the north of Cape Naturaliste and on the inner Recherche Shelf near Esperence. Samples containing carbonate 40-60% occur along the inner shelf between Cape Leeuwin and Albany (Fig. 5.8).

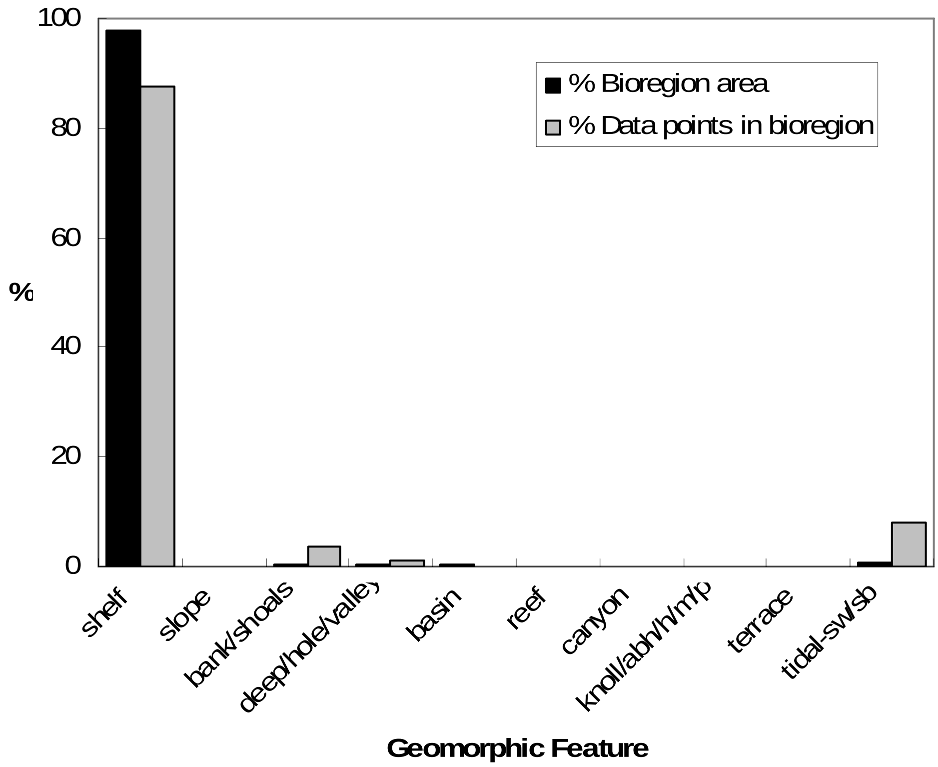

Figure 5.10. Graph of sample coverage distributed by geomorphic features in the South West IMCRA Province.

Deep/hole/valleys are generally dominated by sand with significant gravel at some locations. Mud does not exceed 10% in any sample from these features (Fig. 5.10). A total of 5 of the 6 samples contain >60% sand. The gravel fraction generally ranges from 10-30% and the carbonate content of all sediments is >90%.

5.5. GREAT AUSTRALIAN BIGHT IMCRA TRANSITION

5.5.1. Geomorphology and Bathymetry

The Great Australian Bight IMCRA Transition covers a total area of 144,890 km², all of which lies within the SWPR (Fig. 5.1). This bioregion covers 11% of the total area of the SWPR and approximately 2% of the EEZ. This bioregion is located in the Great Australian Bight (GAB) and is bordered to the east by the Spencer Gulf IMCRA Province, to the west by the South

Table 5.11. Details of the geomorphology of the Great Australian Bight IMCRA Transition.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Shelf	100	43.29	7.33
Slope	<0.01	<0.01	<0.01
Shelf (unassigned)	85.31	40.30	9.93
Reef	0.01	1.25	0.04
Terrace	14.68	11.45	3.67

Table 5.12. Distribution of water depths covered by the geomorphology in the Great Australian Bight IMCRA Transition. Not shown is the slope geomorphic province. This covered smaller area than the resolution of the Bathymetry grid and therefore could not be assessed.

Feature	Depth Range (m)	Mean Depth (m)
Geomorphic Province		
Shelf	10 – 280	70
Geomorphic Feature		
Shelf (unassigned)	10 – 280	80
Reef	10 – 60	30
Terrace	10 – 50	40

West IMCRA Province, and to the south by the deep-water Southern Province. Notably, the continental shelf is approximately 200 km wide in the GAB.

The Great Australian Bight IMCRA Transition extends from the coastline to the shelf break with >99% of the bioregion on the continental shelf. This bioregion makes up approximately 40% of the total area of continental shelf in the SWPR and around 10% of the total area of the shelf in the EEZ.

Water depths in the Great Australian Bight IMCRA Transition range from 10-280 m (Table 5.12). A total of 2,000 km² of this bioregion occurs in water depths of <10 m, representing coastal intertidal areas and islands on the inner shelf. This area has been excluded from the analyses. More than 80% of the remaining bioregion area lies in water shallower than 100 m and approximately 3% of the bioregion area occurs in water depths of >150 m.

A total of 123,150 km² (85%) of the shelf area has no other geomorphic features identified within it (Table 5.11). The Eyre Terrace on the inner shelf in the centre of the GAB covers most of the remaining 21,400 km² (15%) of the bioregion. A very small area of reefs covering <15 km² (<0.01%) of the bioregion occurs on the inner shelf to the east of this terrace. The slope adjacent to this bioregion includes the Ceduna Terrace and a small area of this is included along the southern boundary of the Great Australian Bight IMCRA Transition. Terraces occur extensively elsewhere in the SWPR, and in this bioregion almost half of the total area of terraces occurs in water depths of <500 m.

5.5.2. Sediment Data Coverage

The Great Australian Bight IMCRA Transition contains 141 grainsize and/or carbonate data points (Table 5.13). These attain relatively high densities in water depths of between 100 and 250 m, although 65% of data points occur in water depths <100 m (Fig. 5.12).

Samples achieve coverage of the shelf and terraces which occur on it. Coverage is generally proportional to the total area covered by each of these features, attaining an average sample density of around 1:1,000 km² for the shelf and 1:2,100 km² for terraces. The spatial distribution of samples across both features is relatively even, with similar densities achieved across the entire shelf. No samples were located within reefs (Fig. 5.13; Table 5.13).

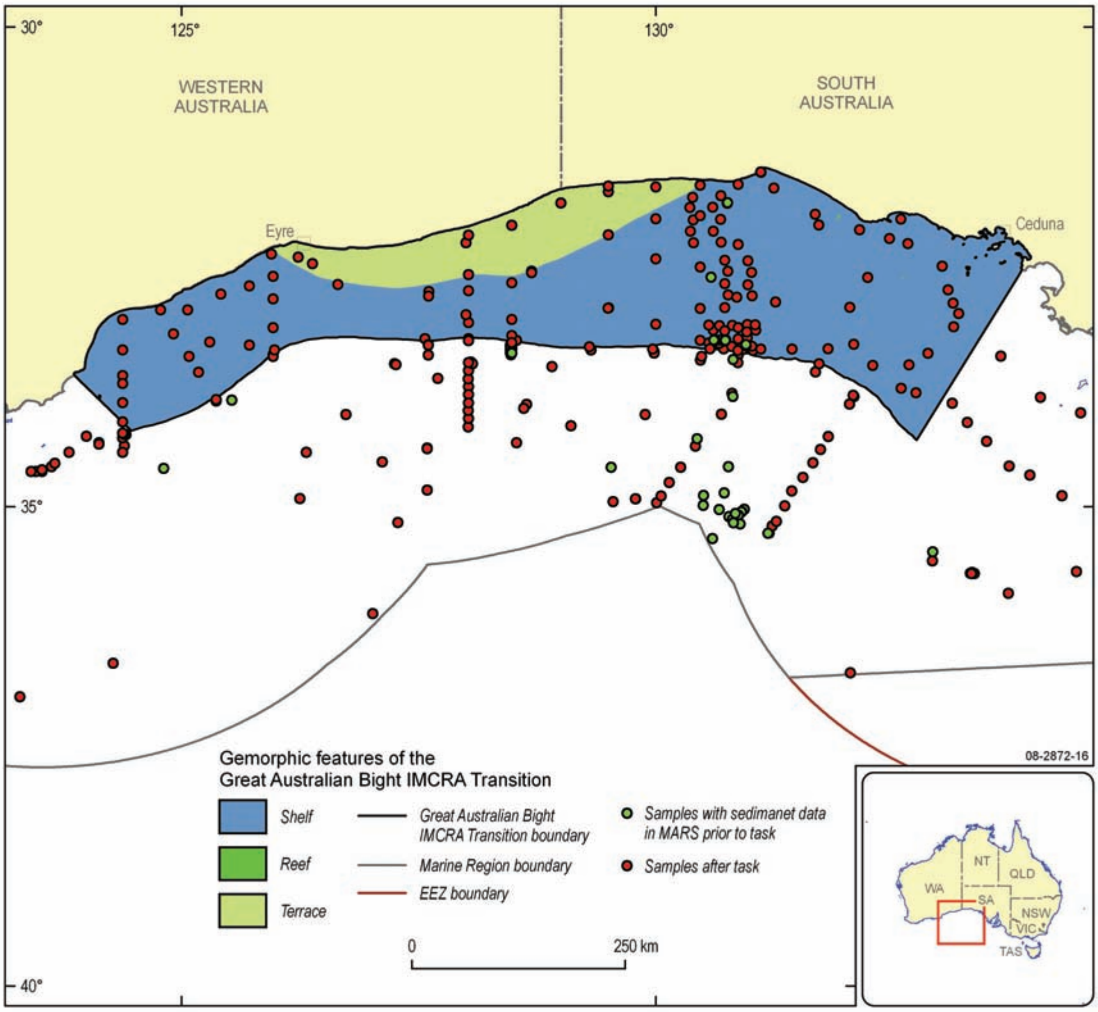

Figure 5.11. Geomorphology of the Great Australian Bight IMCRA Transition with location of sediment samples.

Table 5.13. Sample coverage by geomorphic provinces and features for the Great Australian Bight IMCRA Transition.

Feature	No. of Samples	Average data density (sample:km^2)
Shelf	141	~1:1,000
Shelf (unassigned)	131	~1:1,000
Terrace	10	~1:2,100

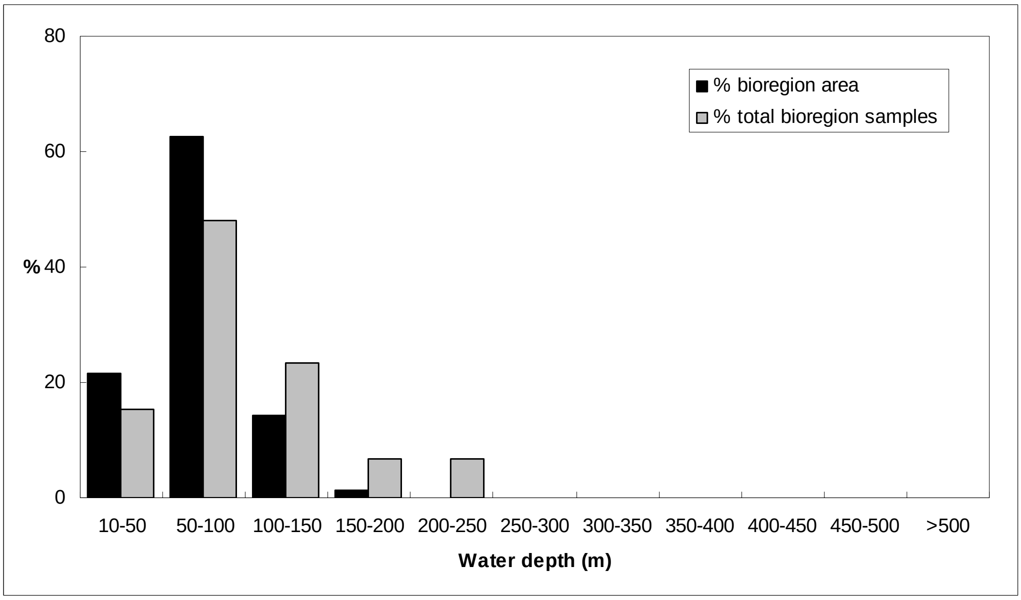

Figure 5.12. Graph of sample coverage distributed by water depth on the shelf in the Great Australian Bight IMCRA Transition.

