Geoscience Australia Record 2006/XX

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

A Spatial Analysis

Anna Potter, Chris Southby, and Andrew D. Heap

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

Australian Government

Geoscience Australia

Geoscience Australia
Chief Executive Officer: Neil Williams

Department of Industry, Tourism & Resources
Minister for Industry, Tourism & Resources: Senator The Hon. Ian Macfarlane, MP
Parliamentary Secretary: The Hon. Bob Baldwin, MP
Secretary: Mark Patterson

ISSN: TBA

GeoCat No. TBA

Bibliographic reference: Potter, A., Southby, C. and Heap, A.D., 2006. Geomorphology and Sedimentology of the South West Planning Region of Australia. Geoscience Australia, Record 2006/XX. Geoscience Australia, Canberra. XXXpp.

Correspondence for feedback:
Anna Potter
Geoscience Australia
GPO Box 378
Canberra
ACT 2601

Andrew.Heap@ga.gov.au

Contents

Page

List of Figures

Page

Page

Page

Page

Page

List of Tables

Page

Page

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 is helping 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 extent 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, a collaborative agreement between Geoscience Australia, CSIRO – Marine and Atmospheric Research, and the Department of the Environment and Heritage (National Oceans Office) 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

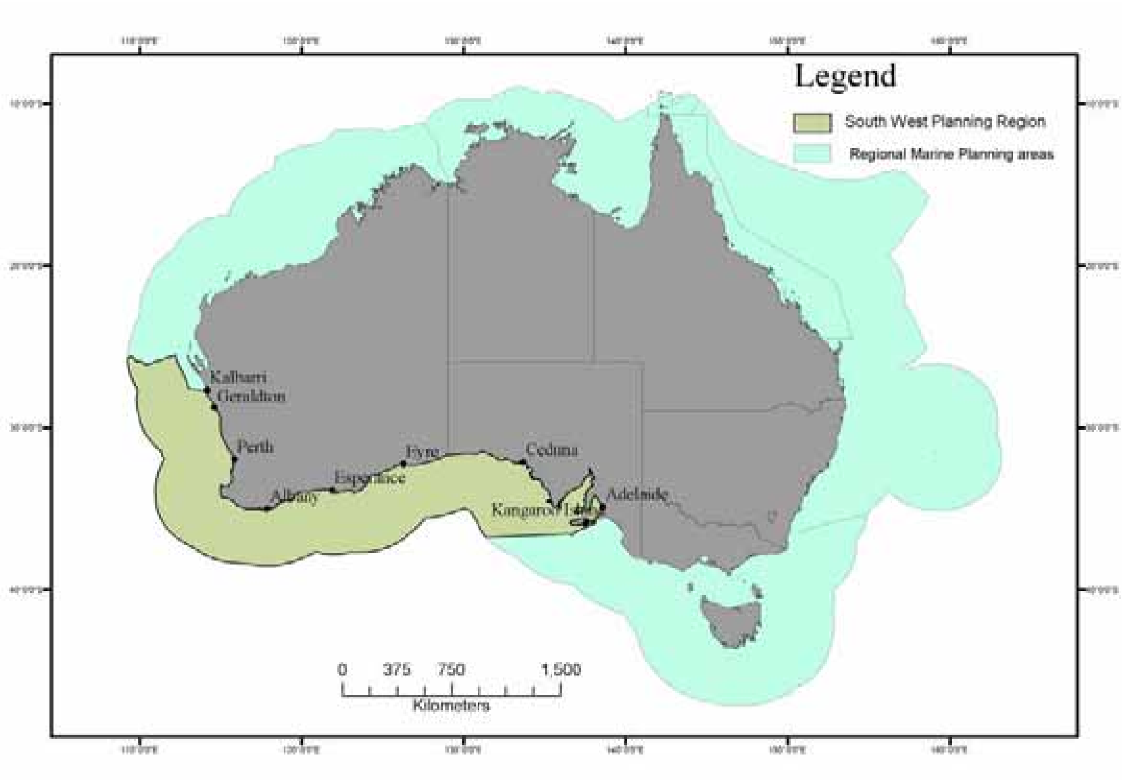


Figure 2.1. Location of South West Planning Region

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).

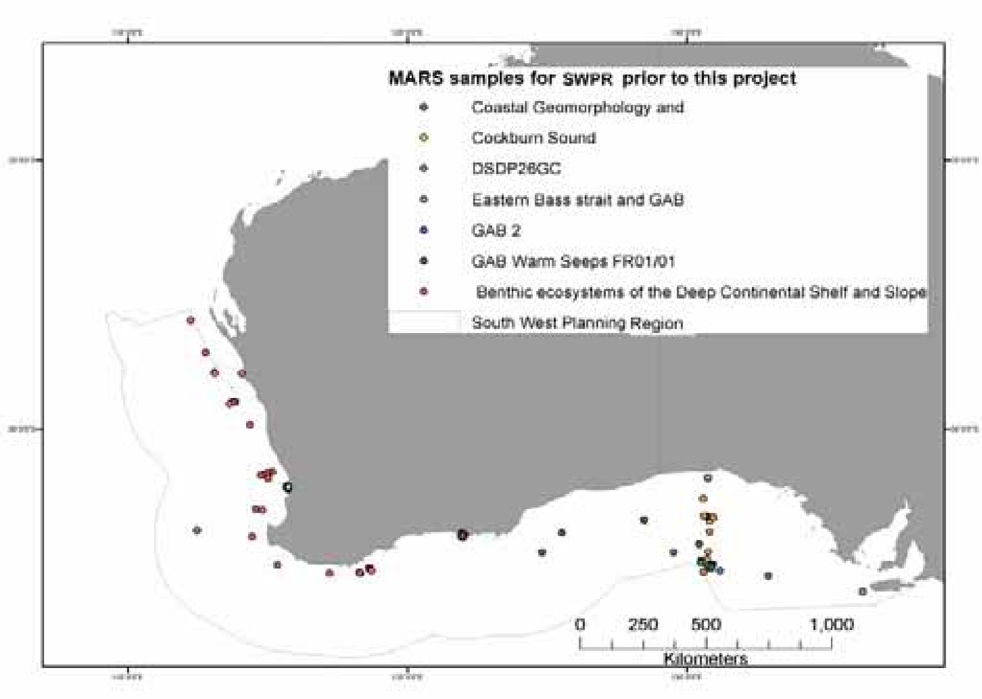


Figure 2.2. Location of MARS samples and surveys in the SWPR prior to this project.

Table 2.1. Samples in MARS prior to the beginning of this project.

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°

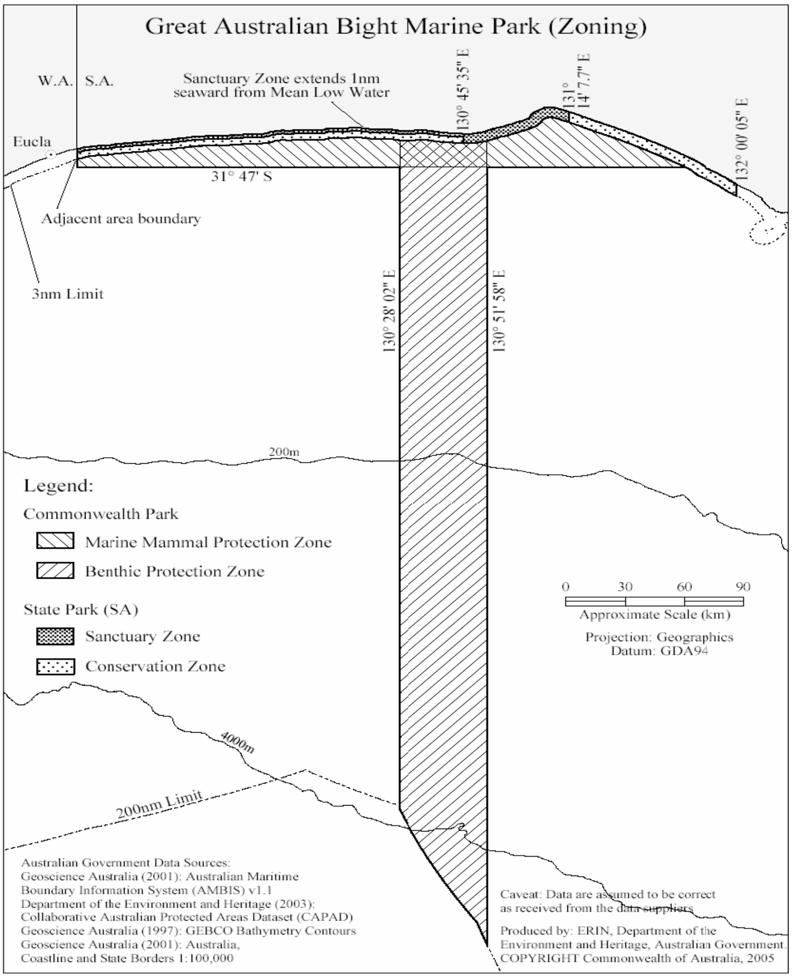


Figure 2.3. Location and zoning of the Great Australian Bight Marine Park (Source: Department of the Environment and Heritage, 2005a).

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 estuarine systems, to maintain ecological processes and systems, and to protect Australia’s biological diversity at all levels in the GAB region. The GABMP is also an important reference area for scientific studies and long-term environmental monitoring. As part of this system, the GABMP helps to conserve ecosystems that are characteristic of the GAB (Department of the Environment and Heritage, 2005a).

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

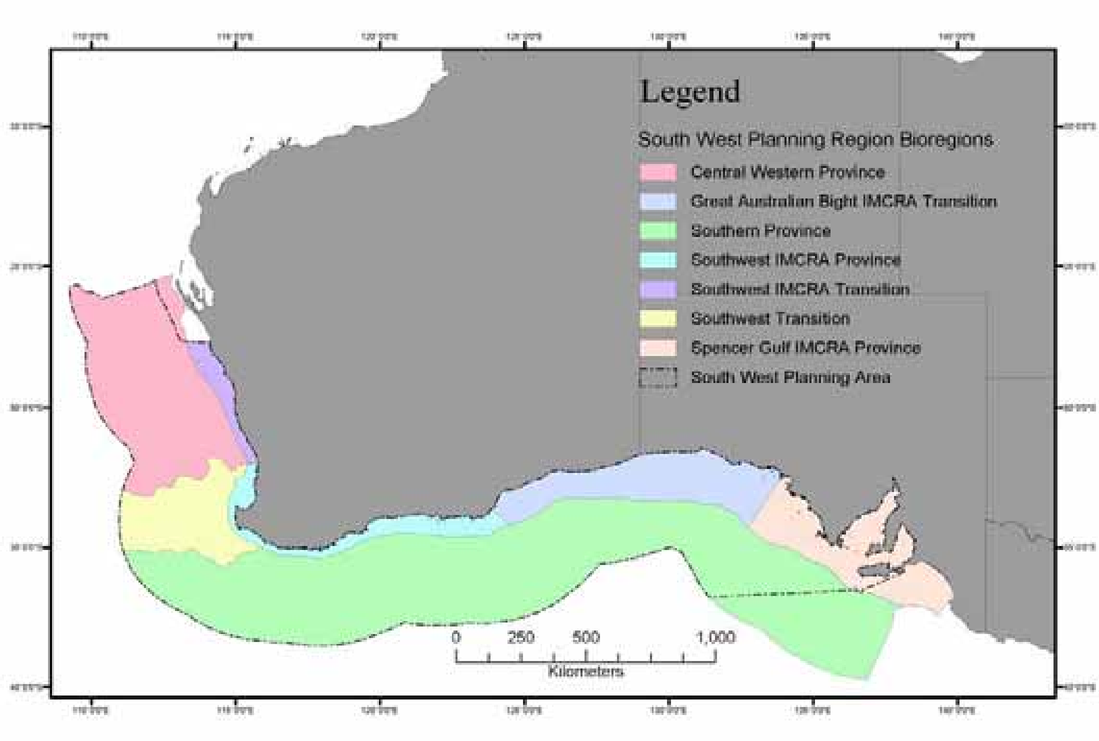


Figure 2.4. Bioregions in the SWPR.

Table 2.2. 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

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.

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 (www.ga.gov.au/oracle/mars).

3.1. DATA COLLECTION AND COLLATION

3.1.1. Sample Identification

Samples contained 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.

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 survey 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. SWPR Sedimentology and Geomorphology

4.1. PHYSICAL PROPERTIES

The SWPR covers an area of 1,375,000 km² which represents around 15% of the Australian EEZ. This includes areas with water depths less than 10 m. 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. 4.1; 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.

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 (Figs. 4.6 & 4.7).

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.