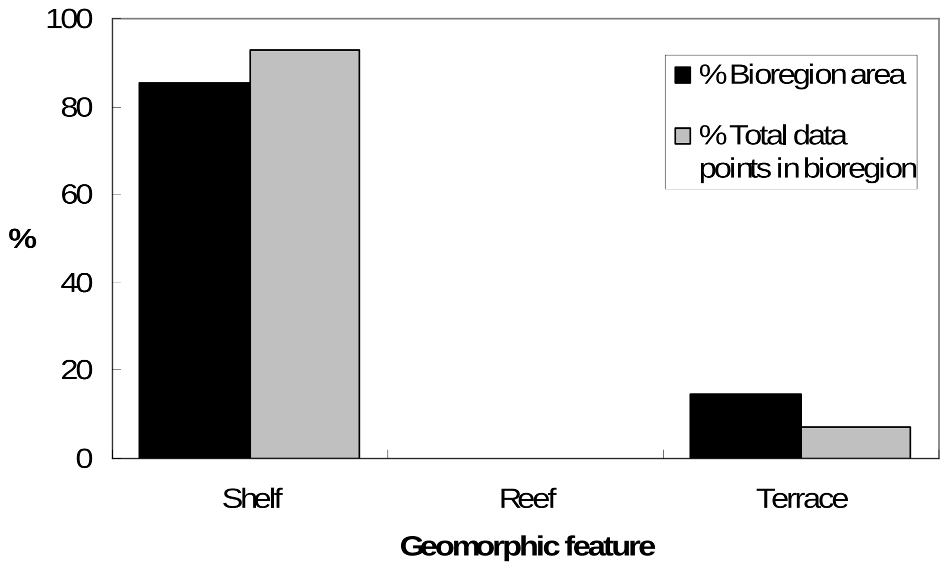

Figure 5.13. Graph of sample coverage distributed by geomorphic features in the Great Australian Bight IMCRA Transition.

5.5.3. Quantitative Regional Sediment Distribution for the Great Australian Bight IMCRA Transition

Sediments for the entire bioregion and unassigned shelf show similar characteristics. Overall variability in the gravel, sand and mud contents is low. Around 109 of the 141 samples contain >75% sand with up to 10% gravel, and up to 5% mud. Areas of very fine sediment (mud up to 60%) and very coarse sediment (gravel up to 100%) occur locally, mainly on the shelf where no other geomorphic units have been identified. Relatively fine-grained sediments occur in water depths of >150 m on the outer shelf, near the shelf break. Gravel sediments occur locally on the inner shelf southwest of Eyre but are sparsely distributed elsewhere in the bioregion. Carbonate content of all fractions is consistently >80%. The non-carbonate fraction attains 65% for gravels and 30% for sands at 8 locations on the inner shelf.

Sediments in terrace features have similar textures and compositions to other areas of the shelf. However, the carbonate content of the sediments, particularly sands, shows slightly greater variability with the non-carbonate component exceeding 20% in 30% of samples.

5.6. SOUTHERN PROVINCE

5.6.1. Geomorphology and Bathymetry

The Southern Province covers a total area of 770,596 km^2 (Fig. 5.1), of which 115,590 km^2 (15%) lies outside the SWPR. The Southern Province covers 48% of the total area of the SWPR, and the area of this bioregion that lies within the SWPR is equal to approximately 7% of the total area of Australia's EEZ. The Southern Province extends from the south west corner of the Australian mainland, east across the Great Australian Bight to the eastern boundary of the SWPR. It is bounded to the north by the Spencer Gulf IMCRA Province and Great Australian Bight IMCRA Transition, and to the west by the South West IMCRA Province.

More than 99.9% of total area of the Southern Province occurs on the slope and abyssal plain/deep ocean floor (Table 5.14). Within the bioregion, the slope ranges in width from approximately 80 km at the western end of the GAB to >250 km in the east. The slope covers 347,170 km^2 (53%) of the bioregion, which represents 60% of the total area of slope in the SWPR, and approximately 10% of the area of slope in the EEZ. In the east of the bioregion, the slope extends to the outer boundary of the EEZ. Abyssal plain/deep ocean floor comprises the remaining 307,840 km^2 (47%) of the bioregion. This represents 75% of the area of this geomorphic province in the SWPR and approximately 10% of the area of abyssal plain/deep ocean floor in the EEZ. Abyssal plain/deep ocean floor covers relatively large areas of the bioregion in regions where the slope is relatively narrow.

Water depths in the Southern Province range from 50 to 7,390 m, with a mean of >4,000 m (Table 5.15). Variations in water depths across the bioregion are large due to the dominance of the slope, which ranges in depth from 50 m at the shelf break and 4,840 m at its base. More than 95% of the abyssal plain/deep ocean floor area lies in water depths of >4,000 m, with the deepest areas located in the trench/troughs of the Diamantina Fracture Zone.

A total of 11 geomorphic features occur in the Southern Province (Table 5.14). Terraces comprise 125,890 km^2 or 19% of the total area of the bioregion, followed by knoll/abyssal hill/hills/peak (66,770 km^2; 10%), ridge (39,660 km^2; 6%), and canyons (19,910 km^2; 3%). Significantly, 100% of the total area of ridges and 99% of the total area for knoll/abyssal hill/hills/peaks in the SWPR occur in the Southern Province. This bioregion also contains a significant portion of the total EEZ area for these same features (ridges = 36%, knoll = 56%). These features occur almost entirely on the abyssal plain/deep ocean floor in the Diamantina Fracture Zone, with the only other occurrences of ridges at one location on the slope. These features occur in water depths that are similar to those found elsewhere in the EEZ.

Combined canyons and terraces in the Southern Province cover approximately 70% of the total area of these features in the SWPR, and 20% of the total area of these features in the EEZ (Table 5.14). More than 60 canyons have been identified occurring mainly in the east (Murray Canyons and eastern end of the Ceduna Terrace) and west (Albany Canyons). In the west, the canyons head on the upper slope and do not extend down to the Abyssal plain/deep ocean floor. These canyons average around 35 km in length and 5 km width. In the east, the canyon heads reach the Ceduna Terrace or intersect the Lincoln Shelf and regularly extend to the base of the slope. Canyons in this area average around 50 km in length and 10 km width. Terraces include the Eyre and Ceduna Terraces which are located in the east of the bioregion and extend up to 200 km down-slope from the shelf break at their widest point.

A total of 26 pinnacles occur in the Southern Province (Table 5.16). Their combined area is ~70 km^2 or <1% of the area of the bioregion. The area of pinnacles in the Southern Province accounts for >55% of the total area for this feature in the SWPR. Trench/troughs on the abyssal plain/deep ocean floor occur at two locations in the south western corner of the bioregion. These features cover ~300 km^2 (<1%) of the total bioregion area. These features represent the deepest-water environments in the SWPR, located in water depths between 5,000-7,400 m. Trench/troughs in water depths greater than 5,000 m are rare across the SWPR and EEZ.

Table 5.14. Details of the geomorphology of the Southern Province.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	<0.01	<0.01	<0.01
Slope	53.00	60.43	8.55
AP/DOF*	47.00	74.54	10.67
Geomorphic Feature			
Shelf (unassigned)	<0.01	<0.01	<0.01
Slope (unassigned)	30.49	58.72	14.53
AP/DOF* (unassigned)	30.63	65.88	8.14
Bank/shoal	<0.01	3.04	0.11
Deep/hole/valley	0.07	13.23	0.27
Trench/trough	0.24	14.86	0.90
Canyon	3.04	68.24	18.65
Knoll/abyssal-hills/hills/peak	10.19	99.90	56.30
Ridge	6.05	100	35.56
Pinnacle	0.06	55.33	7.60
Terrace	19.22	67.81	21.72

*AP/DOF = Abyssal plain/deep ocean floor.

Table 5.15. Distribution of water depths covered by geomorphology in the Southern Province. Not shown are details for the shelf as the area of these are smaller than the cell size of the bathymetry raster and therefore depth range could not be assessed.

Feature	Depth Range (m)	Mean Depth (m)
Geomorphic Province		

Slope	50 – 5,840	3,140
AP/DOF*	840 – 7,390	5,220
Geomorphic Feature		
Slope (unassigned)	50 – 5,840	4,120
AP/DOF* (unassigned)	1,650 – 6,440	5,240
Bank/shoal	3,340 – 3,900	3,660
Deep/hole/valley	4,540 – 6,170	5,710
Trench/trough	4,940 – 7,390	5,890
Canyon	120 – 5,290	2,890
Knoll/abyssal-hills/hills/peak	660 – 7,250	5,340
Ridge	840 – 7,000	4,770
Pinnacle	2,230 – 5,950	5,240
Terrace	90 – 5,020	1,620

5.6.2. Sediment Data Coverage

The Southern Province contains a total of 279 grainsize and/or carbonate data points (Fig. 5.14; Table 5.16). Of this total, 267 (96%) are located on the slope, corresponding to an average sample density of 1:1,300 km^2 (Fig. 5.14; Table 5.16). The remaining 12 samples are located on the abyssal plain/deep ocean floor corresponding to an average data density of 1 sample for every 25,500 km^2.

Only 6 of the 10 geomorphic features in the Southern Province contain data, which correspond to those features covering the greatest area (Table 5.14). However, coverage of knolls/abyssal hills/hills/peaks and ridges is poor relative to their total areas at <1 sample for every 20,000 km^2. As such, the samples achieve coverage of <10% of the area of these features. Samples cover only a small area of ridges on the slope and ridges in the Diamantina Fracture Zone do not contain any samples at all. Results for ridge samples may not be representative of the range of sediments occurring in this feature within the Southern Province (Figs. 5.15, 5.16 & 5.18).

A total of 49 samples are contained within 19 canyons representing an average sample density of 1:400 km^2 for this feature (Table 5.16). While samples are located in both the small and large shelf-cutting and blind canyons, they are clustered on the upper slope, and thus give better coverage of the upper part of canyons.

The Ceduna Terrace contains 150 samples, representing a coverage of 1:1,000 km^2. Samples are relatively evenly spaced over this feature. There are no data points located on the pinnacles (Table 5.16).

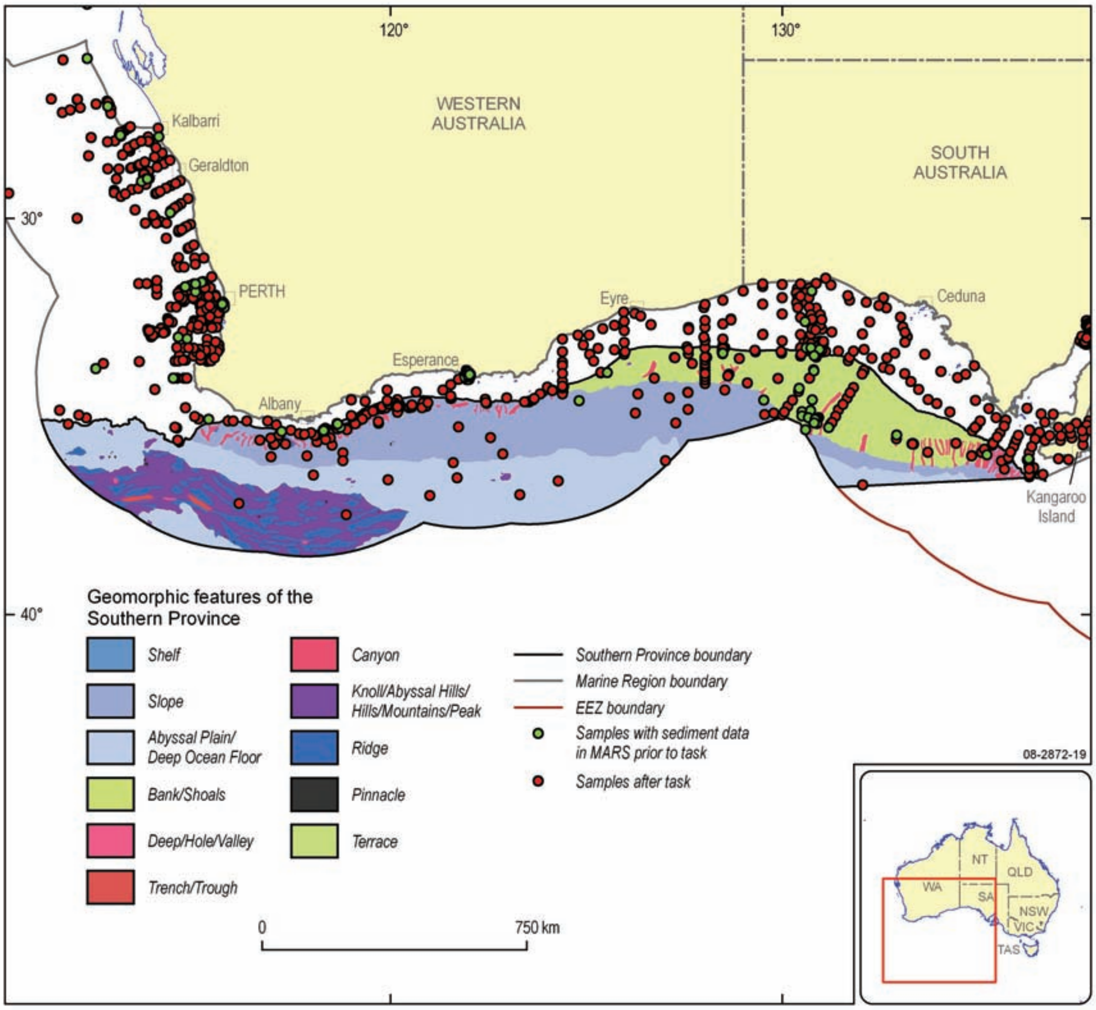

Figure 5.14. Geomorphology of the Southern Province with location of sediment samples.

5.6.3. Quantitative Sediment Distribution for the Southern Province

Samples achieve adequate coverage to assess sedimentology for slope, abyssal plain/deep ocean floor, canyon, and terrace features (Fig. 5.14).

Table 5.16. Sample coverage by geomorphic provinces and features for the Southern Province.

Features	No. of Samples	Average data density (sample:km^2)
Slope	267	~1:1300
AP/DOF	12	~1:25,500
Slope (unassigned)	86	~1:2,500
AP/DOF* (unassigned)	10	~1:20,000
Canyon	49	~1:400
Knoll/abyssal-hills/hills//peak	2	~1:33,500
Ridge	2	~1:20,000
Terrace	130	~1:1,000

* AP/DOF = Abyssal plain/deep ocean floor.

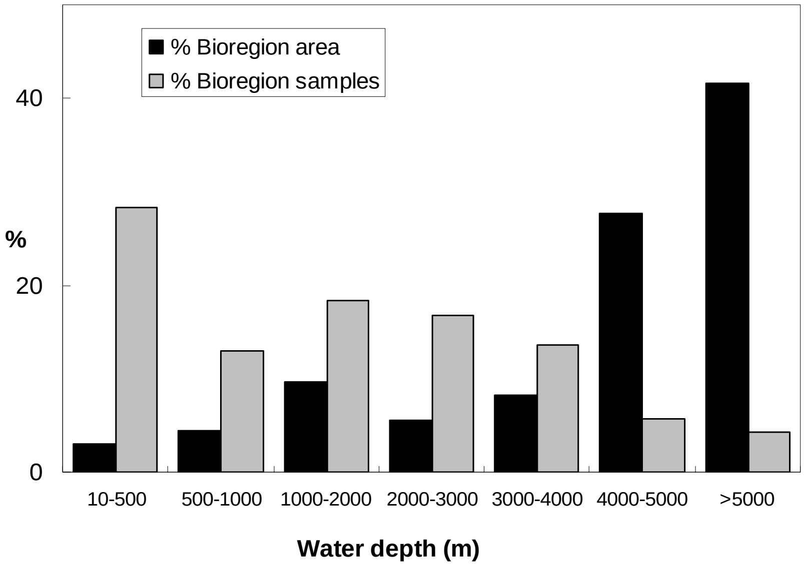

Figure 5.15. Graph of sample coverage distributed by water depth in the Southern Province. Note the inverse relationship between water depth area and number of samples expressed as a percentage. Samples occur in all bathymetric classes, although >40% of the samples occur in water depths of <500 m, and <2% of the samples occur in water depths of >4,000 m even though these depths make up >40% of the total area of the bioregion.

Mud is the dominant size fraction of the sediments in the Southern Province, ranging from 0 to 100%, and with 63% (163) of samples containing >50% mud. Sand is the next most abundant fraction, with a similar range but exceeding 50% in 35% (90) of samples. Gravel generally forms a minor component of sediment (<5%), although isolated samples in shallower water areas on the slope and terrace contain as much as 80% gravel.

Bulk carbonate content exceeds 75% in approximately 80% (203) of samples. Similar carbonate contents occur in all features except the Abyssal Plain/Deep Ocean Floor, where the non-carbonate component exceeds 90% in 50% (6) samples.

Sediments on the slope show variation from sand-dominated to mud-dominated with increasing water depth. Approximately 38% (98) of samples contain >50% sand, and 60% (153) samples contain >50% mud. Mud forms >90% of sediment in 6 of 11 samples recovered from the abyssal plain/deep ocean floor.

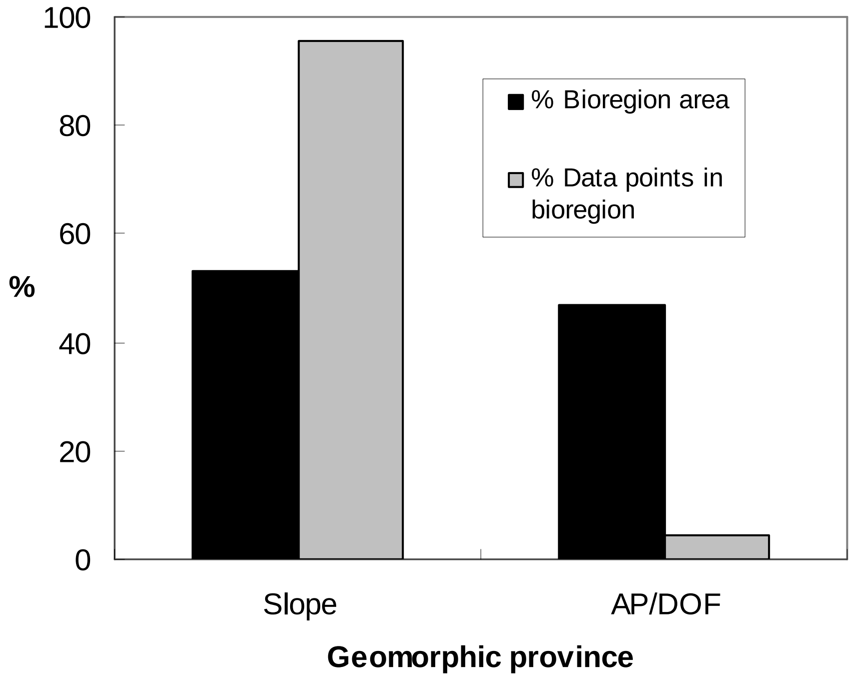

Figure 5.16. Graph of sample coverage distributed by geomorphic provinces in the Southern Province.

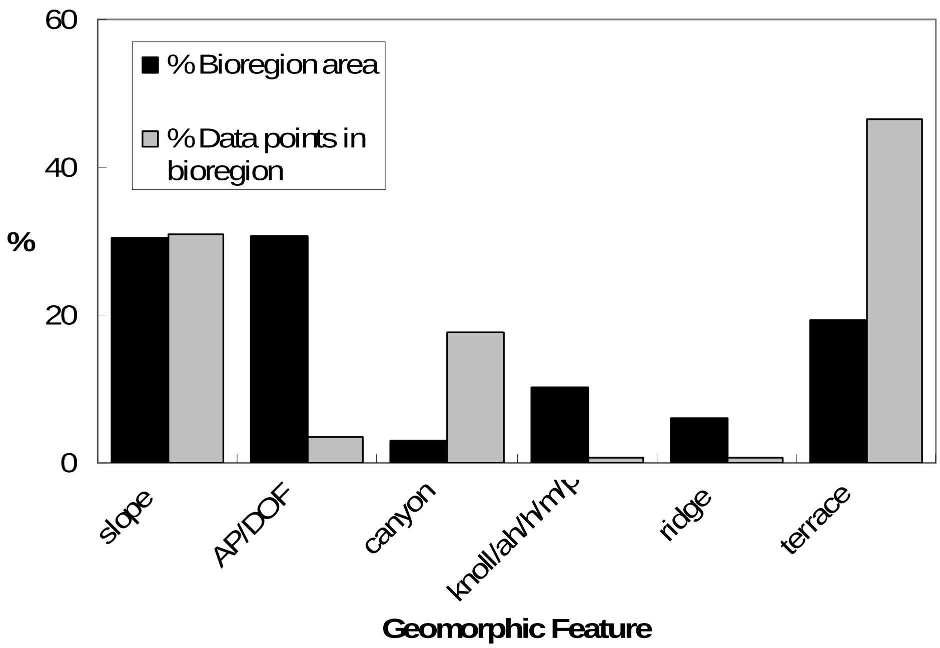

Figure 5.17. Graph of sample coverage distributed by geomorphic features in the Southern Province.

Canyons are dominated by mud, with 63% (31) samples comprising greater than 70% mud. Sand is the next most abundant size fraction with contents generally ranging from 10 - 65% (although individual samples contain as much as 90% sand). Gravel forms less than 3% of sediment in canyons except at one location in the Albany canyons where gravel content exceeds 35%.

5.7. SOUTH WEST TRANSITION

5.7.1. Geomorphology and Bathymetry

The South Western Transition covers a total area of 110,595 km^2, all of which is situated in the SWPR (Fig. 5.1). This bioregion represents 8% of the total area of the SWPR area and 1% of the total area of the EEZ. The South Western Transition is located offshore of Perth off the western Australian margin, and is separated from the coast by the South Western IMCRA Province. It is bounded to the north by the Central Western Province and to south by the Southern Province. This bioregion is composed entirely of slope, which extends approximately 350 km from the shelf break to the outer EEZ boundary (Table 5.17). Water depths vary from <100 m near the shelf break to almost 6,000 m, although 60% of the bioregion lies in depths of >2,000 m (Fig. 5.20; Table 5.18).

The slope contains nine types of geomorphic feature (Table 5.17). However, geomorphic features have not be identified over 53,000 km^2 (48%) of the total slope area. Two terraces run parallel to the shelf break on the upper slope in water depths of between 150 and 1,500 m (Fig. 5.18), and comprise 17,700 km^2 (16%) of the total bioregion area.

The Naturaliste Plateau is the only plateau in the SWPR and covers 30,000 km^2 (27%) of the total bioregion area and extends across much of the lower slope. Water depths in this area range from ~2,000-3,000 m. Trench/troughs are also found in deeper water areas near the base of the slope (water depths > 2,500 m), where they cover 8,800 km^2 (8%) or 85% of the total area of these features in the SWPR. Both of these geomorphic feature types are abundant elsewhere in the EEZ.

5.7.2. Sediment Data Coverage

The South West Transition contains 77 grainsize and/or carbonate data points, with more than 80% of these clustered on the upper slope where no geomorphic features have been identified (Fig. 5.18; Table 5.19). Approximately 40% of all the data points are located in water depths of <500 m, although these areas comprise only 10% of the total bioregion area. Samples are sparse on the rest of the slope, with less than 5% of the samples located in water depths of >3,000 m despite these depths comprising more than 30% of the total bioregion area (Figs. 5.19 & 5.20).

Samples cover five out of 9 geomorphic features in the bioregion (Fig. 5.18; Table 5.19). Average sample density across the bioregion is 1:1,500 km^2. However, sample density is lower for the geomorphic features: 1:7,500 km^2 for plateaus and 1:2,100 km^2 for terraces. There are no data points located in trench/trough features

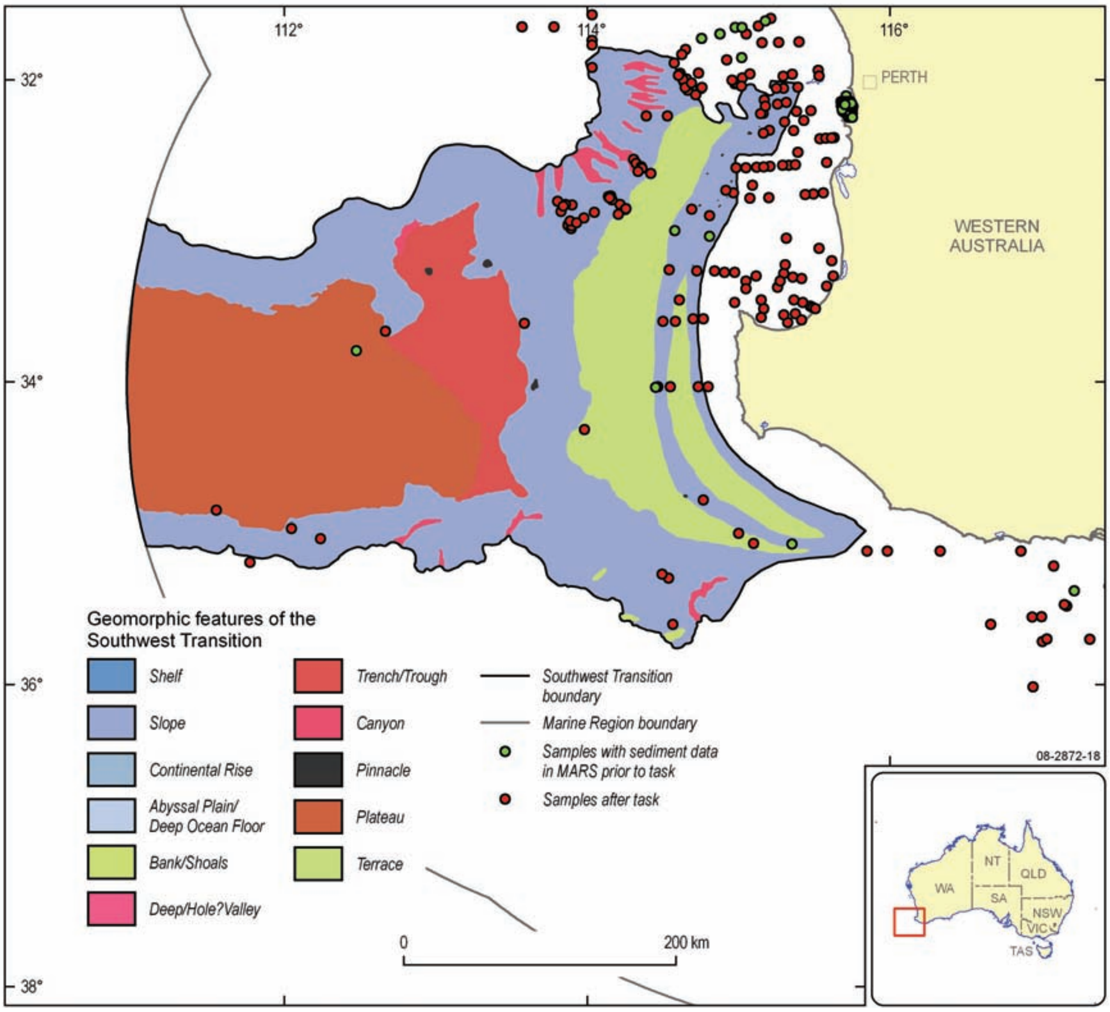

Figure 5.18. Geomorphology of the South West Transition with location of sediment samples.