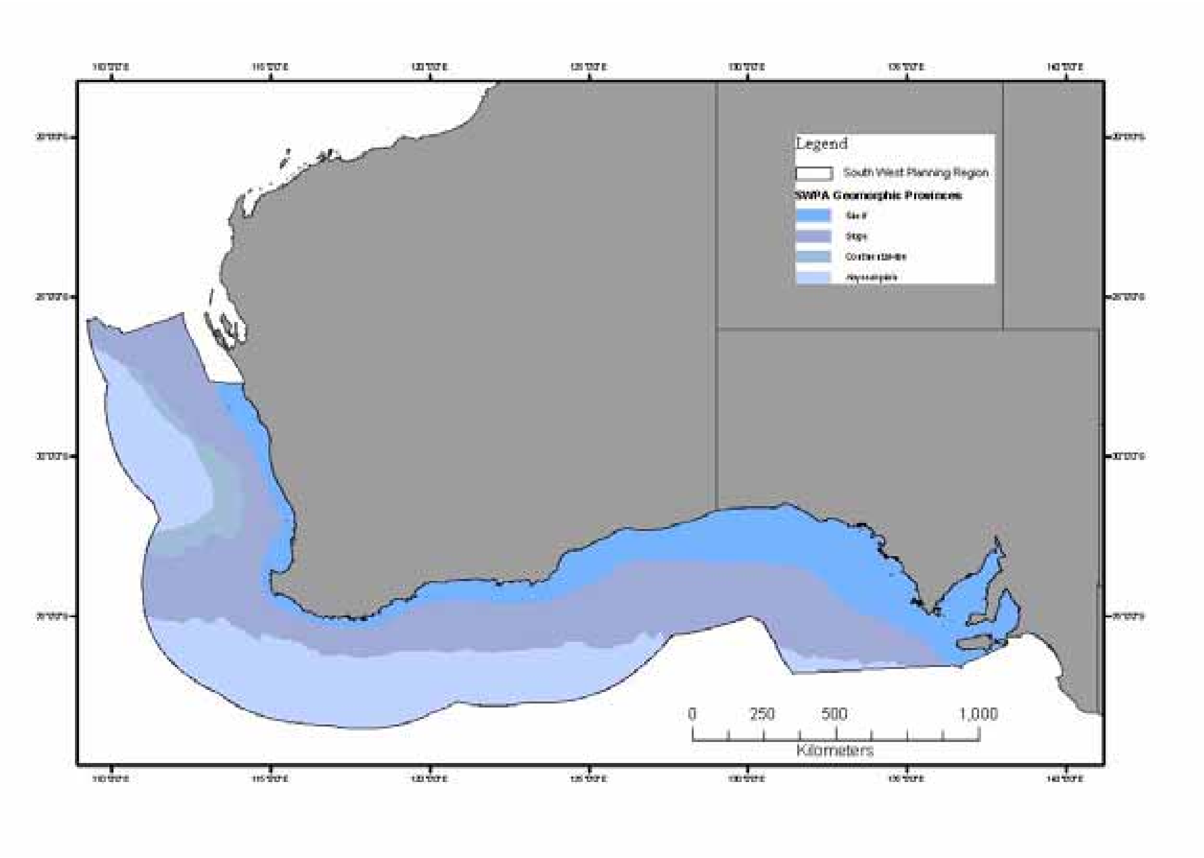


Figure 4.1. Map showing the geomorphic provinces of the SWPR.

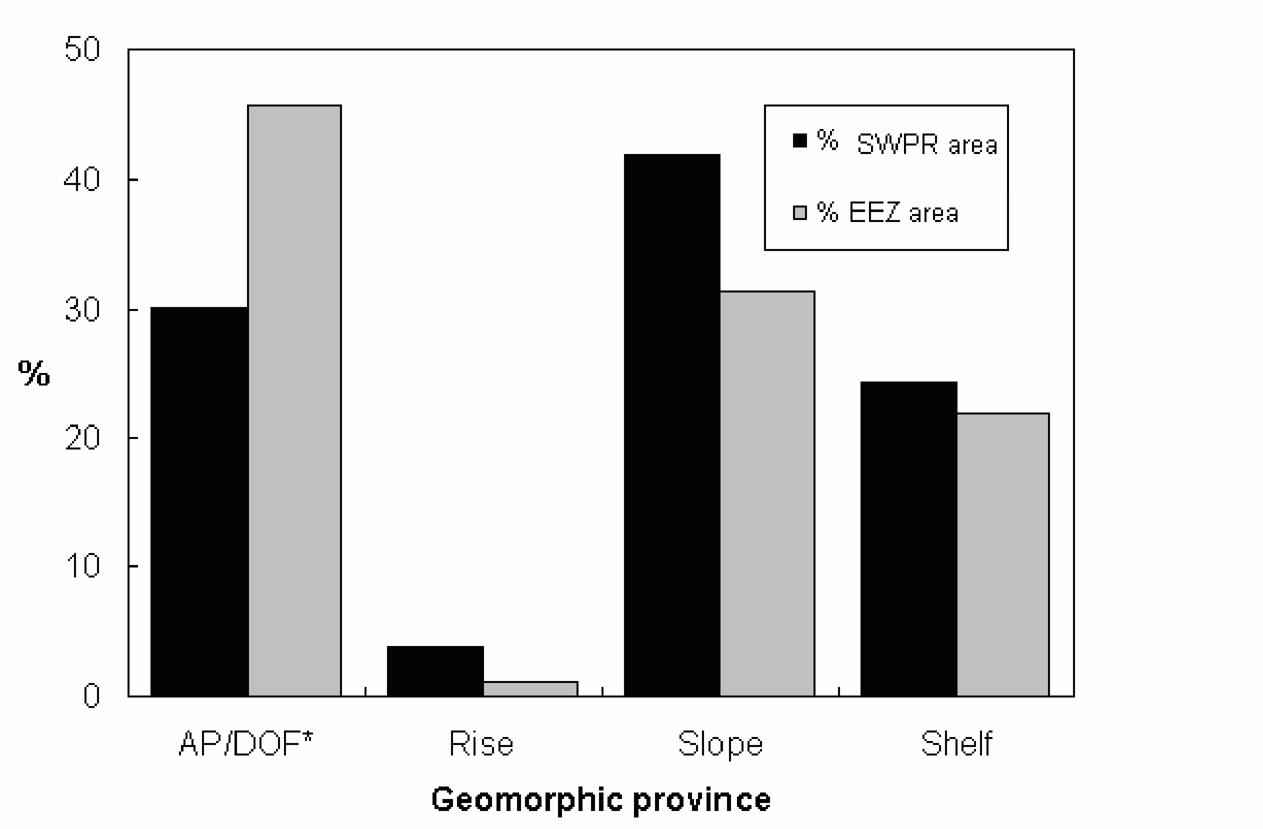


Figure 4.2. Graph showing the area of the geomorphic provinces for the SWPR (black bars) and EEZ (grey bars) expressed as percent.

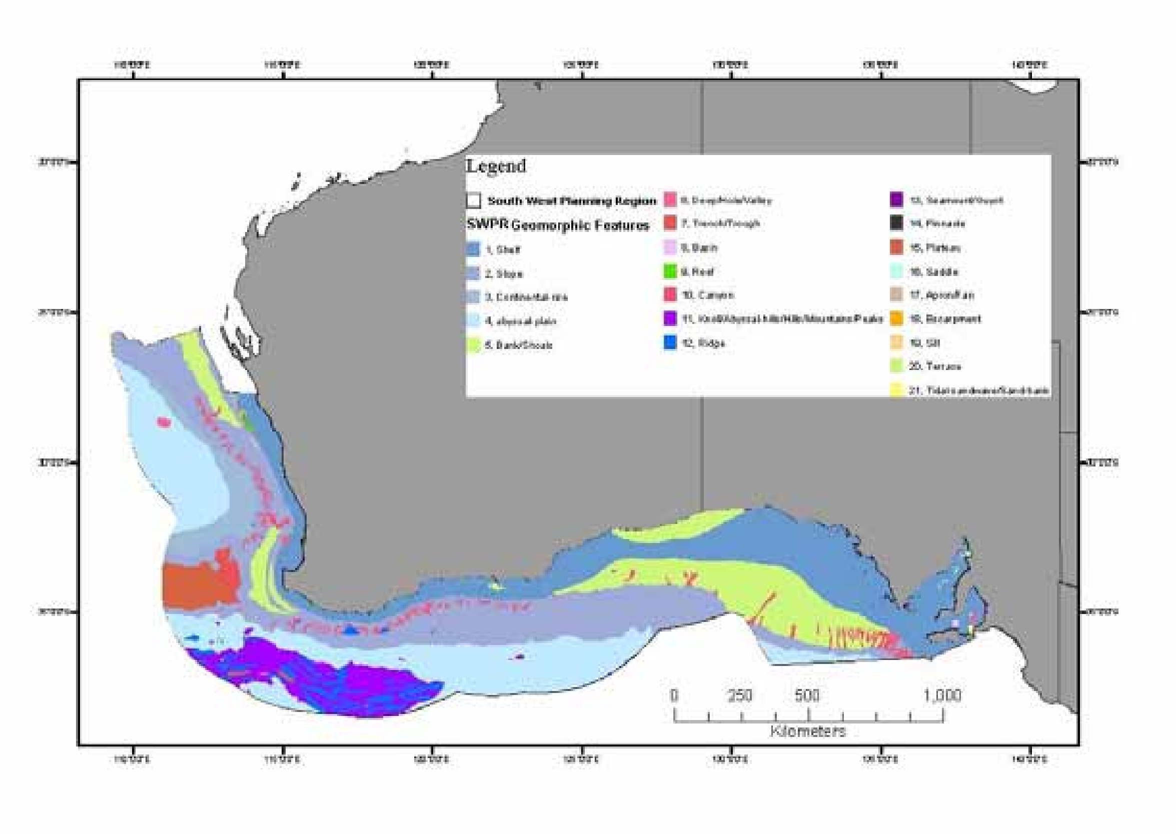


Figure 4.3. Map showing the geomorphic features of the SWPR.

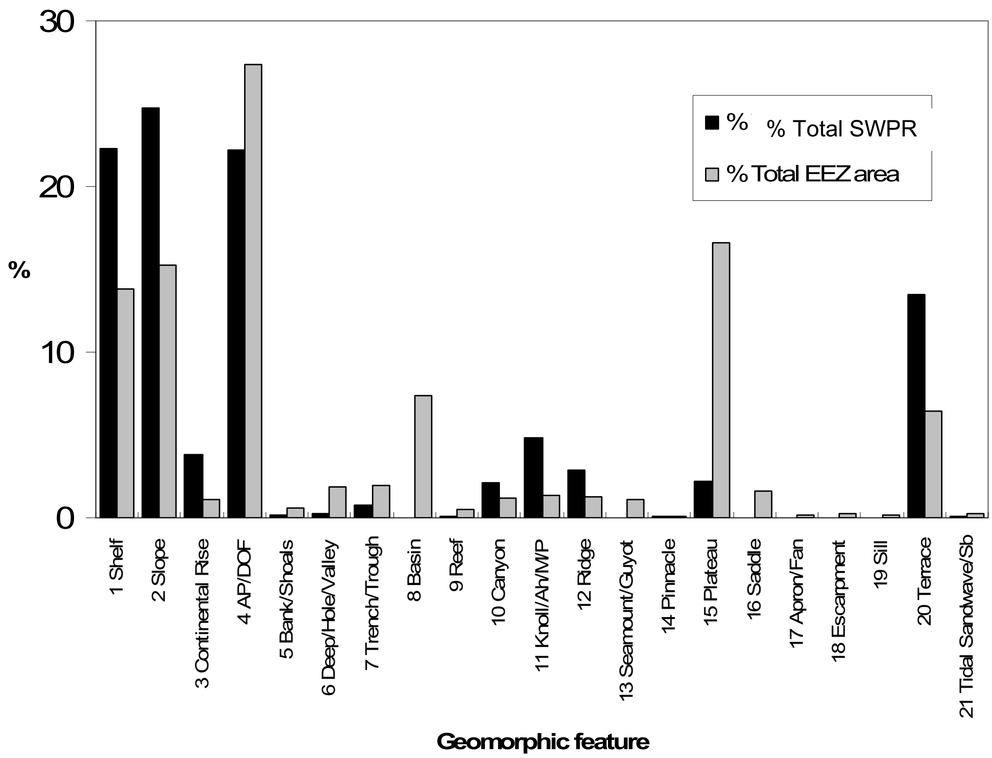


Figure 4.4. Graph showing the area of geomorphic features for the SWPR (black bars) and EEZ (grey bars) expressed as percent.

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 (Fig. 4.9). By contrast, more than 95% of the area of these features across the EEZ lies in water shallower than 500 m (Fig. 4.10). 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 occur in water depths of <500 m, and less than 10% of the total area occur in water depths of >4,000 m (Fig. 4.10).