Table 5.17. Details of the geomorphology of the South West Transition.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	<0.01	<0.01	<0.01
Slope	99.99	19.25	2.72
AP/DOF*	<0.01	<0.01	<0.01
Geomorphic Feature			
Shelf (unassigned)	<0.01	<0.01	<0.01
Slope (unassigned)	47.51	15.45	3.82
AP/DOF* (unassigned)	<0.01	<0.01	<0.01
bank/shoals	0.15	8.73	0.32
Trench/trough	8.07	85.14	5.14
Canyon	1.70	6.43	1.76
Pinnacle	0.10	15.22	2.09
Plateau	26.97	100	1.99

Terrace	15.51	9.24	2.96

* AP/DOF = Abyssal plain/deep ocean floor.

Table 5.18. Distribution of water depths covered by the geomorphology in the South West Transition. Not shown are shelf and abyssal plain/deep ocean floor features. These covered a smaller area than the resolution of the bathymetry grid and therefore could not be assessed.

Feature	**Depth Range (m)**	**Mean Depth (m)**
Geomorphic Province		
Slope	20 – 5,890	2,410
Geomorphic Feature		
Slope (unassigned)	20 – 5,500	2,650
Bank/shoals	3,500 – 5,890	4,610
Trench/trough	2,780 – 4,270	3,360
Canyon	1,680 – 5,190	3,610
Pinnacle	110 – 3,830	2,370
Plateau	1,970 – 3,130	2,550
Terrace	120 – 1,630	780

Table 5.19 Sample coverage by geomorphic provinces and features for the South West Transition.

Feature	**No. of samples**	**Average data density (sample:km^2)**
Geomorphic Province		
Slope	77	~1:1,500
Geomorphic Feature		
Slope (unassigned)	*62*	~1:900
Canyon	2	~1:1,000
Pinnacle	1	~1:100
Plateau	4	~1:7,500
Terrace	8	~1:2,100

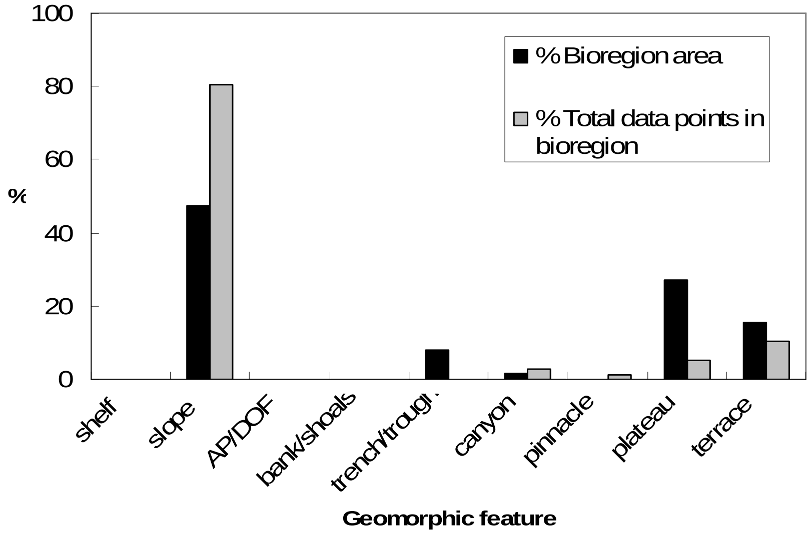

Figure 5.19. Graph showing sample coverage distributed by geomorphic feature in the South West Transition.

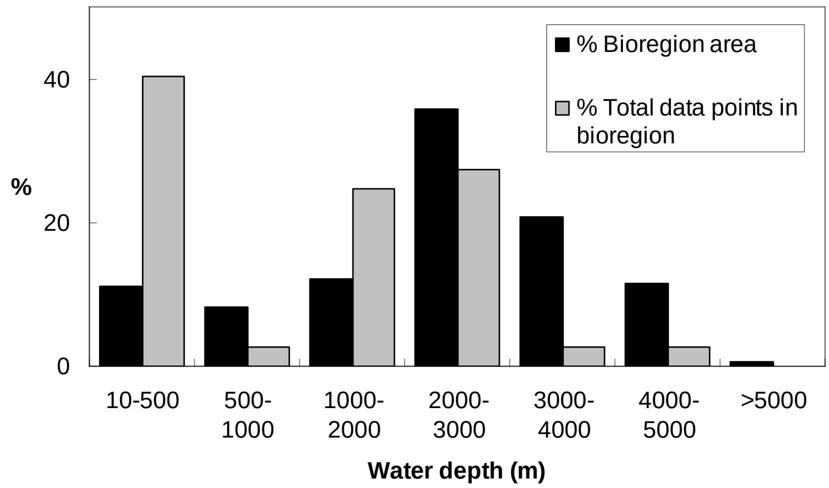

Figure 5.20. Graph showing sample coverage distributed by water depth in the South West Transition.

5.7.3. Quantitative Regional Sediment Distribution for the South West Transition

Samples achieve adequate coverage to assess the sedimentology of the slope and terraces, however, sedimentology is broadly similar across these features so they are not evaluated separately (Fig. 5.18).

As observed in the Southern Province, sand and mud contents vary greatly across the South West Transition, with sand dominating in shallow water areas and mud in deeper water. Sand is the dominant size fraction in the majority of samples, ranging from 2 to 100%, and with 47% (36) samples containing >50% sand, and all but 2 samples containing >5% sand. Mud is the next most abundant fraction, ranging from 0 to 97%. A total of 53% (41) samples contain >50% mud, however 26 contain <5% mud. Gravel forms <25% of all samples except at one location on the upper slope near the shelf break in the north of the bioregion where gravel content exceeds 40%. On the upper slope near the shelf break sand contents generally exceed 75%. In other deeper water areas sand content rarely exceeds 40%. Carbonate content of sediment exceeds 70% in all except 1 of 77 samples.

The large number of samples on the upper slope and shallow water terraces mean that sand is likely to be less abundant than suggested by statistics, and mud is probably the dominant constituent of sediment across most of the bioregions area.

5.8. CENTRAL WESTERN PROVINCE

5.8.1. Geomorphology and Bathymetry

The Central Western Province covers a total area of 286,400 km² (Fig. 5.1), which represents 20% of the total area of the SWPR and 3% of total area of the EEZ. All except 4% of this area (11,460 km²) lies within the SWPR. The Central Western Province is located at the northernmost boundary of the SWPR and is separated from the coastline by the Central Western IMCRA Province in the north (not included in the SWPR) and the South West IMCRA Transition in the south.

The bioregion is composed of slope, rise, and abyssal plain/deep ocean floor (Table 5.20). The composition of the bioregion is reflected in the water depth distribution, whereby 178,090 km² (65%) occurs in water depths of >4,000 m (Fig. 5.22).

A total of 9 geomorphic features occur in the Central Western Province. Areas of abyssal plain/deep ocean floor and slope where no other geomorphic features could be defined cover an area of 108,800 km² (38%) and 91,600 km² (32%), respectively. The rise feature covers an area of 54,400 km² (19%) of the total bioregion area, which represents 100% of the rise area in the SWPR and more than 50% of the total area of rise in the EEZ (Table 5.20).

Canyons and terraces cover the greatest area of the Central Western Province, covering 7,700 km² (2.7%) and 22,000 km² (7.7%), respectively. Although this is a deep-water bioregion, the terraces occur in water depths of between 200 and 1,500 m, and are not representative of the range of water depths over which terraces occur in the SWPR (10->5,000 m) (Fig. 5.24; Table 5.20).

Escarpments and deep/hole/valleys number 1 and 2, respectively, and are restricted to water depths of >4,000 m, although these features occur over a greater range of water depths elsewhere in the SWPR (10-5,000 m) (Fig. 5.24). Note that although escarpments cover ~250 km² (<1%) of the total area of the bioregion, this is the only occurrence of this feature in the SWPR.

Table 5.20. Details of the geomorphology of the Central Western Province.

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion
Geomorphic Province			
Shelf	<0.01	<0.01	<0.01
Slope	42.56	34.86	5.90
Rise	19.06	100	53.81
AP/DOF*	38.38	25.46	2.55
Geomorphic Feature			

Shelf (unassigned)	<0.01	<0.01	<0.01
Slope (unassigned)	32.06	25.83	6.39
Rise (unassigned)	19.04	100	54.49
AP/DOF* (unassigned)	37.92	34.12	4.21
Deep/hole/valley	0.46	37.34	0.76
Canyon	2.70	25.32	6.92
Pinnacle	0.03	12.66	1.74
Escarpment	0.09	100	1.19
Terrace	7.70	11.37	3.64

*AP/DOF = Abyssal plain/deep ocean floor.

Table 5.21. Distribution of water depths covered by the geomorphology in the Central Western Province.

Feature	**Depth Range (m)**	**Mean Depth (m)**
Geomorphic Province		
Shelf	200 – 270	250
Slope	10 – 5,620	2,360
Rise	2,830 – 5,940	4,830
AP/DOF*	4,560 – 5,910	5,300
Geomorphic Feature		
Shelf (unassigned)	200 – 270	250
Slope (unassigned)	10 – 5,620	2,680
Rise (unassigned)	3,830 – 5,940	4,830
AP/DOF* (unassigned)	4,560 – 5,910	5,300
Deep/hole/valley	5,400 – 5,640	5,480
Canyon	50 – 5,090	2,900
Pinnacle	70 – 4,440	2,680
Escarpment	4,000 – 4,270	4,120
Terrace	190 – 1,470	780

5.8.2. Sediment Data Coverage

A total of 139 grainsize and/or carbonate data points are located in the Central Western Province giving an average sample density of <1 sample for every 2,000 km^2 (Fig. 5.22; Table 5.22). Actual sample density varies across the bioregion from <25 km to >150 km between samples. More than 75% of the area of the bioregion is within 100 km of a data point.

Samples give good coverage of shallower water areas on the upper slope, with clusters of points at several locations near the shelf break (Fig. 5.21). Samples are sparse on the lower slope, rise and abyssal plain/deep ocean floor (average densities 1:9,000 – 1:35,000 km^2) (Fig. 5.23; Table 5.22).

The Central Western Province includes 25% of all canyons in the SWPR. Water depths for canyons (range 50-5,000 m) (Fig. 5.24) suggest that these may be a representative sample of canyons across the SWPR. However canyons form isolated environments, and although average data density is relatively high in these features (1:250 km^2), data points are clustered within a single large canyon in the south of the bioregion. The size and extent of this canyon is not representative of canyons in this bioregion.

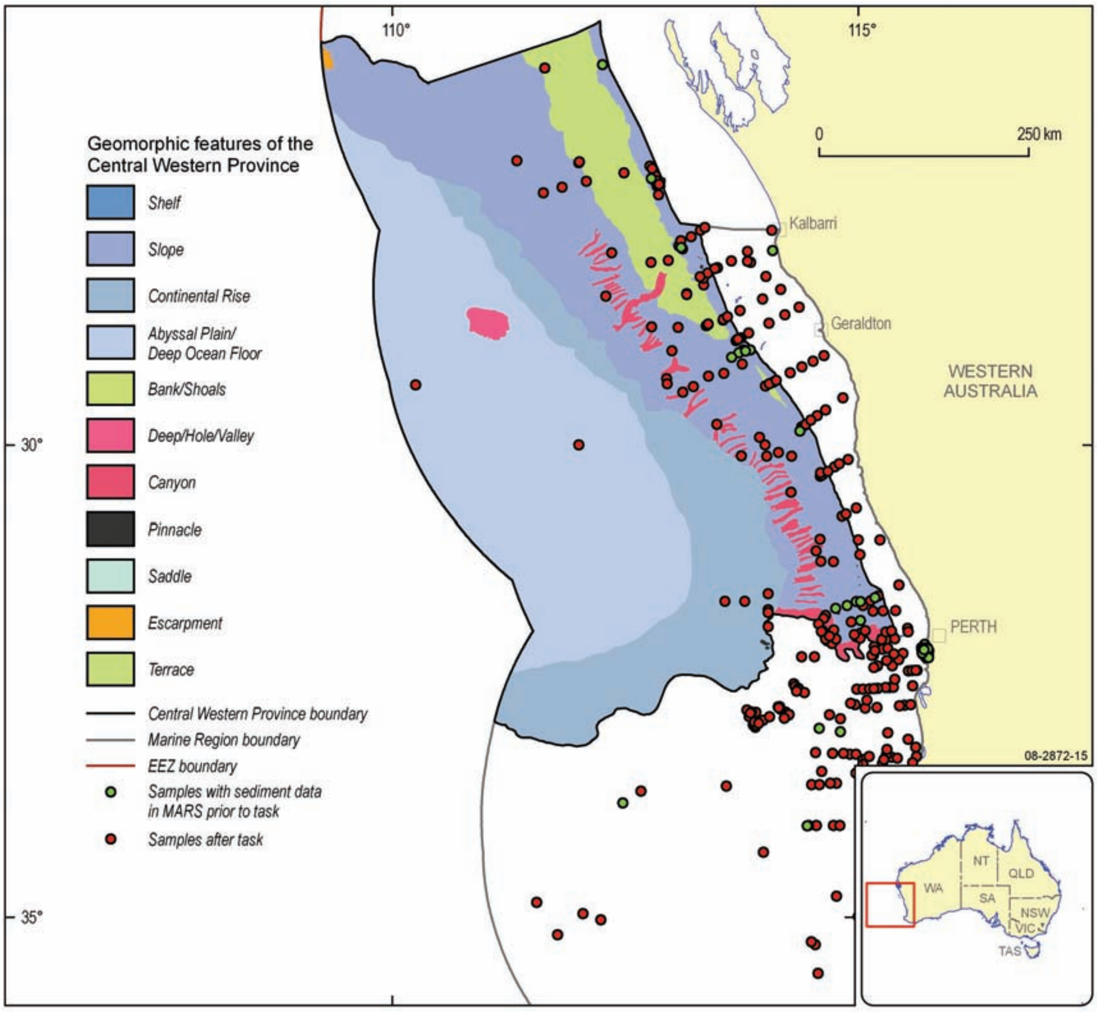

Figure 5.21. Geomorphology of the Central Western Province with location of sediment samples.