Basins and apron/fans in the SWPR occur only in water shallower than 500 m. Across the entire EEZ more than 50% of the basins and around 40% of the apron/fans occur at water

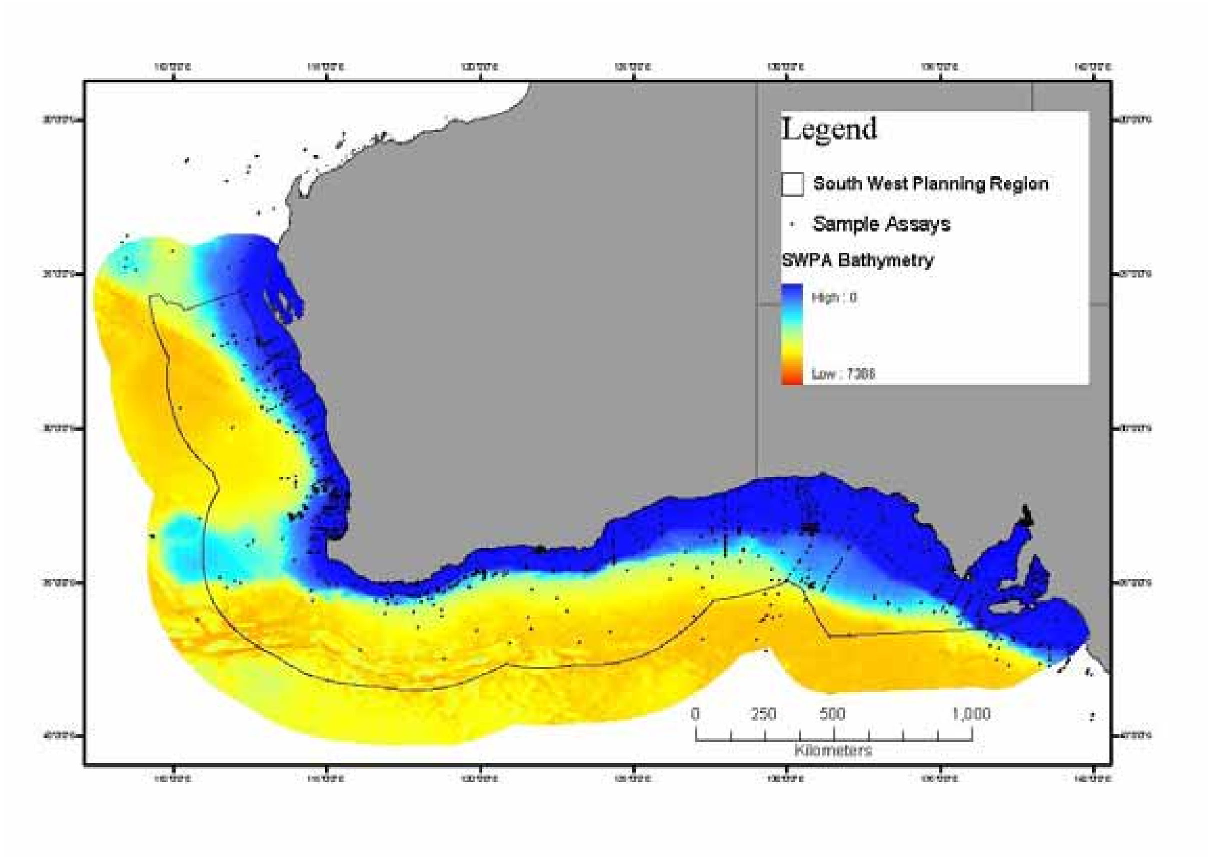


Figure 4.5. Map showing the bathymetry for the SWPR and the sample points used in this study.

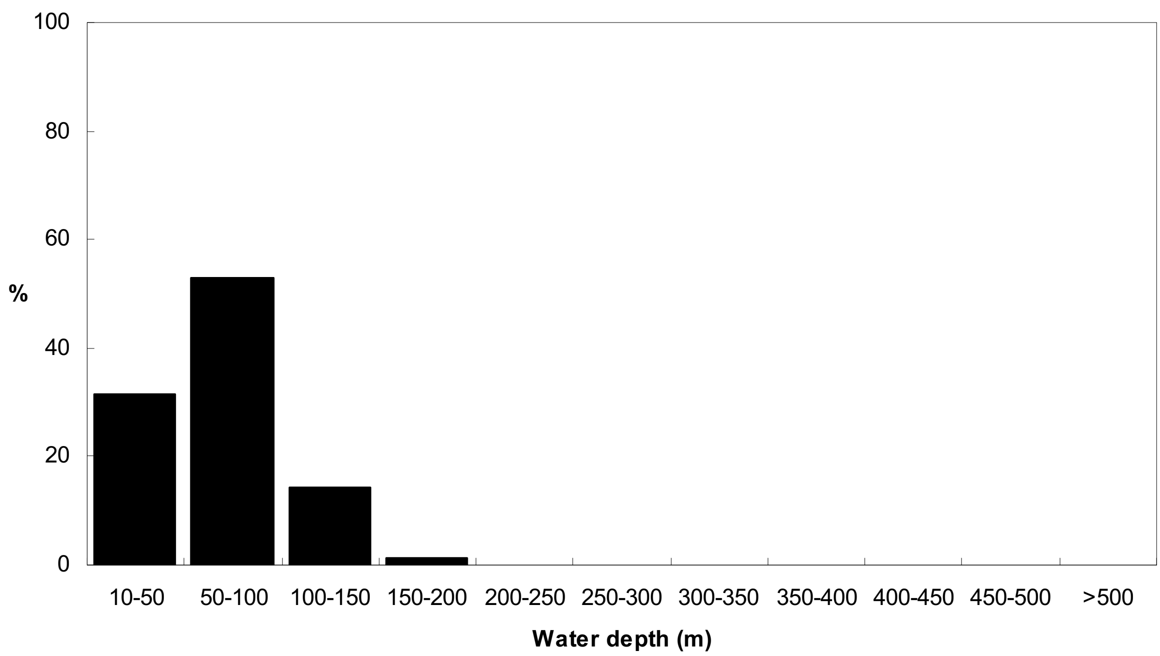


Figure 4.6. Graph showing the distribution of water depths for the continental shelf in the SWPR, expressed as percentages.

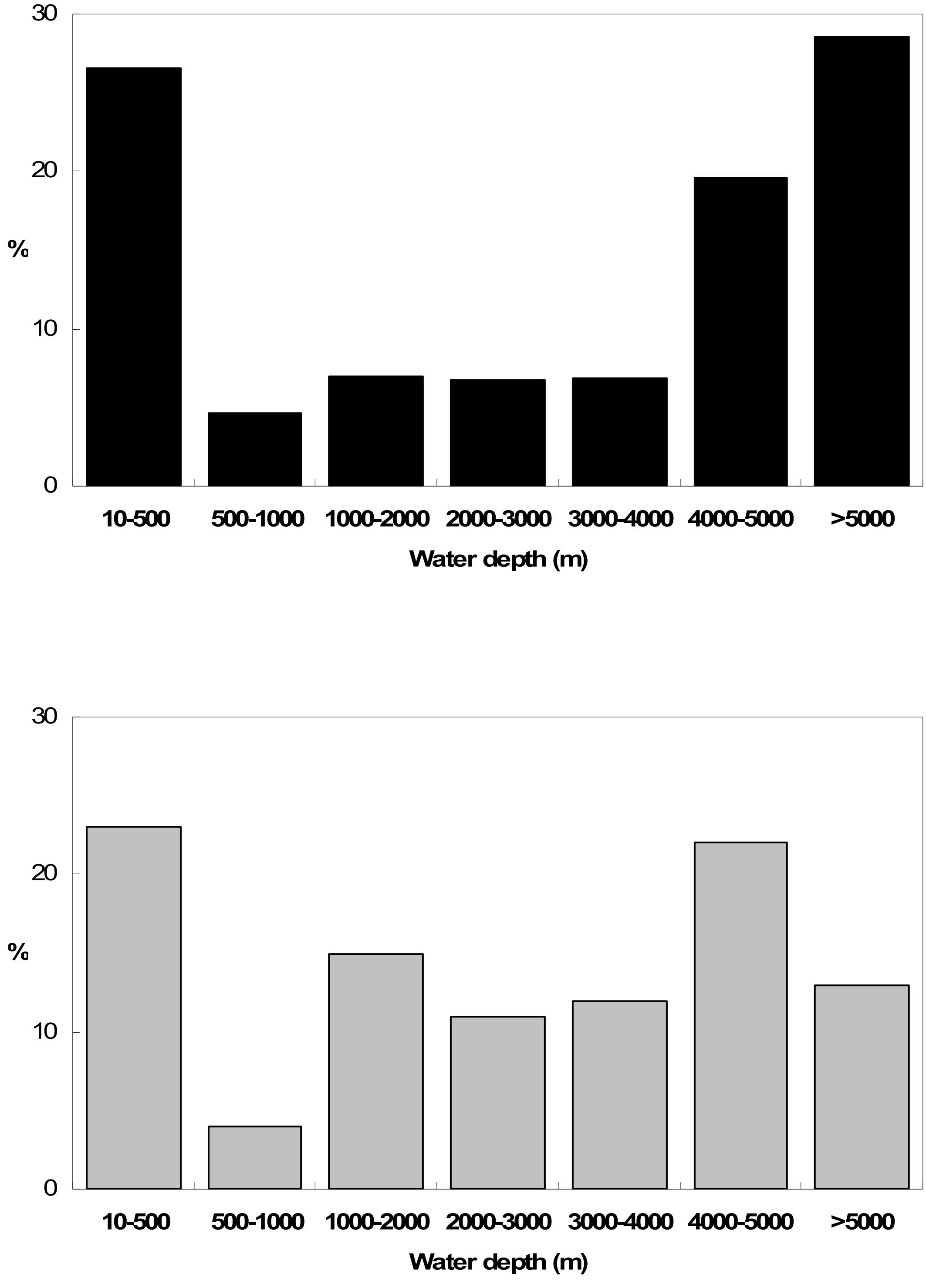


Figure 4.7. Graphs of the distribution of water depths expressed as percentages for the SWPR (black bars) and EEZ (grey bars) for water depths >10 m.

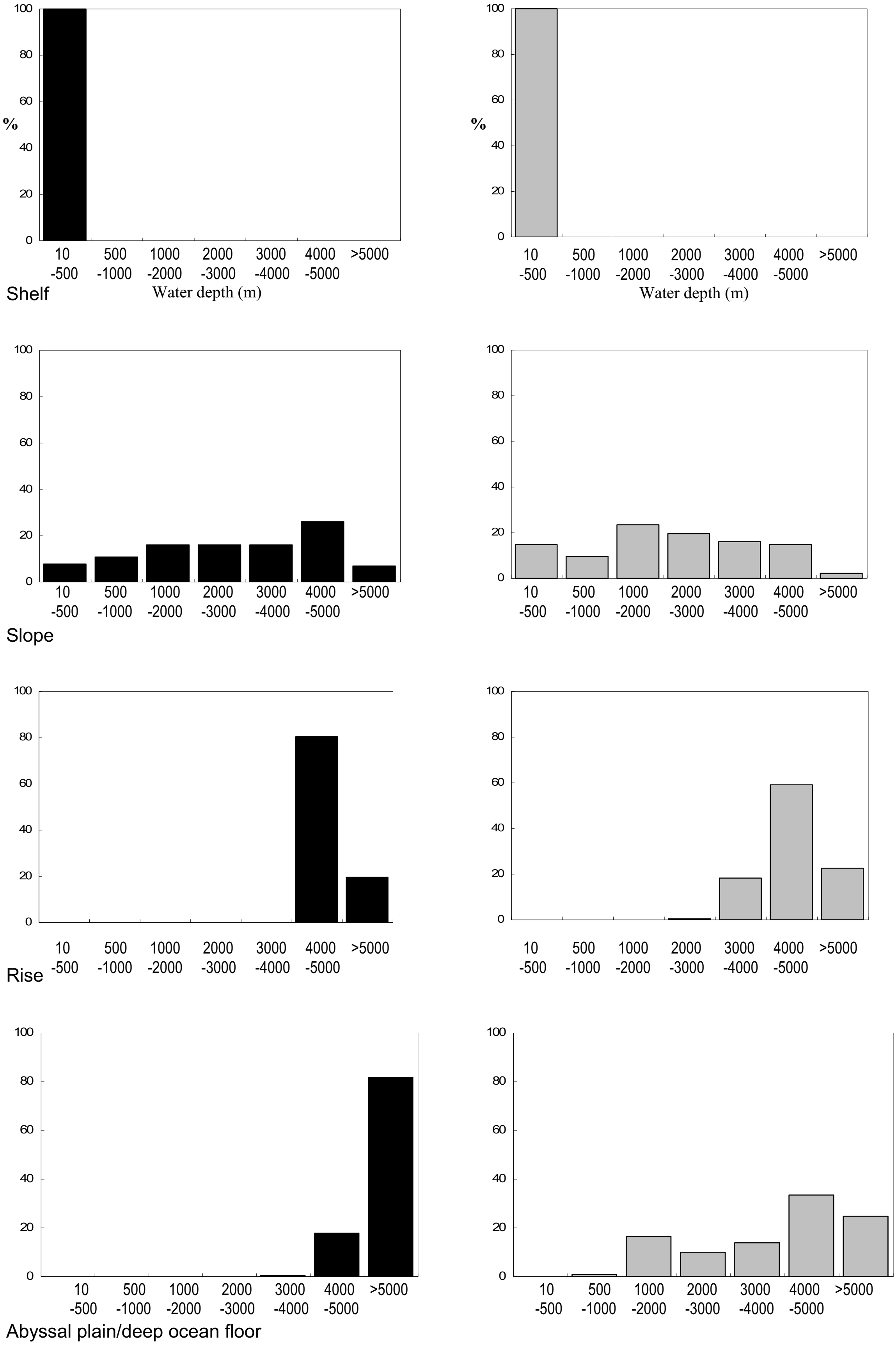


Figure 4.8. Graphs showing the distribution of water depths by geomorphic provinces for the SWPR (black bars) and EEZ (grey bars), express as percentage.