5.8.3. Quantitative Sediment Distribution for the Central Western Province

Samples achieve adequate coverage to assess sedimentology for the slope, rise, canyons and terraces.

Sediments in the Central Western Province show similar variable sand and mud content to that observed in other offshore bioregions in the SWPR, with similar spatial distribution related to water depth. Both fractions range from 0-100% of sediment. Sand forms more than 50% of sediment in 35% (49) samples and exceeds 80% in 20% (29) samples. Mud dominates in 65% (89) samples, and exceeds 80% in 37% (52) samples.

Table 5.22. Sample coverage by geomorphic provinces and features for the Central Western Province.

Feature	No. of Samples	Average data density (sample:km^2)
Geomorphic Provinces		
Slope	130	~1:900
Rise	6	~1:9,000

AP/DOF	3	~1:35,000
Geomorphic features		
Slope (unassigned)	87	~1:1,000
Rise (unassigned)	6	~1:1,500
AP/DOF* (unassigned)	3	~1:35,000
Canyon	28	~1:250
Terrace	15	~1:1,000

* AP/DOF = Abyssal plain/deep ocean floor.

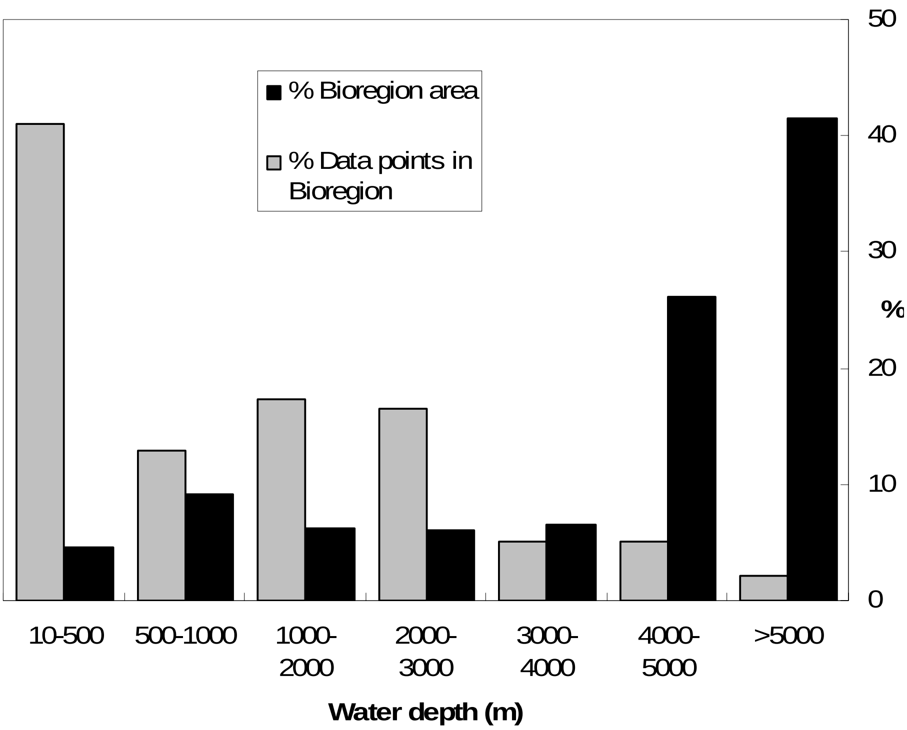

Figure 5.22. Graph showing sample coverage distributed by water depth in the Central Western Province. Note the inverse relationship between water depth area and percent number of samples. Samples occur in all bathymetric classes, although >40% of the samples occur in water depths of <500 m, and <2% of the samples occur in water depths of >4,000 m even though these depths make up >40% of the total area of the bioregion.

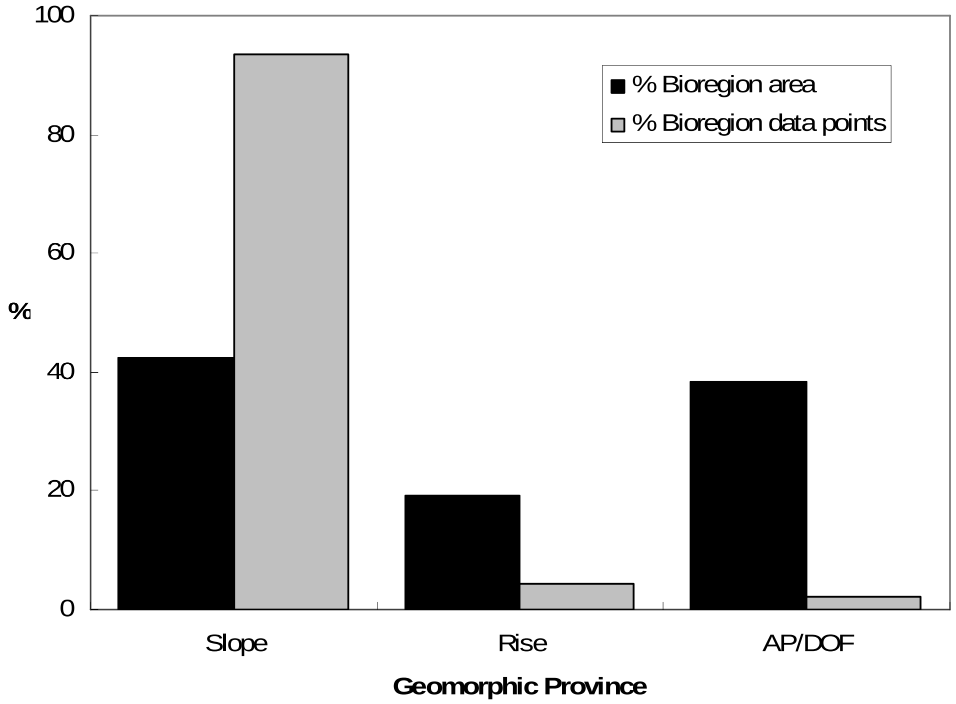

Figure 5.23. Graph showing sample coverage distributed by geomorphic province in the Central Western Province.

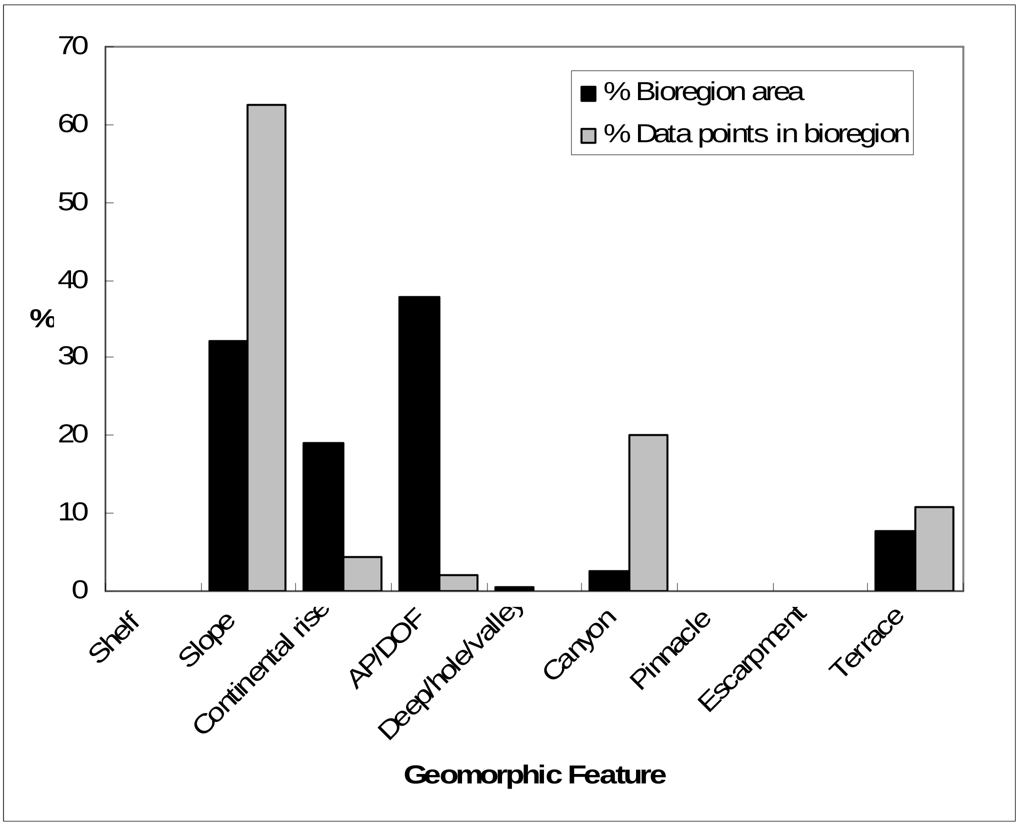

Figure 5.24. Graph showing sample coverage distributed by geomorphic features in the Central Western Province.

Gravel is a minor constituent comprising <5% in 75% (112) samples, although gravel contents attain 30% at 4 locations on the upper slope near the shelf break. Carbonate grains dominate all size fractions, with 50% (78) samples containing >80% bulk carbonate, and similar carbonate contents for all fractions.

Areas of slope where no other geomorphic features are identified have a similar sedimentology to that of the whole bioregion, as the majority of samples occur in this area. However this area can be distinguished by slightly lower maximum mud content (90%) and higher minimum sand content (10%). Carbonate contents in this feature are also generally slightly higher, with bulk carbonate exceeding 40% in all samples.

The rise is dominated by mud, with contents ranging from 40 to 95% and exceeding 65% in 75% (5) samples. Sand formed the remaining volume in all samples. Carbonate content varied greatly, with most variation occurring in the mud fraction (ranging between 3-83%). Carbonate content of sand was less variable, exceeding 80% for all samples.

All canyon samples in this bioregion occur in the Perth Canyon (Fig. 5.21). Mud is the dominant fraction, ranging from 77 to 95%, with 50% (12) samples containing between 85 and 90% mud. The remainder of sediment is generally sand, although gravel forms a minor component of sediment (<5%) in 14 samples. Carbonate exceeds 75% in 75% (25) samples.

Terrace sediments are dominated by mud, with contents ranging from 20 to 88% and 85% (13) samples containing >60% mud. The remainder of sediment volume in all samples was composed of sand, with gravel content not exceeding 1%. . Carbonate content exceeds 75% in all samples from terraces.

6. Discussion

Our newly-created database of the texture and composition of the seabed sediments for the Southwest Planning Region (SWPR) permits quantitative comparisons of the sedimentology to be made for the SWPR and the entire Australian margin. It allows us to identify relationships, and draw comparisons, between the bioregions of the SWPR, and also to identify relationships between geomorphology, bathymetry and sediment properties that may prove useful in predicting sediment distribution in areas for which we have no data.

Our data builds on, and allows us to understand the relationship between, other mainly qualitative studies that exist for this margin. Previous work for these margins has focussed principally on the shelf, and so much of the following discussion comparing our results with the findings of these studies is restricted to this area. Where possible, we also comment on how our results compare with previous sedimentological models of the deep seabed.

6.1. REGIONAL SEDIMENT DISTRIBUTION PATTERNS

6.1.1. Summary of distribution patterns

Across the SWPR, seabed sediments show a broad zoning with water depth, and generally become finer with depth. The total variation in sediment texture and composition also generally decreases with increasing water depth, with the rise and abyssal plain/deep ocean floor showing more homogeneous sediment characteristics than the slope and shelf. Moreover, the distances over which significant variations in the texture and composition of the sediments occur are greater in the deep ocean (lower slope, rise and abyssal plain/deep ocean floor) than on the upper slope and shelf. Significant variability in the texture and composition occurs over relatively short distances on the upper and mid-slope, principally associated with the varied environments associated with submarine canyons.

Sediments over the entire SWPR are dominated by carbonate grains. Sediments dominated by terrigenous grains are restricted to isolated regions of the inner shelf. Bulk carbonate content generally decreases with increasing water depth. In the deep ocean, the muddy sediments contain a relatively high non-carbonate component, associated with siliceous grains from sponge spicules and diatoms.

6.1.2. Comparison to previous work in the SWPR

At a regional scale, our results agree with previous sedimentological work on the southern and western margins (cf. James et al., 1999; 2001). These studies indicate that the entire southern and western Australian margins are carbonate dominated and that the shelf is an area of relatively high carbonate production.

Data for the deep ocean (>2,000 m) was relatively sparse prior to this study. The few samples from these regions indicate that the seabed on the lower slope, rise and abyssal plain is principally composed of foraminifer-nannofossil ooze. Our results have added detail and confirmed these initial observations with the sediments contained in the new samples composed mostly of carbonate and siliceous ooze. Our data show much higher variability in the texture and composition of the seabed than previously observed.

Most previous study has focussed on the shelf, providing finer resolution detail of local and regional sediment distribution patterns in this area. On the western margin, our results agree with the distribution of shelf sediment facies described by James et al. (1999). Significantly, our results reveal a relatively narrow band of sediments containing gravel that corresponds to the 'Rhodolite gravel' facies of James et al., (1999). The gravel content of this facies is highly variable, reaching >60% in the south, but generally not exceeding 30%. The distributions of sand and mud fractions described in the shelf facies model are also generally consistent with our results. On the upper slope and outer shelf, samples coinciding with the silt facies of James et al. (1999) are mostly composed of >70% sand, although some samples contain up to 50% mud.

Our data suggests deepwater areas are generally dominated by mud, although sand dominated sediments do occur in water depths of >4,000 m on the rise and abyssal plain/deep ocean floor regions. Where sand does dominate at great depths, these areas coincide with the presence of submarine canyons on the slope, and may reflect the transport of sediment down the canyons by mass movements. Away from the canyons, the relatively coarse sediment may represent regions of fine-sediment winnowing by deep ocean currents.

Collins' (1988) interpretation of sediment facies distribution for the southern Rottnest Shelf showed this region as characterised by up to five shelf-parallel sediment facies, ranging from siliciclastic-dominated sands near the coast to carbonate-dominated facies offshore. Our data reveal that all of these facies are dominated by sand, with local gravel concentrations of up to 60%. Interestingly, our data suggest that both the carbonate and non-carbonate fraction are comprised of sand grains and gravel clasts, whereas over most of the western and southern shelves the concentrations of non-carbonate gravel and sand is relatively low.

Carrigy and Fairbridge (1954) mapped the texture and composition of seabed sediments on the southern Rottnest and Recherché shelves, and the slope, rise and abyssal plain/deep ocean floor regions off Perth and adjacent to the Naturaliste Plateau. Our results agree with the broad distributions of sand and gravel they described for the shelf, and the marked transition from sand-dominated sediments on the shelf to mud-dominated sediments on the slope, rise and abyssal plain/deep ocean floor. Across this transition we find that there is generally lower sand content and higher mud content than observed by these previous workers. However, our results provide detailed quantitative evidence to support the claim that sediments grade from sand- to mud-dominated in this area.

On the southern margin, the shelf sediments have been described by James et al. (2001). This region is the largest cool-water carbonate margin on Earth and the seabed sediments can be divided into 12 sedimentary facies that form broad, shelf-parallel zones distinguished by different skeletal assemblages (James et al., 2001). Our results confirm the dominance of sand across the shelf, and we also show that gravel locally comprises up to 50% of the sediments. Although not coinciding with a particular facies identified by James et al. (2001), gravel content in the western bight attains 35%; elsewhere gravel is generally <10%. Again, our results confirm a transition from sand-dominated to mud-dominated sediments from the outer shelf to the slope, rise and abyssal plain/deep ocean floor. Mud content attains 30% on the outer shelf and increases to between 80 and 100% on the upper slope, where it generally remains at >80% down the slope and onto the rise and abyssal plain/deep ocean floor.

Bulk carbonate concentrations show similar distributions to those observed by previous workers (cf., Carrigy and Fairbridge, 1954; Collins, 1988; James et al., 1999; 2001). Concentrations of <20% coincide with locations of relatively high terrigenous sediment on the shelf identified by these previous workers. Our data reveal that the 'Quartzose skeletal sand' facies of James et al. (1999) on the shelf north of Perth contains between 0 and 20% carbonate. Other regions of low bulk carbonate contents correspond to the 'Quartz gst' facies of Collins (1988) for the southern Rottnest Shelf. The spatial variation in bulk carbonate content on the southern Rottnest Shelf is much greater than depicted by Collins (1988), with regions most proximal to the coast generally containing <20% carbonate, and mid-shelf regions containing between 40 and 60% in the north and 20 and 40% in the south.

On the southern shelf, little new data has been added since interpretation by James et al. (2001). All of the shelf facies identified by James et al. (2001) are dominated by carbonate grains, with bulk concentrations of >80%. Such high concentrations reflect the influence of local carbonate production on the shelf. While we have limited data from James et al. mapped quartzose sand, where we do have samples bulk sediment remains at >80% carbonate suggesting that the quartzose sands are not as widely distributed as previously indicated.

Regions of significant terrigenous sediments occur in Spencer Gulf, Investigator Strait, Gulf of St Vincent and on the inner shelf east of Kangaroo Island (James et al., 1997). Our data show larger ranges in sediment properties and changes in properties occurring on smaller spatial scales than interpreted by James et al. (1997). In addition, our data agree with the presence of a large region of non-carbonate, mud-dominated sediment on the slope south of the Eyre Peninsula (cf. James et al., 1997), with concentrations ranging between 20 to 70%.

6.2. CORRELATION BETWEEN SEDIMENT PROPERTIES AND OTHER PHYSICAL DATASETS

6.2.1. Relationships between sediment properties and bathymetry

As noted above, sediment data in the SWPR shows some correlation to bathymetry.

- Mud content of sediment generally increases with increasing water depth
    - Mud is present in almost all samples occurring in water depths exceeding 500 m, and is the dominant sediment type at most locations in water depths >1,000 m.
- Sand and gravel content generally decreases with increasing water depth:
    - Sand is the dominant sediment fractions on the shelf and upper slope in water depths <500 m.
    - Gravel is found mainly on the inner shelf in water depths <50m, but occurs in low concentrations across the shelf and slope in water depths >1,500 m.
    - Gravel is generally absent on the abyssal plain/deep ocean floor in water depths >3,000 m.
- Carbonate content generally decreases with increasing water depth, although exceptions to this occur locally where terrigenous sediment is supplied to the inner shelf.

The differences in physical conditions across the Australian Margin mean that relationships that have been identified in the SWPR may not hold elsewhere in the EEZ. In contrast, the regional scale at which we are assessing relationships means that far stronger relationships between sediment properties and bathymetry and geomorphology may exist at more local scales.

At a regional scale, relationships between sediment properties and water depth are clearly apparent when assays are observed spatially, however they are difficult recognize or to quantify statistically. Across the SWPR, sediment characteristics do not change in the same way with change in water depth. Samples are often clustered in areas that are not representative sediment properties generally occurring at that water depth. This creates results in broad range of sediment properties associated with a single depth, and obscures the relationship that generally exists between these variables. This is often the case in shallow water on the inner shelf, for example in the Spencer Gulf and Geographe Bay. This situation also arises on the slope where sampling often targets specific features that contain sediments not representative of those generally occurring at specific water depths, for example the Albany Canyons.

The reasons for this variation are that other physical variables influence sediment distribution. However, it was not within the scope of this study to test relationships between these variables and sediment properties. Data sets describing disturbance regimes and seabed temperature and current conditions are increasingly available in formats that give full coverage at regional scales, allowing statistical comparison with sediment data (e.g. Seascapes).

6.2.2. Relationships between sediment properties and geomorphology

Statistics also suggest that relationships exist between sediment properties and geomorphic feature types in the SWPR. A geomorphic feature type often represents a common set of physical conditions that affect sediment distribution. Where this is the case, the feature may have a distinctive sedimentology – for example, banks/shoals contain sediments generally comprising 70-100% sand, with minor gravel (<20%) and mud (<6%) - areas of abyssal plain/deep ocean floor are generally mud dominated with no gravel present. Sedimentology of these features contrasts to that of other feature types and of the surrounding seabed.

Other feature types in the SWPR may also have a distinctive sedimentology that cannot be identified from existing data coverage and distribution. However, sedimentology of some feature types will vary between individual features. This may occur for several reasons. If a physical variable that influences sediment distribution varies varies significantly for different occurrences of a feature type, then sedimentology is likely to show similar variation. An example of this is where features occur over a large bathymetric range, for example terraces in the SWPR. Terraces in shallow water contain more coarse sediments and commonly contain gravel, while those in deeper water contain finer sediment dominated by sand and mud. This is likely to be the case for other features in the SWPR but cannot be observed with existing data coverage.

A single feature type can also show variation in sediment properties between occurrences when features are located in areas where sediment sources have strongly contrasting properties. An example of this is deep/hole/valleys in the SWPR. Separate occurrences of these features show contrasting sediment properties that are not linked to differences in water depth. Thus, sediments in deep/hole/valleys in the north of the SWPR have consistently high sand with little gravel or mud, while those further south on the western margin have higher gravel (generally >8%), and those in mouth of the St Vincent

Gulf have higher mud (>6%). In some features, variation in sediment properties may result from a combination of these factors. For example, the large variation in sediment properties observed in canyons in the SWPR is likely to result from a combination of large bathymetric range, down-slope transport and sorting, and differences in sediment source.

Low numbers of sample points for most features in the SWPR mean that data is often inadequate to characterise sedimentology or identify sediment sources. Although some features show a distinctive common sedimentology in statistics, in many cases this is an artifact resulting from the distribution of sample points. If all data points are in a single occurrence of a feature, then this feature will appear to have a characteristic sedimentology (e.g. Rise and Plateaus in the SWPR). Also, if data are in several but not all occurrences of a feature type, this may not represent the range or frequency of sediment properties generally present in these features in the SWPR. Or, data may be clustered in an area that has an abberant localized sedimentology. This may exaggerate the frequency of some sediment properties, preventing recognition of a common set of sediment properties that charactise the majority of the area of this feature type in the SWPR. This is likely to be the case for tidal sand wave/sandbanks in the northern Spencer Gulf, an area known to have input of coarse terrigenous sediment. This results in these features being characterized by sediments containing up to 25% gravel and highly variable sand:mud ratios. Sediments occurring in the tidal sand waves in the central Spencer Gulf, and near the mouth of the St Vincent Gulf would be expected to have a different profile, but no data are available for these.

We can also observe differences in the distance over which variation in sediment properties occur within different geomorphic feature types. For example, on the abyssal plain/deep ocean floor sediment properties appear to remain relatively constant over distances exceeding 100 km. However, variations occur over distances of 100s of metres on terraces in the SWPR and are observed to occur over 10s of metres in features such as tidal sand wave/sandbanks. However, there is some uncertainty in assessing this characteristic as detection of changes is dependent on sample spacing, which varies between feature types.

There are also differences in seabed complexity or the range of environments that occur within different geomorphic feature types. For example, the slope in the SWPR contains a large range of sediment properties, while the abyssal plain/deep ocean floor contain more homogeneous sediments. Again, this is difficult to accurately assess as all environments that exist within a feature type may not have been sampled.

6.3. SEDIMENT PROPERTIES OF SWPR BIOREGIONS

6.3.1. Characteristic sedimentology of IMCRA and Offshore bioregions

Differences between the IMCRA and offshore bioregions are not evidenced well in statistics. Sample coverage in deepwater bioregions is biased toward shallower water depths on the upper slope; large portions of offshore regions comprise abyssal plain/deep ocean floor (water depths >4,000 m) but these are poorly represented in the data.

IMCRA bioregions cover the area of the continental shelf, while offshore bioregions include the slope and deep water environment to the EEZ boundary.
Generally, IMCRA bioregions correspond to areas of shallow (0-350 m) and deeper (200-8,000 m) water, although there is some overlap at the shelf break due to the uncertainty in mapping this boundary. A large portion of the samples in the SWPR lie within a distance

likely to represent this area of uncertainty/crossover. Statistically, this results in some damping of the distinctive properties that characterize these two areas of the margin. This has a greater affect in offshore bioregions, where data on or near the shelf break represents a far higher percentage of the total data available for these provinces, and a large portion of the total area occurs in deep water on the lower slope, rise and abyssal plain/ deep ocean floor.

However, knowledge of the geomorphic and bathymetric composition of IMCRA and offshore bioregions and relationships between these and sedimentology, mean that we can infer some differences which may not be obvious from statistics. IMCRA bioregions share characteristics of shallow water and continental shelf areas discussed previously. Moderate to high density sample coverage indicates that sediments across most of this area are relatively homogeneous, dominated by carbonate sand, although gravel and mud and non-carbonate material are all abundant locally.