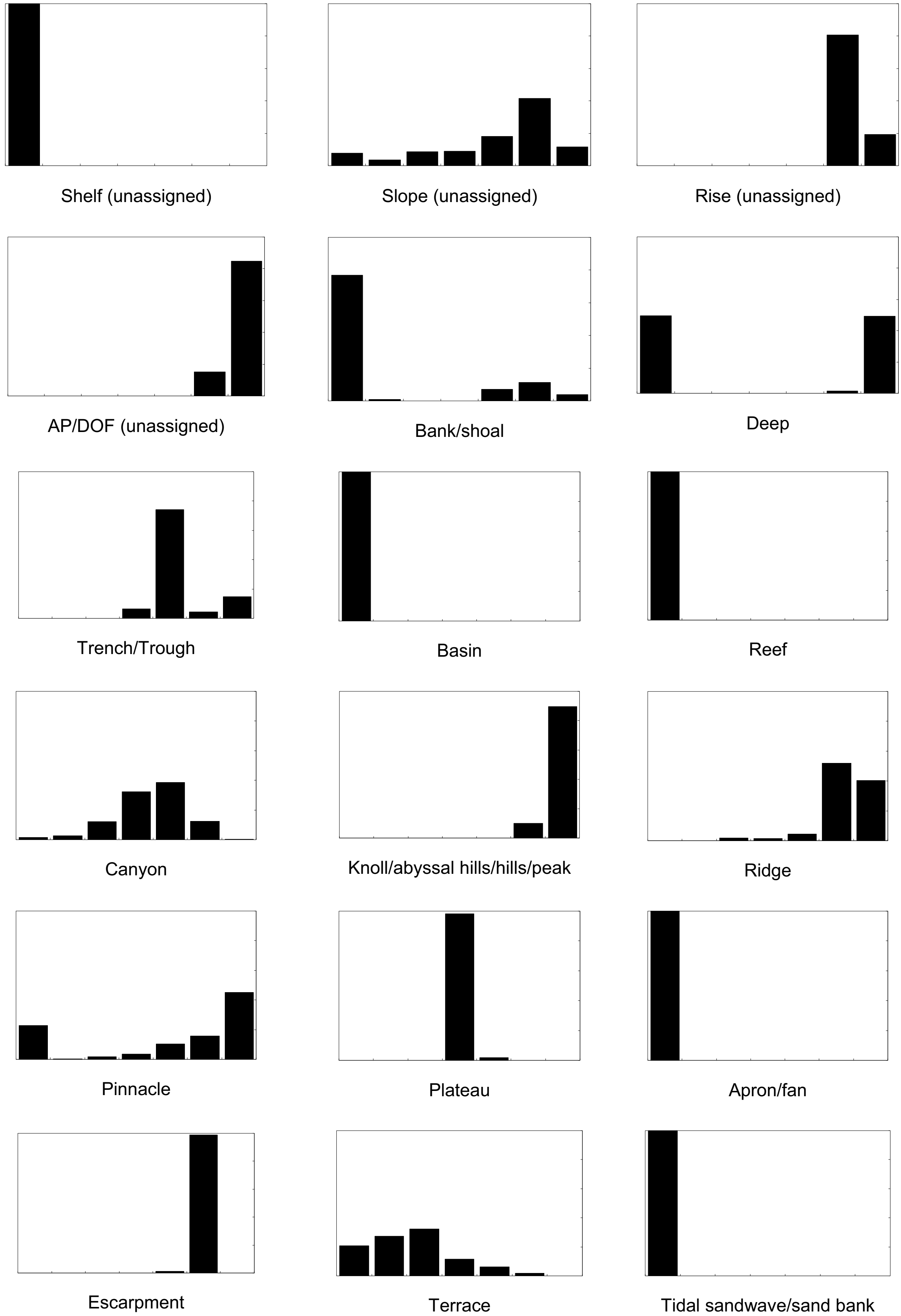


Figure 4.9. Graphs of the distribution of water depths by geomorphic features for the SWPR expressed as percentages. See Fig. 4.8 for axes labels.

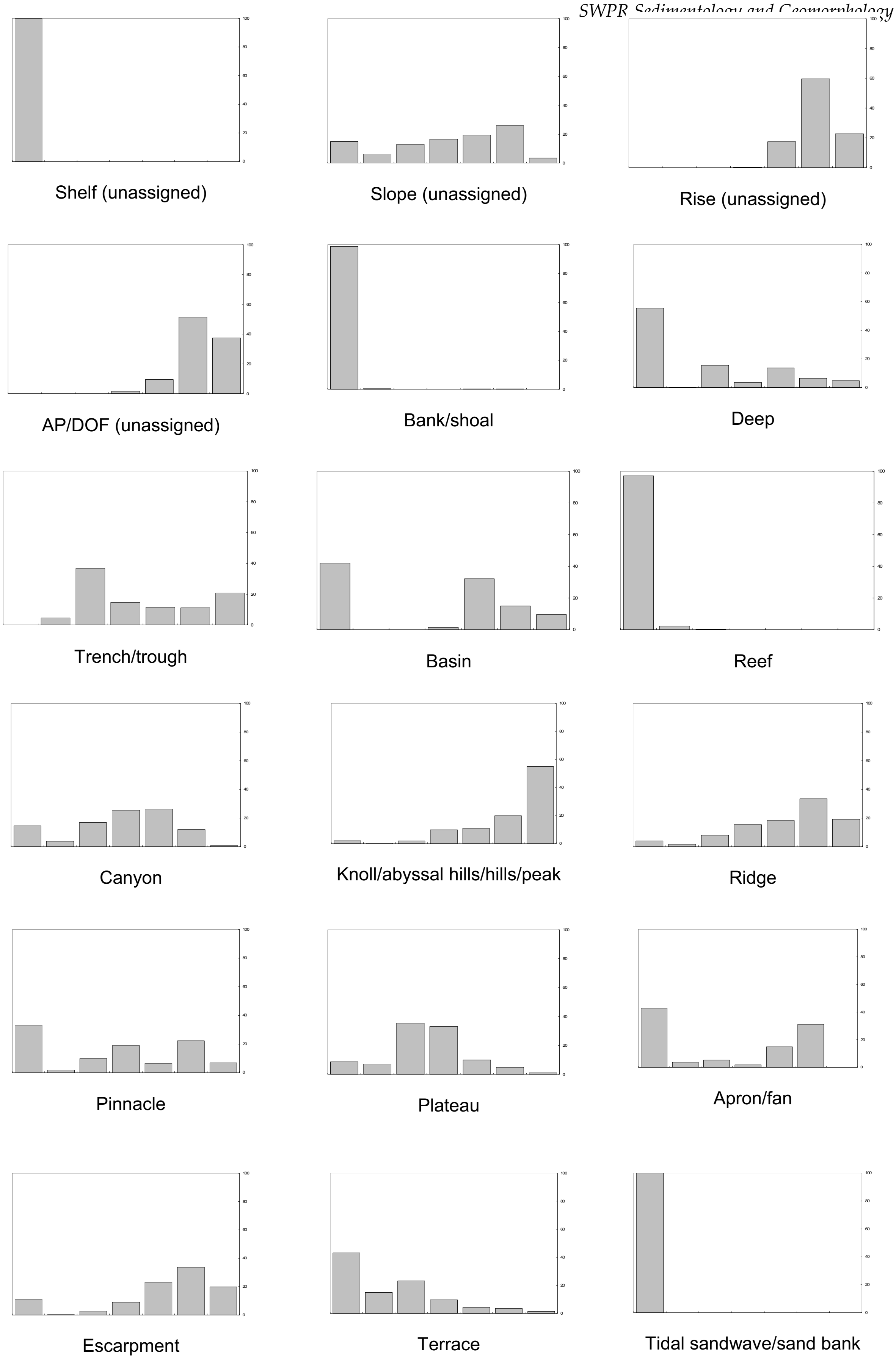


Figure 4.10. Graphs showing distribution of water depths by geomorphic features for the EEZ expressed as percentages. See Fig. 4.8 for axes labels.

depths >3000 m (Fig. 4.9). As such, basins and apron/fans in the SWPR may not include all habitats occurring in these geomorphic features across the entire EEZ.

4.3. SAMPLE COVERAGE

Sample density varies significantly across the SWPR (Fig. 4.11). 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. 4.12). 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 (Figs. 4.13 and 4.14). 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. 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 and 1:8,700 km for the abyssal plain/deep ocean floor and rise, respectively.

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. 4.15).

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).

4.4. SEDIMENTOLOGY

4.4.1. Overview of Distribution and Properties

Across the SWPR, gravel concentrations are generally <10%, although concentrations attain >90% at eight sites (Fig. 4.16). Sand and mud content is highly variable, with sand on average comprising >35% and mud <60%. This is highlighted by the strongly negatively skewed frequency distributions for mud and gravel, and the slightly less extreme positive skew of the sand distribution (Fig. 4.16). The high proportion of samples located in shallow water on the shelf where the sand content is higher and mud content is generally lower results in a slight bias for sand in the results.

Spatial distribution of gravel (Figs. 4.17 & 4.18), sand (Figs. 4.19 & 4.20) and mud (Figs. 4.21 & 4.22) across the SWPR has been interpreted by interpolating sediment properties from sample points. Interpolation of the sediment data achieves a total coverage of 825,000 km^2 or 60% of the SWPR area, including complete coverage of the shelf (Fig. 4.23). As such, the areas for sediment classes on histograms (Figs. 4.18, 4.20 & 4.22) are given as a percentage of the area of the shelf only.

Maps of interpolated sediment properties agree with the statistics, which show that sediment texture become finer with increasing water depth. Overall, the gravel content of the sediment decreases and mud content increases with increasing water depth. Sandy sediments sand generally occur on the shelf; more than 301,150 km^2 or 90% of the total shelf

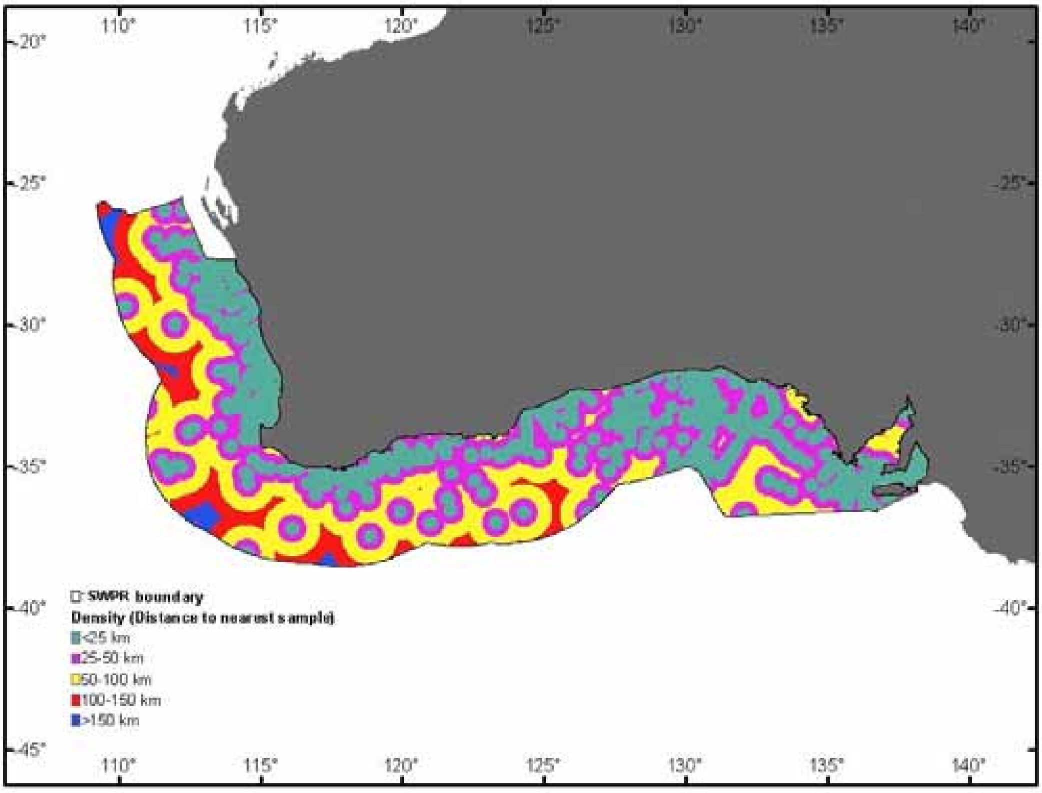


Figure 4.11. Map showing the sample density distribution across the SWPR.

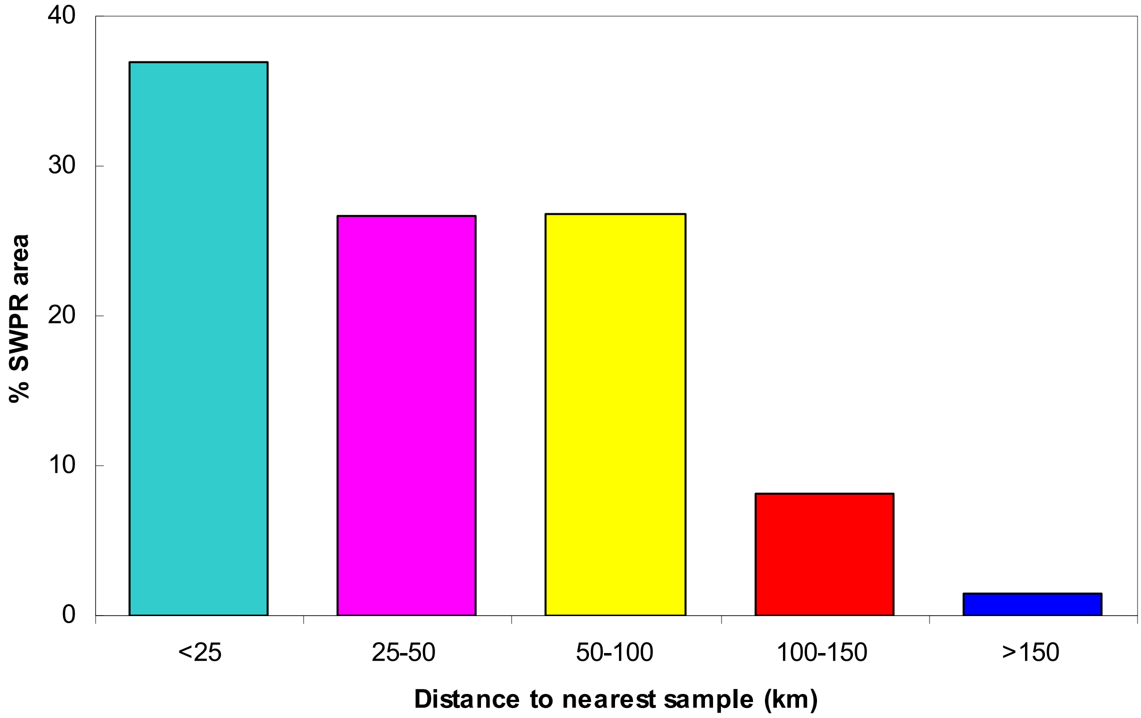


Figure 4.12. Graph showing the frequency distributions of sample density within the SWPR.