Data for offshore bioregions is more incomplete and less likely to be representative of all sediments or the relative proportions of these present. Taking into account the distribution of data in these areas, we can infer that sediments in offshore bioregions differ from IMCRA bioregions in: 1) textural and compositional properties; and 2) the way these vary spatially.

Texture and composition of sediments vary greatly on the slope. As noted previously, generally this change is occurs gradually at regional scales, with sediment fining and carbonate content decreasing with increasing water depth. However the slope also contains complex areas of seabed where sediment properties change dramatically over short distances. In the SWPR, these changes are only detected occasionally where data are closely spaced. As data density in offshore bioregions is generally inadequate to detect these areas of seabed complexity, they are likely to be far more abundant in these areas than evidenced in statistics.

Offshore bioregions also contain areas of abyssal plain/deep ocean floor where sediment properties contrast to those on the slope. Despite low sample densities, it is evident that the abyssal plain/deep ocean floor contains far more homogeneous sedimentology than the slope, with generally low-carbonate sediments comprising mud and lesser sand. Most variation in sediment properties appears to occur in the area close to the base of the slope which is locally supplied with coarser carbonate sediment, particularly where canyons are present.

6.3.2. Differences in sedimentology between IMCRA bioregions

Differences between IMCRA bioregions seen in statistics are at least partially the result of sample distribution. Local clustering of samples in some regions (e.g. the inner shelf in the Southwestern IMCRA Province) provide evidence of local sedimentology that is not detected in other areas of the region or in other bioregions, although it may be present. This is particularly obvious for samples on the inner shelf near the coast. Samples in this area occur in local clusters. Sediments in this area vary in properties considerably, with areas of terrigenous input and gravels present that are spatially restricted.

As when comparing bioregions on the shelf and in deepwater (Chapter 6.3.1), we may infer some differences between IMCRA bioregions that may not be obvious from statistics. Areas of distinctive sedimentology that occur on large scales are most likely to represent real differences between bioregions. This applies particularly where sediments are associated with a unique geomorphology that is not present elsewhere in the SWPR, or, where it does occur, has been sampled and found to contain non-distinctive sediments. Examples of this are the significant terrigenous component and the abundant mud/gravels present in sediments found in the shallow water embayments in the Spencer Gulf IMCRA Province (unique geomorphology), and the large area of gravel present on the unassigned area of the shelf in the Great Australian Bight IMCRA Transition (unique sedimentology not occurring in areas with similar geomorphology).

6.3.3. Differences in sedimentology between offshore bioregions

Differences between offshore bioregions that can be seen in statistics are also strongly influenced by sample distribution. Surveys in deep water in the SWPR have often targeted individual features, and tend to favour more accessible areas in shallow water. The features targeted and the frequency distribution of samples in relation to bathymetry and geomorphology differ between bioregions, and are not representative of the actual differences in composition of the bioregions.

In IMCRA regions, sampling may capture areas of distinctive sedimentology that occur on large scales, but the very sparse sample coverage in deep water means that sediment types that cover significant portions of the total area of offshore bioregions may not even be detected in our data.

The most significant differences between sedimentology of the offshore bioregions in the SWPR are likely to reflect the variations in their bathymetric and geomorphic composition. For example, offshore bioregions like the Southern Province in which a high proportion of the total area occurs on the abyssal plain/deep ocean floor distal to the base of the slope are likely to have a more homogeneous sedimentology dominated by muddy sediment with variable carbonate content. In contrast, offshore bioregions that occur at shallower water depths and have a larger percentage of their area on the slope (the Southwest Transition and to a lesser degree the Central Western Province), are likely to have a more variable sedimentology with higher carbonate contents and more abundant sand and gravel.

6.3.4. Implications of findings

Analysis of relationships between physical datasets and the sedimentology appears to offer a practical solution to interpreting sediment properties in areas of the seabed for which no data currently exists. Such interpretations facilitate identification of seabed environments that are potentially unique or rare at regional scales, and differences between seabed sedimentology of bioregions. This information forms an important contribution to decision making processes in regional marine environmental planning for the SWPR. In this report we have used geomorphology and bathymetry, however there are indications that other physical variables may be more relevant for predicting sediment properties for some areas of the seabed, particularly at more local scales. These include current strength and direction, slope gradient and proximity to rivers with high sediment output.

6.4. HOW MUCH DATA ARE REQUIRED TO CHARACTERISE THE SEABED?

Relationships are recognised to exist between the texture and composition of seabed sediments and biota (e.g., Day and Roff, 2000; Roff and Taylor, 2000; Roff et al., 2003; Kostylev et al., 2001). For this reason, sediment properties as measured in this study are an important input into statistical models used to approximate the nature and extent of seabed marine habitats (e.g., seascapes of Day and Roff, 2000). The accuracy of the seascapes in representing the seabed habitats is directly related to the quality and resolution of the underlying sediment data. Major sources of spatial error in sediment data used to characterize habitats are data density and inadequate interpolation methodologies.

6.4.1. Data Density

Benthic biota have identified and measurable relationships with the gravel and mud content of seabed sediments (e.g., Post et al., 2006). Our data show that where seabed environments are relatively complex, such as on the inner shelf and in submarine canyons, sediment properties including gravel and mud contents vary over relatively small distances. This requires a much higher sample density in these environments to more accurately map the spatial distribution of the properties (and by association benthic biota). In areas where seabed environments are relatively uniform, such as over most of the abyssal plain/deep ocean floor, sediment properties are more constant over larger distances, and can be accurately mapped from fewer samples.

The spatial variation shown by these properties in our study provides a guide to the resolution at which they must be known to map changes in sediment characteristics for regional marine planning. We have used these thresholds to assess data coverage in the SWPR.

Our results reveal that the distance over which changes in sediment properties occur also varies between geomorphic features. The sample spacing required to accurately map sediment properties in any geomorphic feature must be less than the distance over which significant changes occur. Our data can be used with geomorphology maps to guide the degree to which sediment properties can be extrapolated over the seabed.

6.4.2. Spatial Interpolation

All of the sediment properties must be interpolated between the samples to create regional maps. Sample density limits the accuracy of these maps. A variety of methods are available for interpolating between the samples (e.g., Nearest Neighbour, Inverse Distance Weighting, Kriging, Spline). Each method uses the spatial relationships between the data to fill gaps between data points. All of the methods work well where the sample density is high enough to capture trends in sediment distribution (i.e., distance between samples is << distance over which change in sediment characteristics occurs).

In this study we have used the inverse distance weighting method (see Appendix C), which has been used by Geoscience Australia to interpolate all of its point data across Australia's marine jurisdiction. The maximum distance that any data were extrapolated was 45 km. This method is adequate to produce maps of regional sediment distributions, but is likely to be a simplification of the actual distribution of sediments where sample densities are low. Although not presented in this study (see Hinde et al., 2006), testing of the interpolation methods for the sediment properties indicates that the overall fit of the data is moderate (at about 60%) and that different interpolation methods affect the fit by less than 5%. (All of the sediment property values quoted in this record are from the laboratory analyses.) The key question for regional marine planning is "*How much simplification is acceptable?*" Sample spacing for most geomorphic features in the SWPR is >50 m, and frequently as much as 200 m. This provides the minimum distances over which variations in the sediment properties can be detected.

Recognising the differences in extrapolation distances for different geomorphic features has implications for assessment of sampling gaps and error in current sediment data layers produced for the SWPR. In the SWPR, relatively high sample densities are achieved on the shelf and for some geomorphic features (e.g., banks, deep/holes, canyons; Table 4.2). However sample density remains low in deeper water areas, particularly on the abyssal plain/deep ocean floor. This has is a significant data gap as the abyssal plain/deep ocean floor represents a large portion of the SWPR area.

6.4.3. Addressing Sample Density Problems

For habitat mapping purposes, future sampling in the SWPR should focus on features where seabed habitats are known to be complex and sediment properties are highly variable over small distances. Within this selection of features, sampling should focus on features which cover the greatest area of the SWPR, and those which are rare elsewhere in the EEZ, as these are most likely to contain unique habitats that need to be identified for regional marine planning purposes.

During this task we have procured and analysed the majority of samples taken from the SWPR which are still in existence. Additional sediment samples are collected on marine surveys, but these generally amount to only a few hundred samples per year. This quantity of samples is not adequate to increase sample density significantly on timescales useful for regional marine planning.

Addition of geomorphic information to aid the interpolation methods has the potential to increase the accuracy of regional scale sediment maps using current sample densities. Relationships between existing physical data sets and sediment assay results could be identified in areas of high sample density. This could then be used to extrapolate sediment properties across areas where sample coverage is poor.

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8. APPENDIX

8.1. APPENDIX A: BATHYMETRY IN THE SWPR AND EEZ

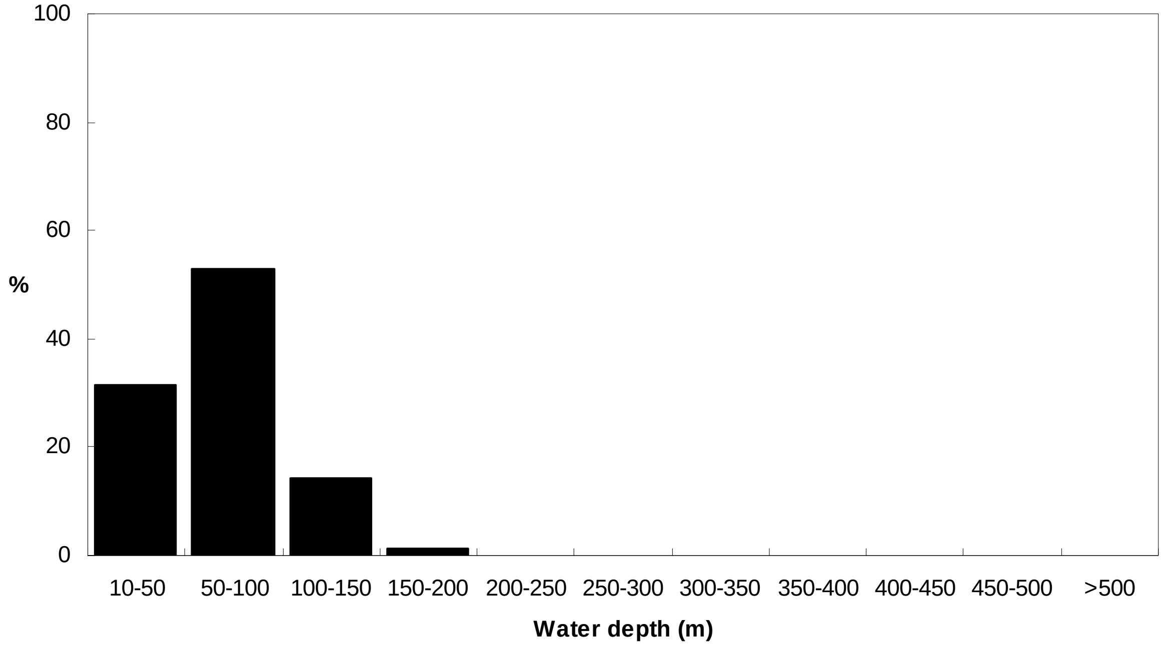
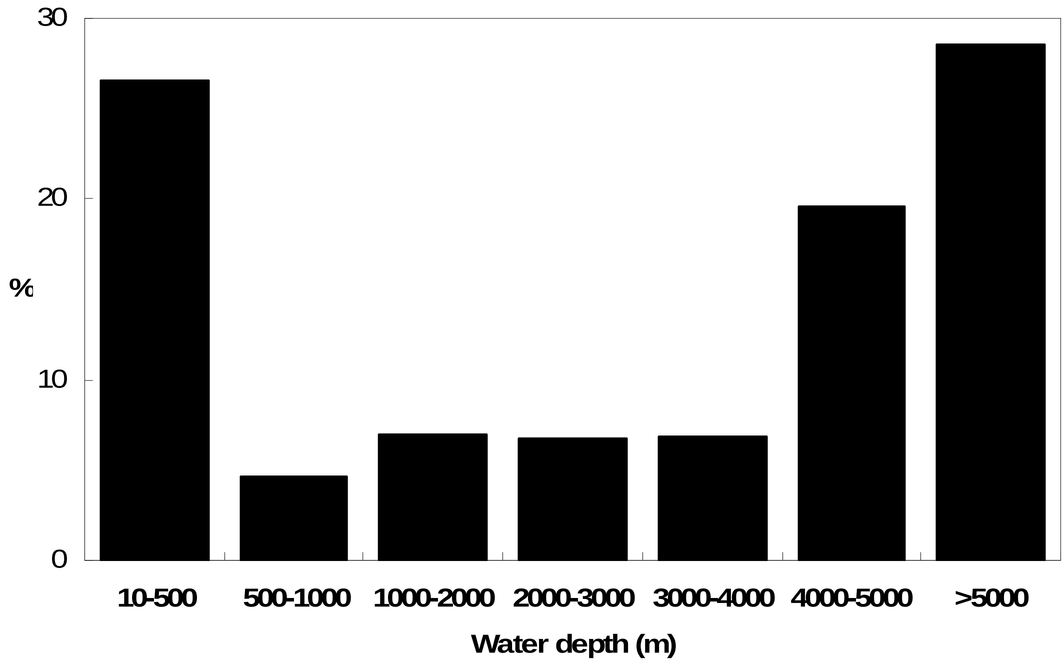


Figure 8.1. Graph showing the distribution of water depths for the continental shelf in the SWPR, expressed as percentages.