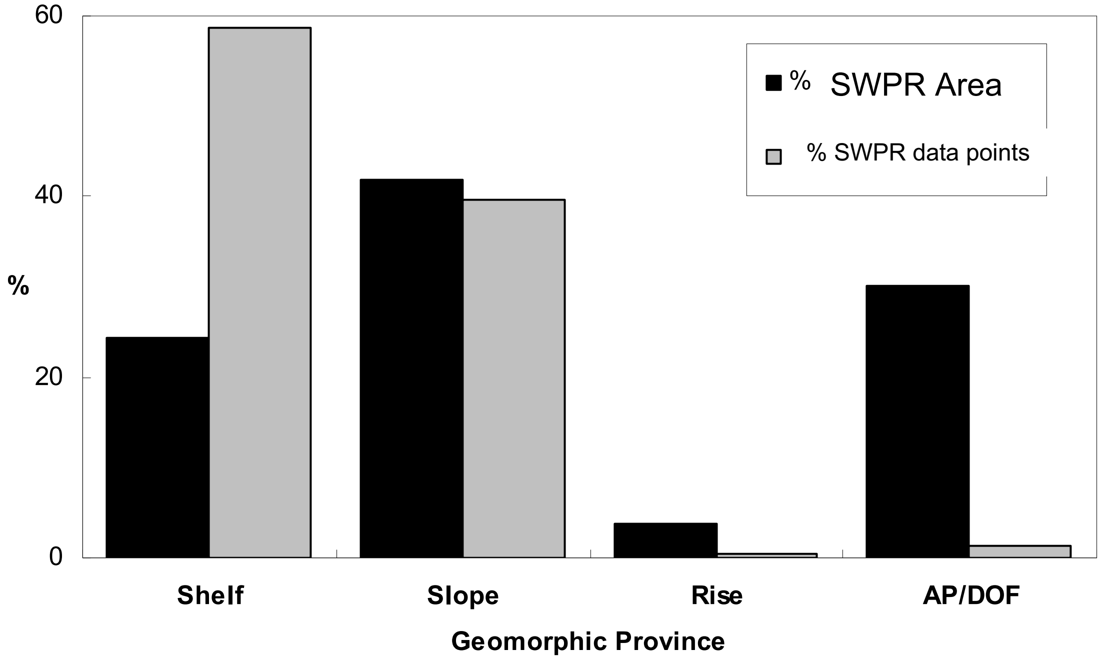


Figure 4.13. Graph showing coverage of geomorphic province covered by sample points expressed as percent (grey bars) and total geomorphic province area expressed as percent (black bars) for SWPR.

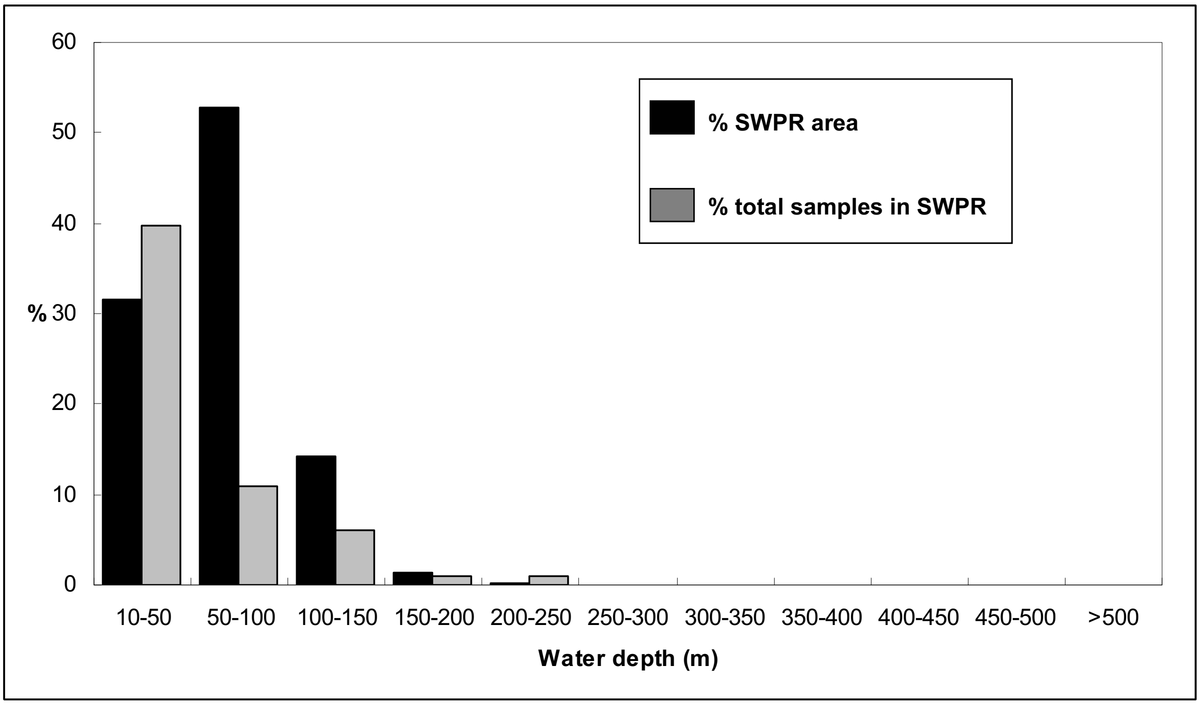


Figure 4.14. Graph showing percent sample coverage by water depth for the continental shelf in the SWPR. Percent total area of the SWPR (black bars) is compared to percent total samples in the SWPR (grey bars).

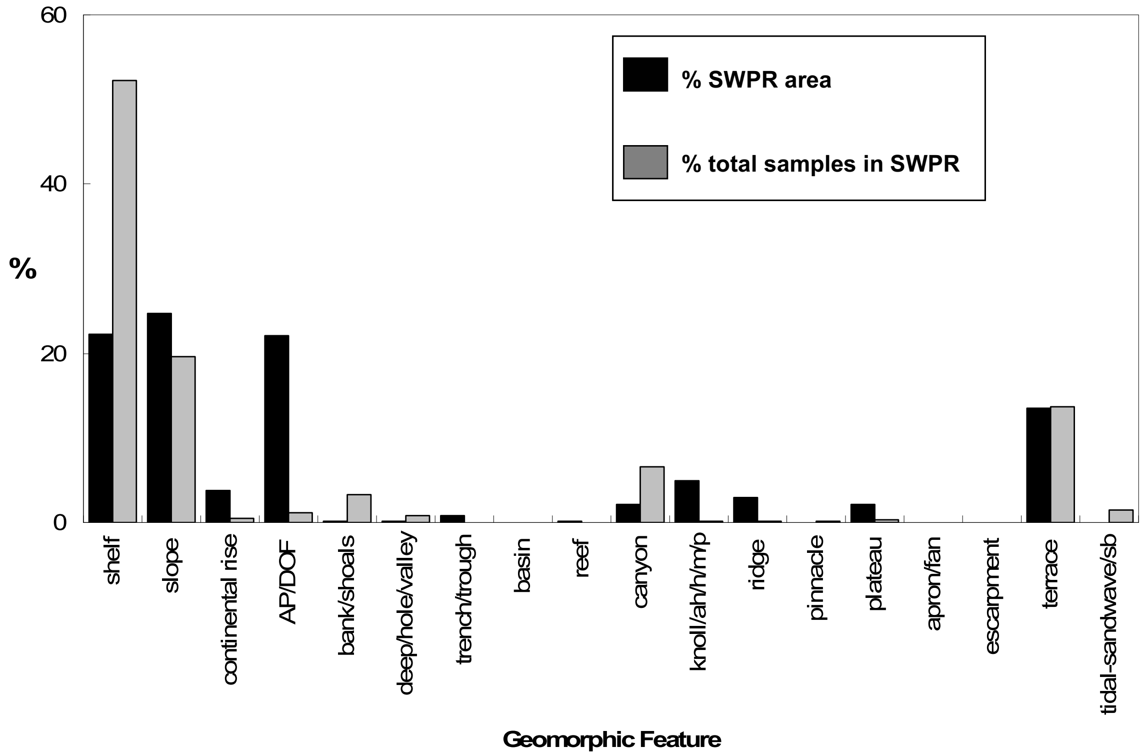


Figure 4.15. Graph showing sample coverage of geomorphic features expressed as percent total samples in the SWPR (grey bars) and total SWPR area of geomorphic features expressed as percent (black bars) for SWPR.

area contains a sand content of >60%. Gravel is abundant south west of Eyre and Perth and just offshore of Esperance on the inner shelf (Figs. 4.17 & 4.18). However, the total area where the gravel content exceeds 80% covers only 13,400 km^2 (<5%) of the total shelf area. Gravel contents of <20% cover 301,150 km^2 (90%) of the shelf, but gravel is absent on most of the slope, rise and abyssal plain/deep ocean floor. Similarly, mud contents of <20% cover the same area of the shelf. Mud generally comprises >60% of the sediment on the slope, rise and abyssal plain/deep ocean floor.

The SWPR seabed 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. 4.16, 4.25 & 4.26). Gravel, where present, is composed almost entirely of carbonate grains, with concentrations of >90% at 570 sites or 80% of locations where gravel was sampled. 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. 4.16). Carbonate sand and mud concentrations <65% occur locally and form a small percentage of the total sites sampled (Fig. 4.16).

Carbonate concentrations show zoning from high to low with increasing water depth (Fig. 4.25). Bulk carbonate content of >80% covers a total area of 301,150 km^2 (90%) of the shelf area and is consistently >80% on the middle and outer shelves. Carbonate content is <20% at some locations on the inner shelf in close proximity to the coast (Figs. 4.25 and 4.26). Areas with bulk carbonate concentrations of <40% cover 13,000 km^2 or <5% of the shelf area (Fig 4.26).

On the slope, the bulk carbonate content ranges between 60 and 100%. Lowest

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

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
Geomorphic Provinces					
Shelf	144	703	14	~1:500	Bioregion level in SWIT,SWI,SG, GAB
Slope	193	474	38	~1:1,200	Bioregion level in SWT, CW, SP
Rise	3	6	1	~1:8,700	Bioregion level in CW
AP/DOF*	93	15	4	~1:27,500	Bioregion level in SWI, CW, SP
Geomorphic Features					
Shelf (unassigned)	7	626	1	~1:500	Bioregion level in SWIT, SWI, SG, GAB
Slope (unassigned)	10	235	4	~1:1500	Bioregion level in SWT, CW, SP
Rise (unassigned)	1	6	1	~1:1000	Bioregion level in CW
AP/DOF* (unassigned)	4	13	3	~1:23,500	Bioregion level in SWI, CW, SP
Bank/shoal	65	40	6	~1:50	Bioregion level in SWI, SG
Deep/hole/valley	14	10	4	~1:350	Bioregion level in SWI
Canyon	127	79	25	~1:400	Bioregion level in SP, CW
Knoll/abyssal-hills/hills/ peak	14	2	1	~1:33,400	Only at SWPR level
Pinnacle	80	1	1	~1:700	Only at SWPR level
Plateau	1	4	1	~1:7,500	Bioregion level in SWT
Ridge	54	2	2	~1:19,800	Only at SWPR level
Terrace	8	163	6	~1:1100	At bioregion level in SWT, CW, SP, GAB
Tidal sandwave/sand bank	5	17	2	~1:50	At bioregion level in SG

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

concentrations occur on the abyssal plain/deep ocean floor, with 12 (80%) samples containing <50% carbonate. These observations correspond to minor frequency highs around 0% observed on histograms for gravel carbonate (inner shelf locations) and mud carbonate (abyssal plain/deep ocean floor) (Fig 4.16). 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).

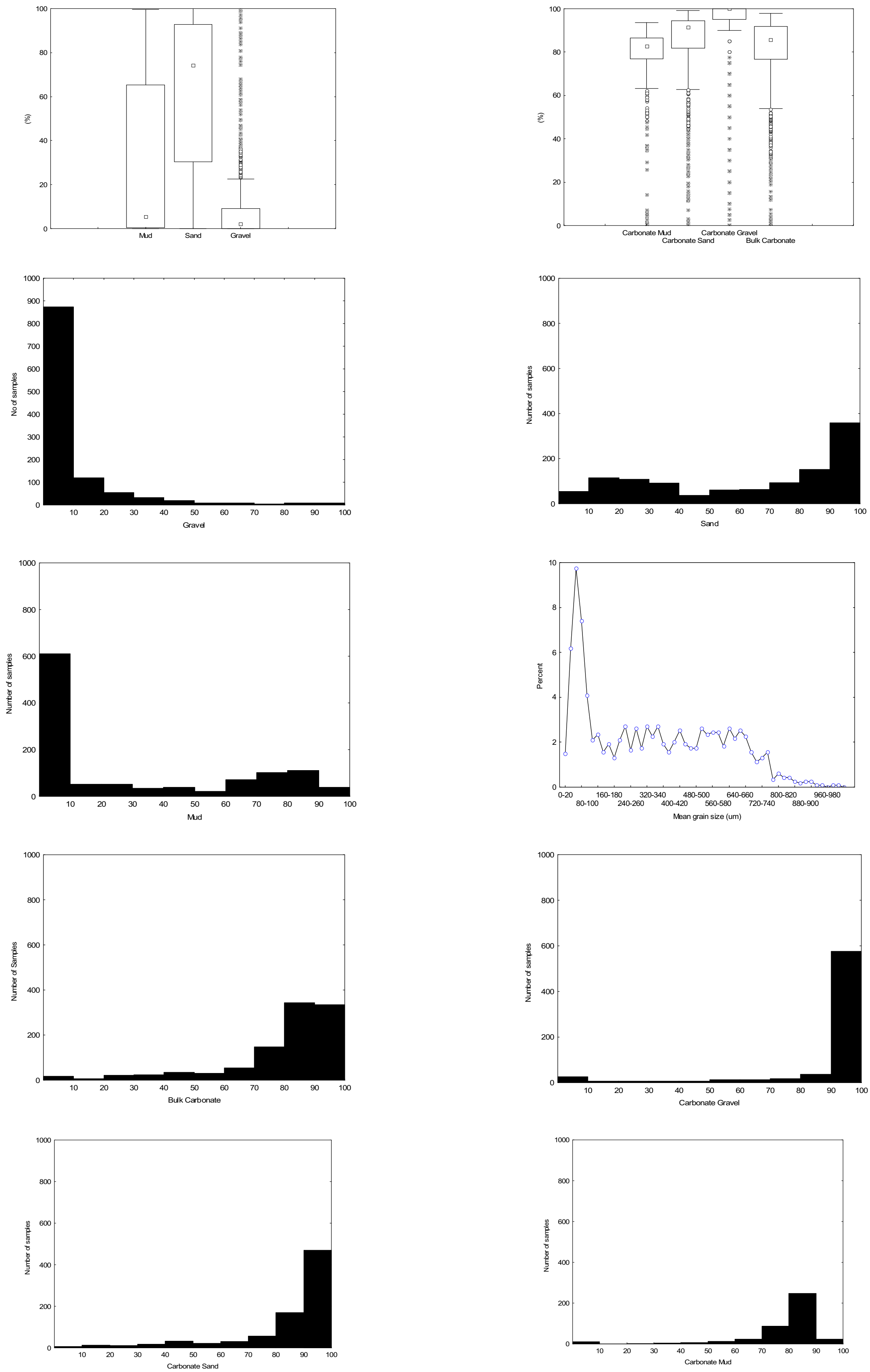


Figure 4.16. Box and whisker plots and frequency distribution histograms for seabed sediment properties.

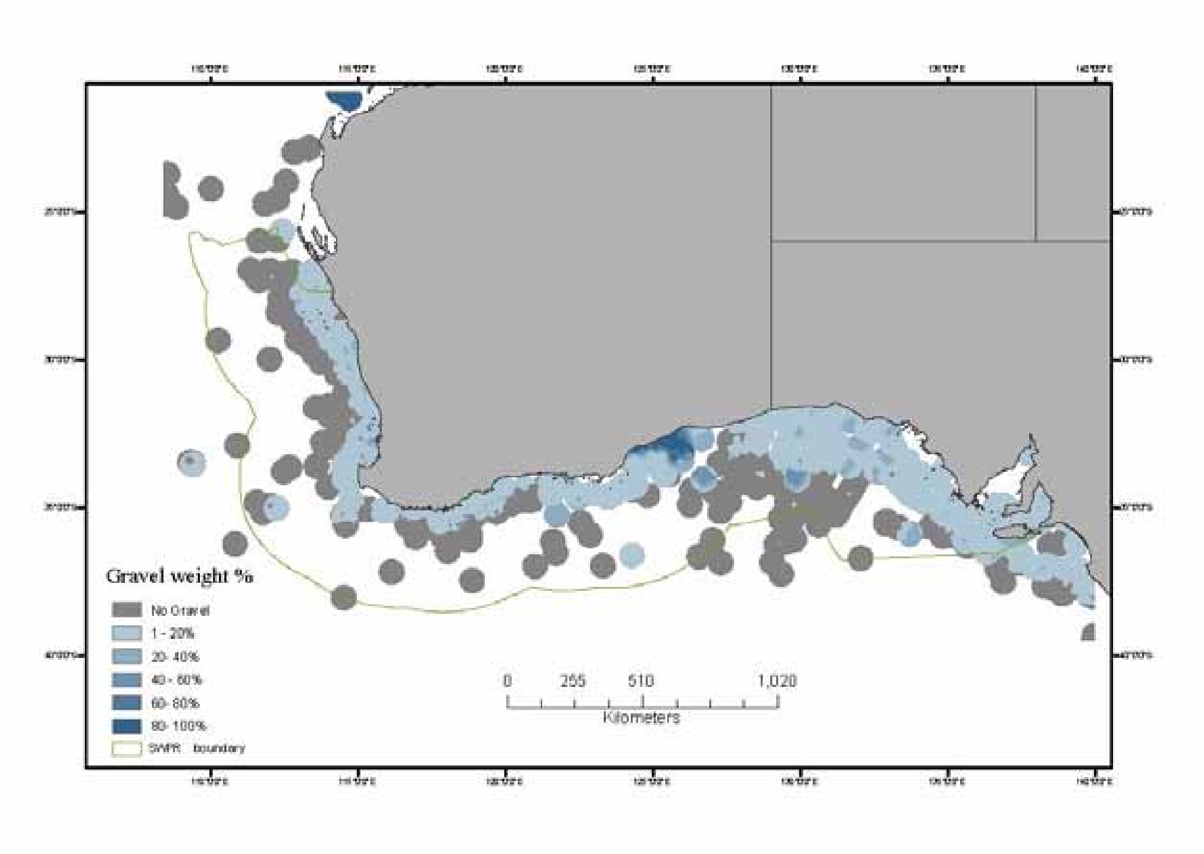


Figure 4.17. Map showing the distribution of gravel on the seabed of the SWPR.

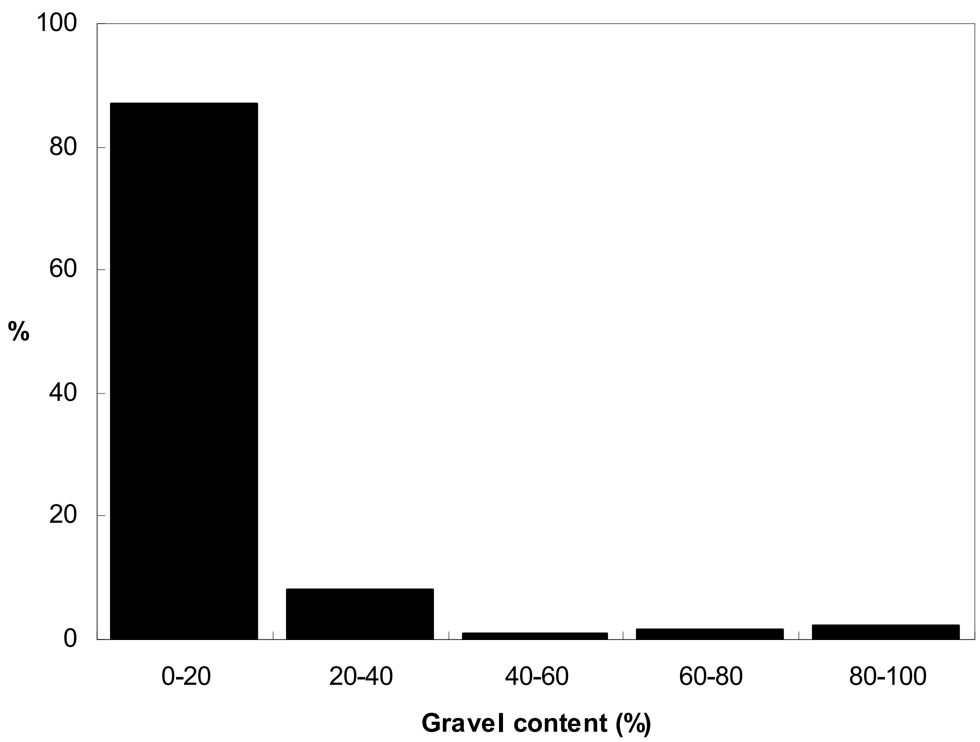


Figure 4.18. Graph showing the distribution of gravel content over the shelf in the SWPR.

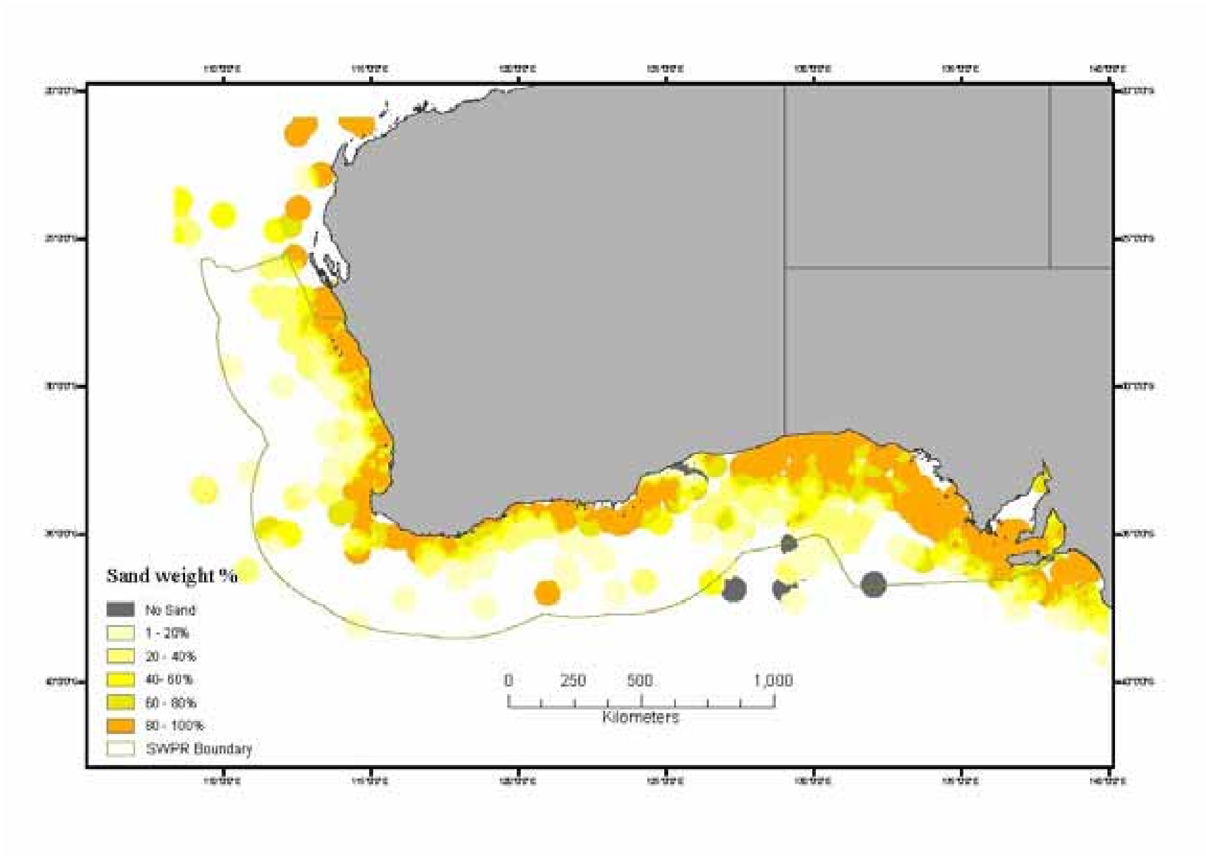


Figure 4.19. Map showing the distribution of sand on the seabed of the SWPR.

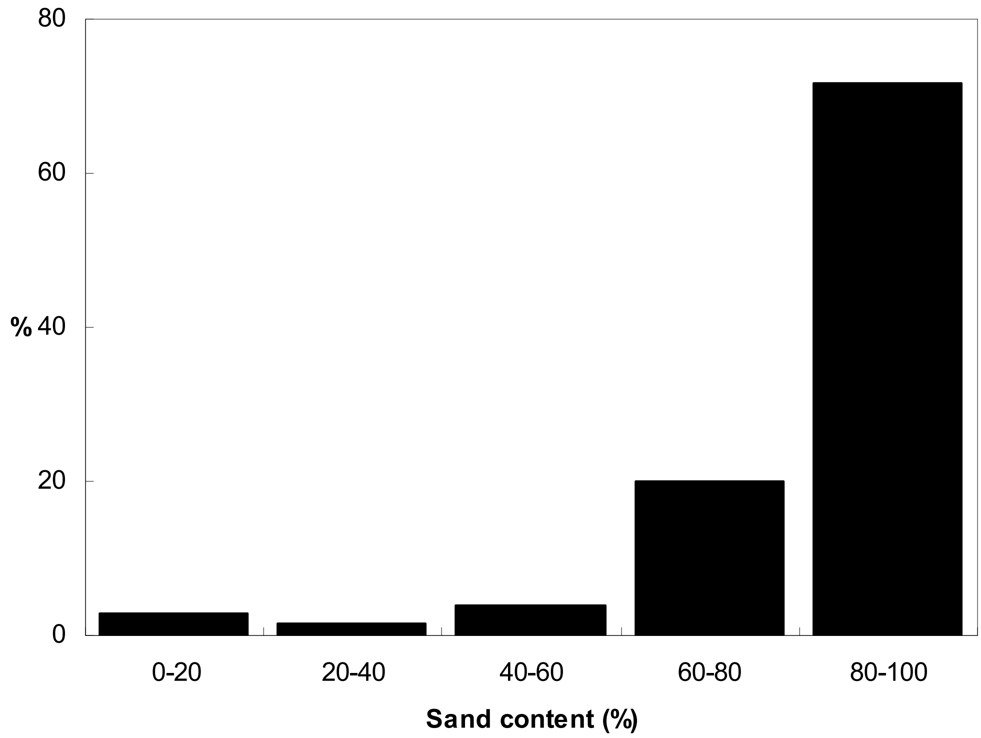


Figure 4.20. Graph showing the distribution of sand content over the shelf in the SWPR.