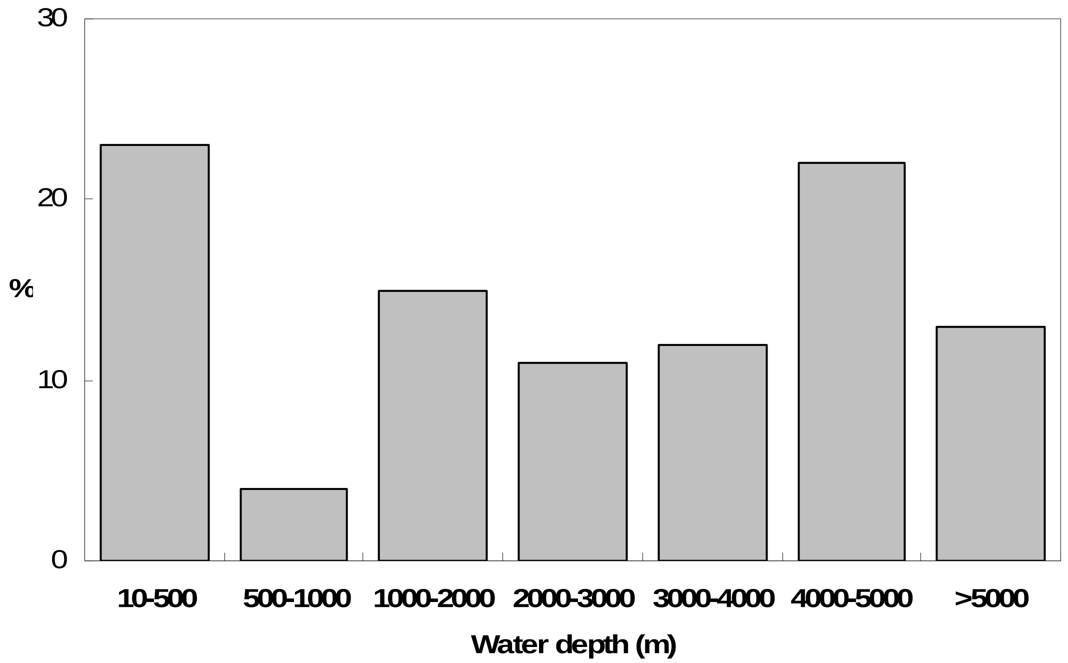
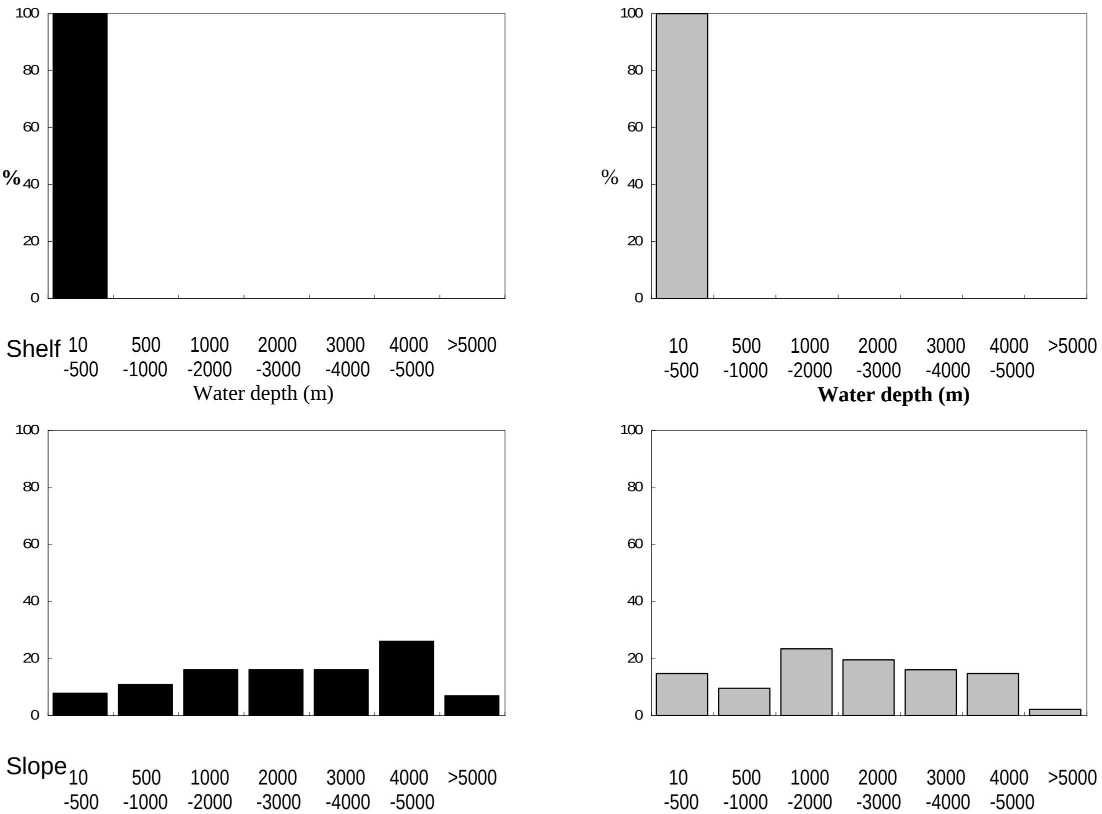
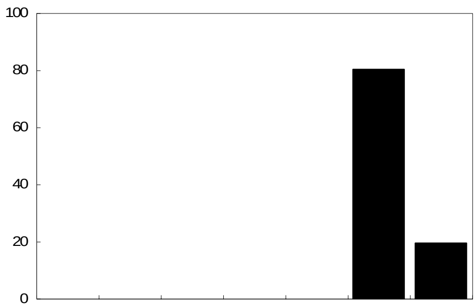
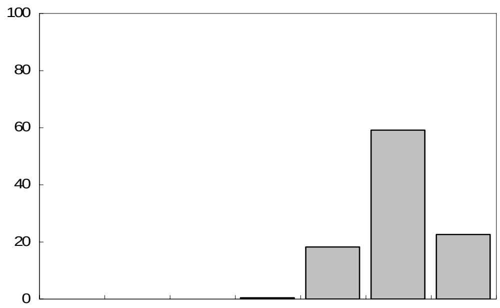


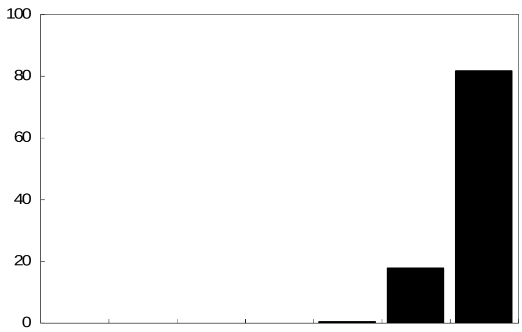
Figure 8.2. a) Graphs of the distribution of water depths expressed as percentages for the SWPR (black bars) and b) EEZ (grey bars) for water depths >10 m.

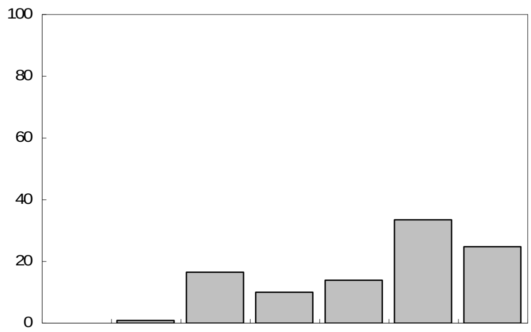






Rise





Abyssal plain/deep ocean floor

Figure 8.3. Graphs showing the distribution of water depths by geomorphic provinces for the SWPR (black bars) and EEZ (grey bars), express as percentage.

8.2. APPENDIX B: PROJECT STAFF

Name	Substantive Role
Dr Andrew Heap	Project Manager/Geomorphologist/Sedimentologist
Anna Potter	Project Scientist/Sedimentologist
Chris Southby	Project Scientist/Sedimentologist

8.3. APPENDIX C: ARCGIS MAPPING PARAMETERS

8.3.1. Gravel, Sand, Mud, Carbonate and Mean Grainsize Maps

- data imported to ArcGIS in csv format
- interpolate to raster using:
  i) inverse distance weighted interpolator
  ii) cell size of 0.01 decimal degrees (dd) – about 1 kilometre
  iii) optimal parameters: search radius of 12 points and power parameter of 1
  (Ruddick, 2006).
  iv) maximum extrapolation distance of 0.45 dd – about 45 kilometres

- raster image clipped to Australian Economic Exclusive Zone limit and the National Mapping 1:250,000 coastline from the National GIS.
- additional clip areas were added where interpolator extrapolation produced
- artefacts that were not consistent with the surrounding data points.

8.3.2. Sedbed Sediment Type – Folk Classification

- samples allocated to one of 15 Folk sediment type classifications based on gravel/sand/mud percentages prior to ArcGIS import
- data imported to ArcGIS in csv format
- interpolate to raster using:
  - i) Euclidian distance interpolation
  - ii) cell size of 0.01 decimal degrees (dd) – about 1 kilometre
  - iii) maximum extrapolation distance of 0.45 dd – about 45 kilometres
- raster image clipped to Australian Economic Exclusive Zone limit and the
- National Mapping 1:250,000 coastline from the National GIS.
- additional clip areas were added where interpolator extrapolation produced
- artefacts that were not consistent with the surrounding data points.

8.4. APPENDIX D: EXPLANATION OF TABLE FIELDS

8.4.1. Section 4 Tables

E.g. Table 4.1.

Feature	Area in SWPR	% total* SWPR Area	% EEZ Area	% Total EEZ area located in SWPR	Water Depth Range* in SWPR (m)

Area in SWPR: Area in km² covered by this feature within the SWPR.

% total* SWPR Area: Percent of the total area of the SWPR (not including areas with water depths <10m) which is allocated to this feature.

% EEZ Area: Percent of the total area of the EEZ which is allocated to this feature.
% Total EEZ area located in SWPR: The proportion of the EEZ area allocated to this feature that lies within the SWPR.

Water Depth Range* in SWPR (m): Range of water depths occurring in the SWPR area (not including areas with water depths <10m) allocated to this feature. Values are rounded to the nearest 10 m.

E.g. Table 4.2

Feature	Total number of features	Total number of samples	Number of features covered	Average density (samples per km²)	Adequate coverage to assess sedimentology in these bioregions

Total number of samples: The total number of samples used in this study that are located within the area allocated to this feature. Some samples included in this figure have only textural or compositional data.

Average density (samples per km^2): The average sample density across all occurrences of the feature in the SWPR. This is calculated by dividing the total area of the feature by the number of sample points within it. Results have been rounded to the nearest 50 km^2.

Adequate coverage to assess sedimentology in these bioregions: Sedimentology statistics were generated for features at a SWPR level where 4 or more sample points were located within them. Bioregion level analysis of a feature was only completed when the area of the feature in the area of the bioregion included in the SWPR also contained 4 or more sample points.

8.4.2. Section 5 Tables

E.g. Table 5.1.

Bioregion	% bioregion included in SWPR	Water type	% total SWPR area

% bioregion included in SWPR: Some Bioregions are cut by the boundaries of the SWPR. This gives the percentage of the total area of the bioregion (including areas with water depths <10m) that falls within the SWPR.

Water type: The water type for this bioregion as described in the National Marine Bioregionalisation of Australia (2005).

% total SWPR area: The proportion of the total SWPR area that falls within this bioregion.

E.g. Table 5.2

Feature	% of bioregion area covered	% of SWPR area this unit lies within this bioregion	% of EEZ area this unit lies within this bioregion

% of bioregion area covered: The percentage of the total area of the bioregion that is included in the SWPR that falls within this feature. Calculations do not include areas with water depths <10m.

% of SWPR area this unit lies within this bioregion: The percentage of the total area covered by this feature in the SWPR that lies within the area of this bioregion included in the SWPR.

% of EEZ area this unit lies within this bioregion: The percentage of the total area covered by this feature in the EEZ that lies within the area of this bioregion included in the SWPR.

E.g. Table 5.4

Feature	No. of Samples	Average data density (sample:km^2)

No. of Samples: The total number of samples used in this study that are located within the area covered by this feature within the area of this bioregion that is included in the SWPR. Some samples included in this figure have only textural or compositional data.

Average data density (sample: km^2): The average sample density across all occurrences of the feature within the area of this bioregion that is included in the SWPR. This is calculated by dividing the total area of the feature in the SWPR area of the bioregion by the number of sample points within it. Results have been rounded to the nearest 50 km^2.