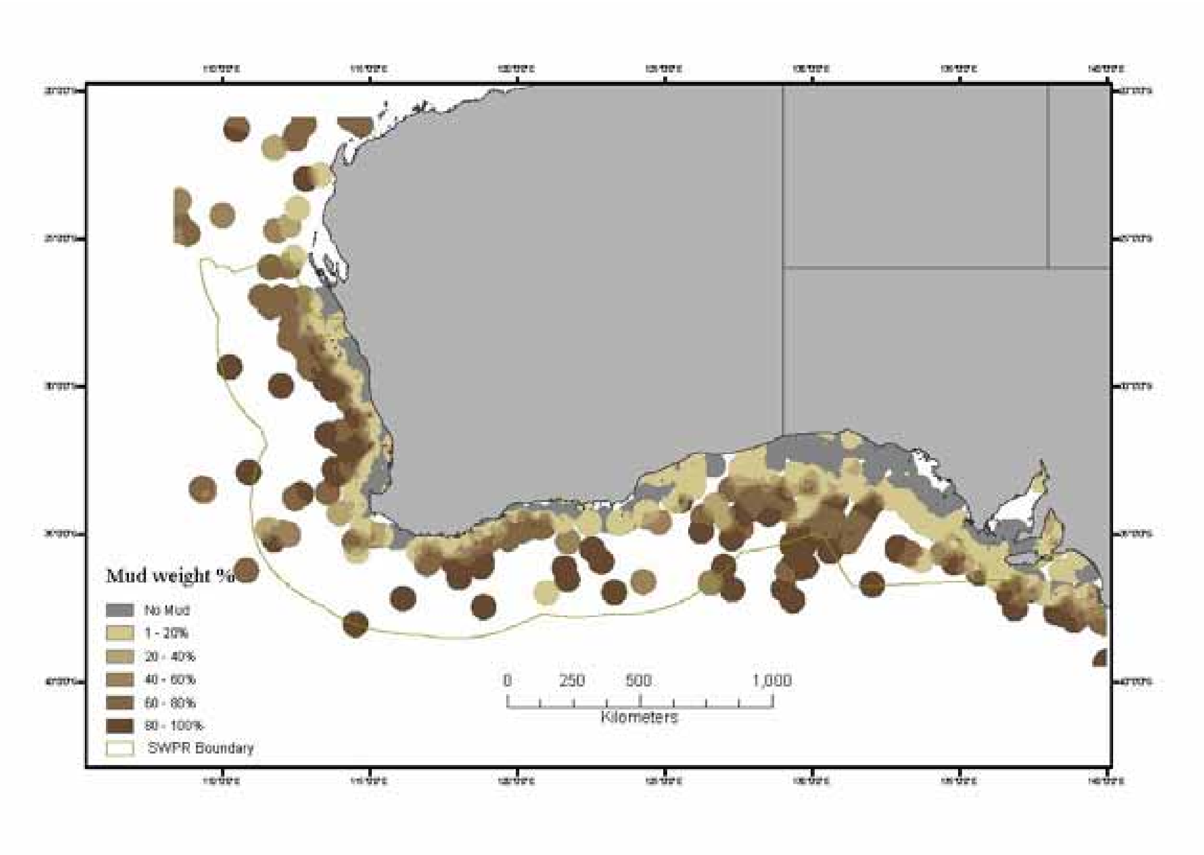


Figure 4.21. Map showing the distribution of mud on the seabed of the SWPR.

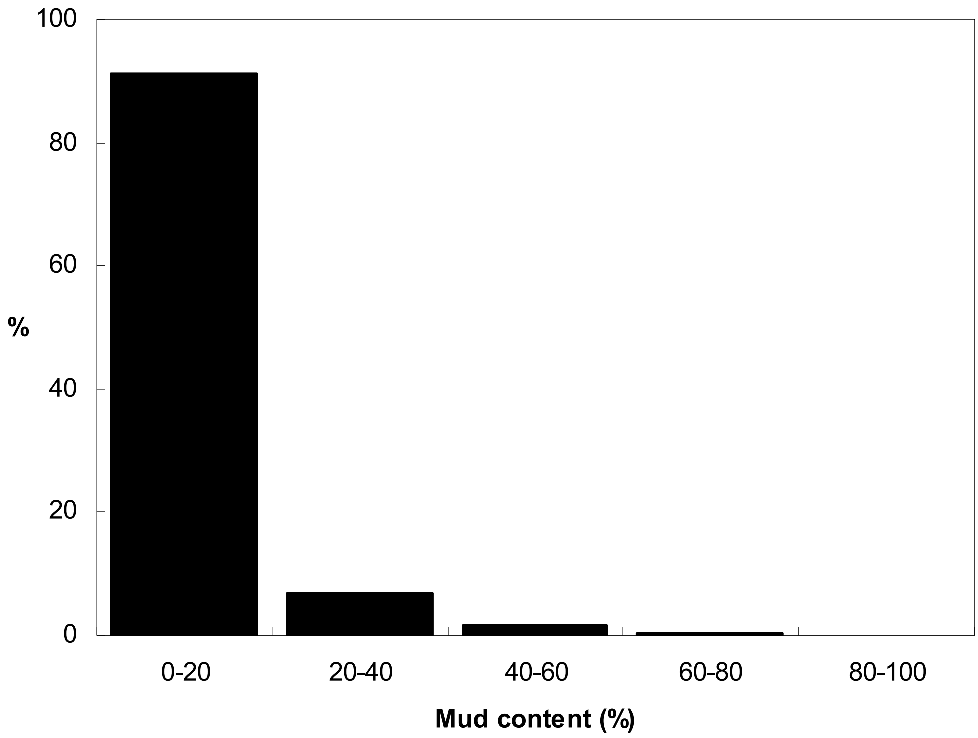


Figure 4.22. Graph showing the distribution of mud over the shelf in the SWPR.

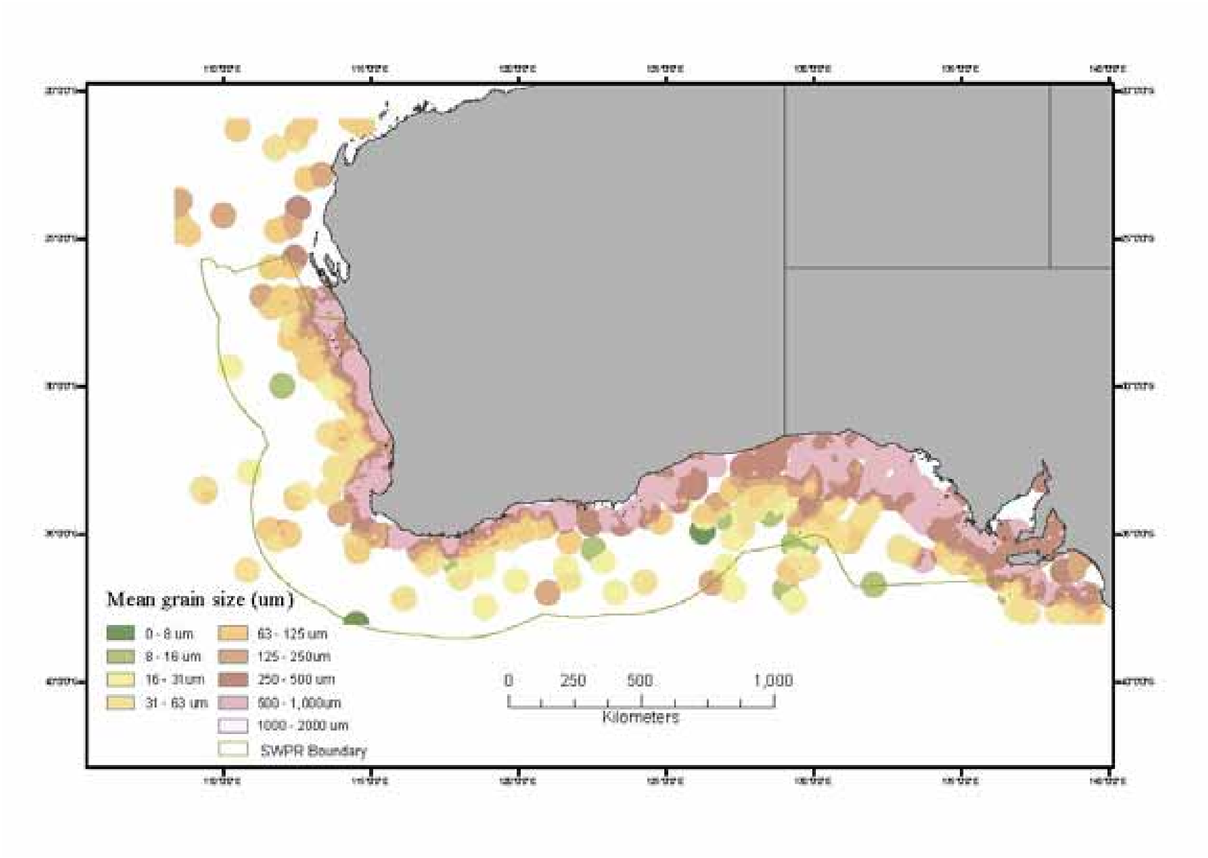


Figure 4.23. Map showing the distribution of mean grain size (μm) on the seabed of the SWPR.

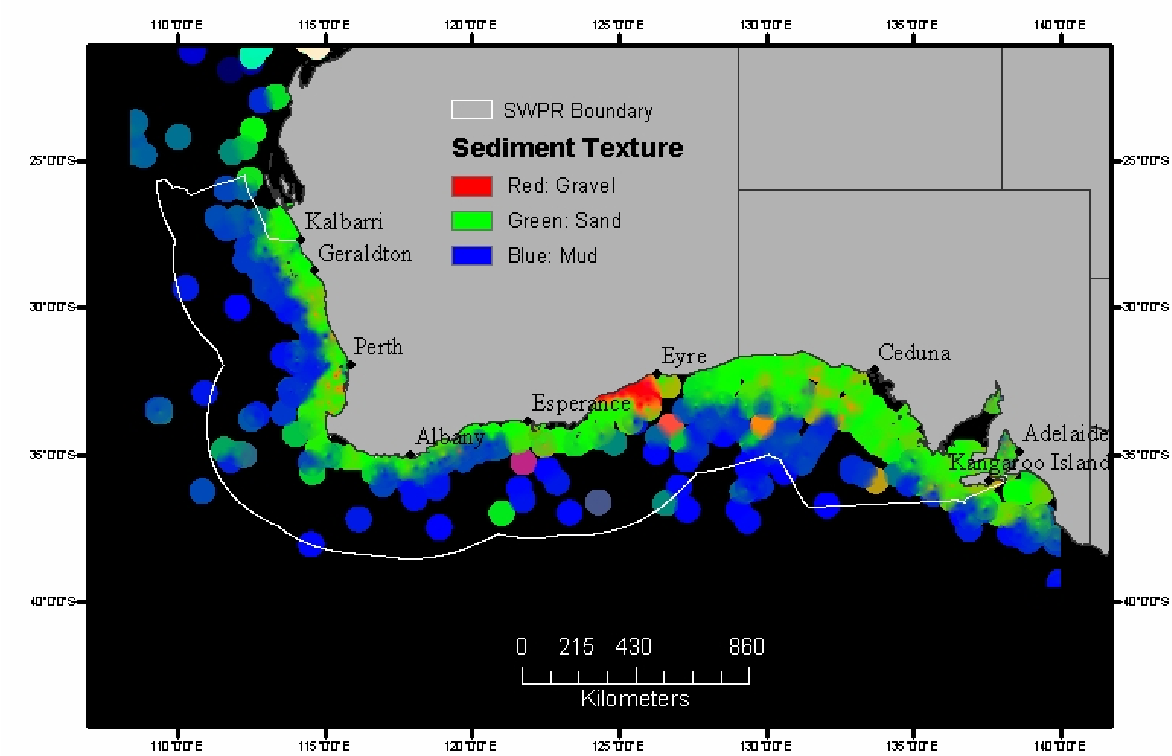


Figure 4.24. Map showing a red, green and Folblue (RGB) colour map of gravel, sand and mud for the SWPR.

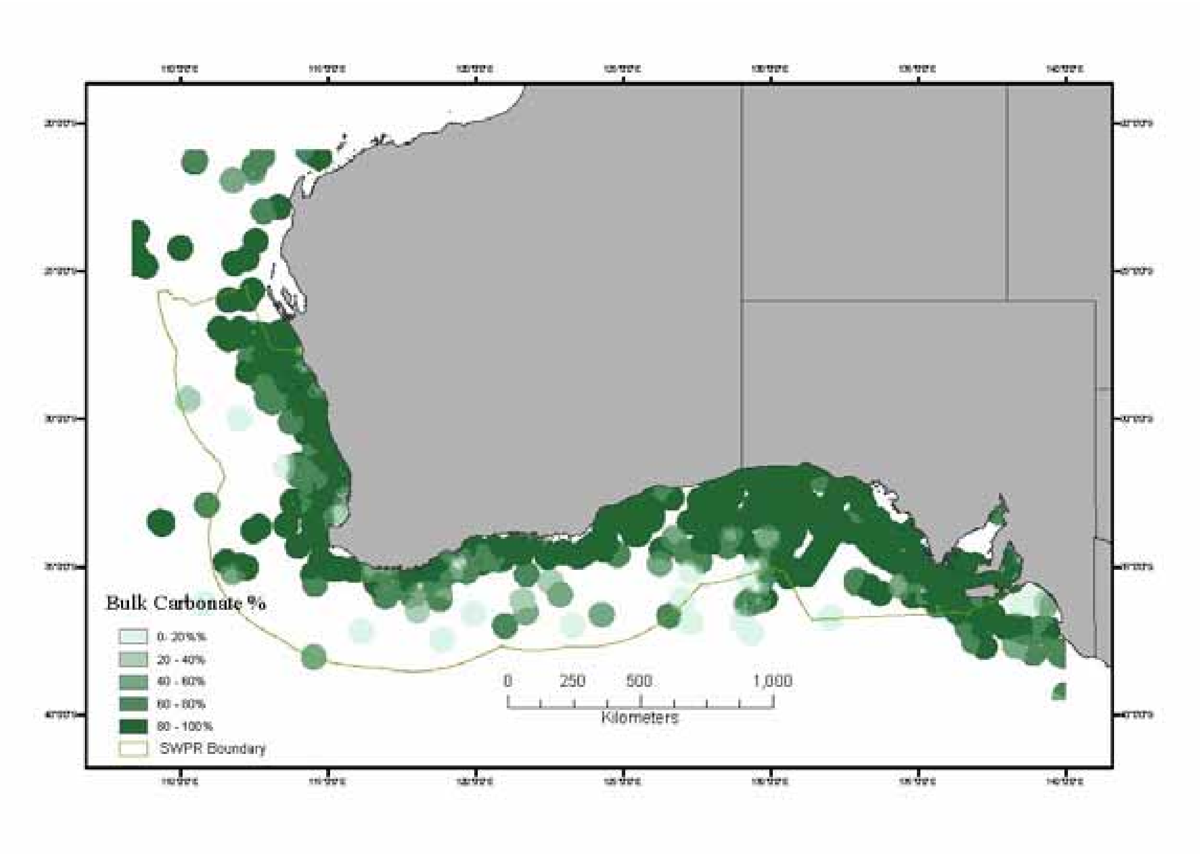


Figure 4.25. Map showing the distribution of bulk carbonate on the seabed of the SWPR.

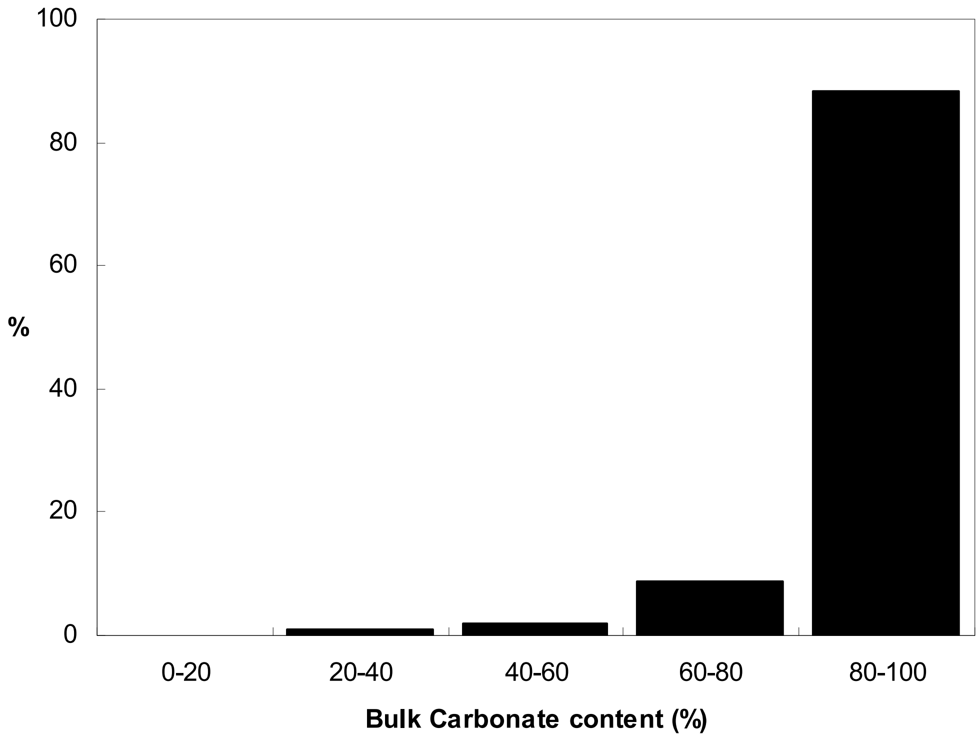


Figure 4.26. Graph showing distribution of bulk carbonate content for the shelf in the SWPR.

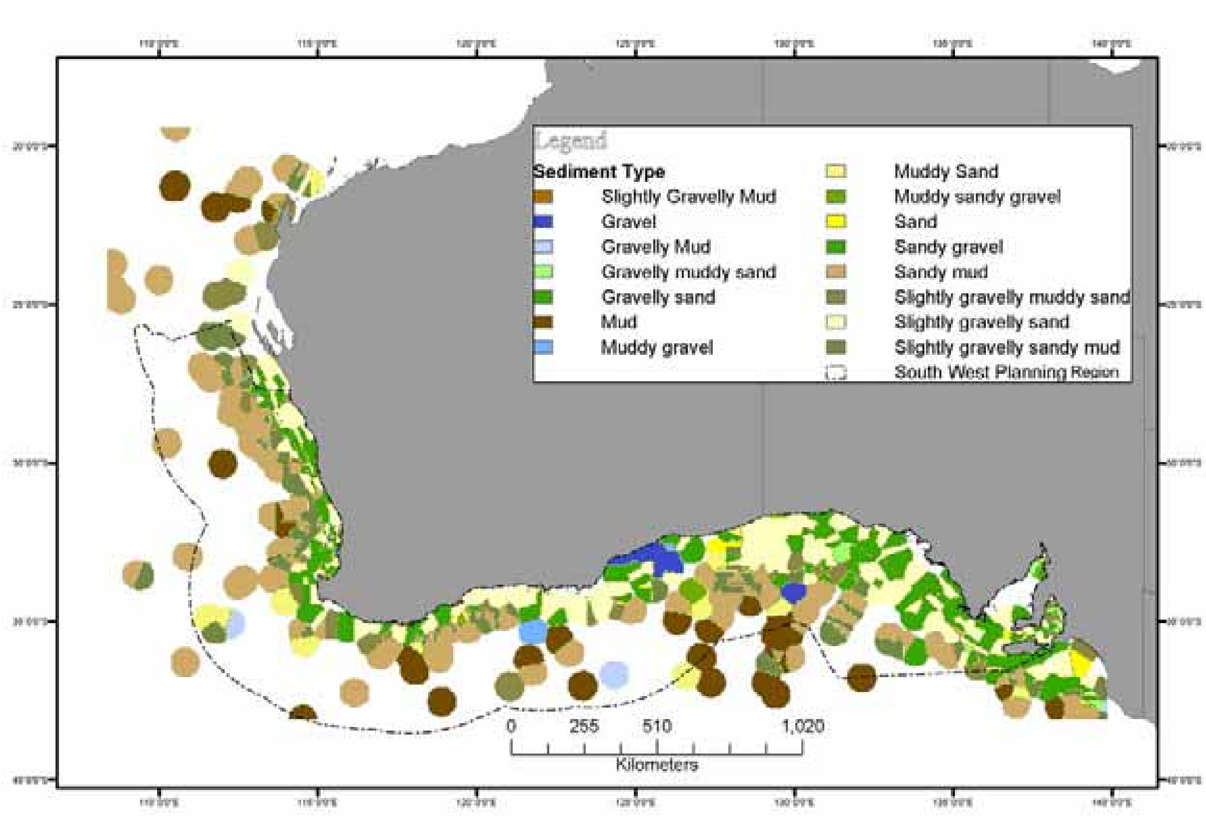


Figure 4.27. Map showing the Folk Classification of seabed sediments across the SWPR (after Folk, 1954).

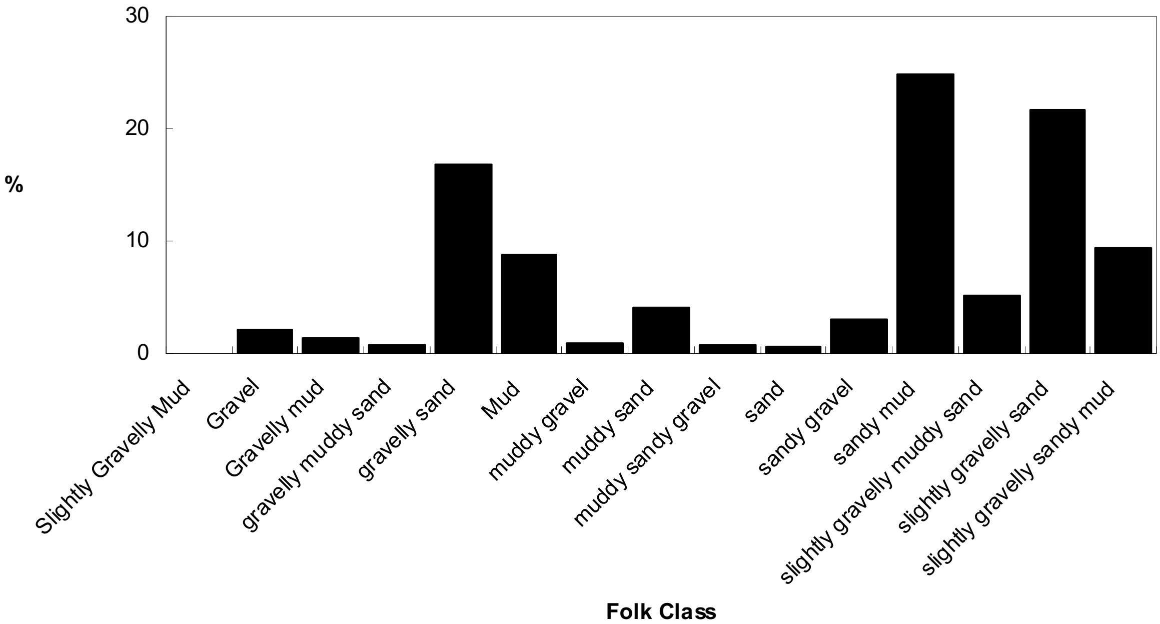


Figure 4.28. Graph showing distribution of Folk classes across the SWPR (after Folk, 1954).

4.4.2. Sedimentology of the Geomorphic Provinces

4.4.2.1. Shelf

Shelf sediments are dominated by sand, with 480 of the 663 samples comprising >70% sand (Fig. 4.29). By contrast, gravel and mud contents are low (<20%) except for 26 locations where they range between 80 and 99% (Fig. 4.29). Data coverage of the shelf in the SWPR is dense enough that we may conclude areas of high gravel content are relatively rare in 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. 4.24).

Bulk carbonate content for the shelf sediments is generally >80% (Fig. 4.29). Carbonate mud has the lowest concentrations of <85%. Carbonate sand is present in concentrations between 70 and 85%, and carbonate gravel is present in concentrations of >90%, although concentrations are below 10% at 3 locations in the Spencer Gulf.

4.4.2.1. Slope

On the slope sand and mud contents range between 0 and 100% (Fig. 4.30). Sand contents are higher on the upper slope, near the shelf break, and generally decrease down slope, corresponding to a relative increase in mud content (Fig. 4.24). Gravel forms <5% of the sediment composition at 382 of 455 locations sampled. Exceptions to this trend are localised gravel concentrations of up to 80% that occur off Esperance and in submarine canyons on the lower slope.

4.4.2.3. Rise

The rise covers in only a relatively small area of the SWPR and contains only 6 data points (Fig. 4.31). Mud is the dominant sediment fraction with contents generally ranging between 70 and 90%, and being >60% in 5 out of the 6 samples. Sand occurs in small amounts in concert with the mud concentrations as gravel does not occur at any of the sites. Carbonate content ranges from 5 to 85% (Fig. 4.31), although because of the small number of samples we can not say whether such significant variation is also present in the other fractions. The variability of carbonate content is likely to be exaggerated because of the low number of data points available for this province, as outliers could not be identified and removed from statistical assessment of variability.

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) the variability in the contents of each sediment fraction is relatively low, and the results display consistent textural properties across the entire province (Fig. 4.32). Mud is the dominant fraction of the sediments on the abyssal plain/deep ocean floor, comprising >80% in 12 out of 14 samples assayed for sediment texture (Fig. 4.32). Sand and gravel comprise <15% each for all but one of the samples (Fig. 4.32).

Bulk carbonate content ranges between 0 and 80% (Fig. 4.32). The number of assays was not sufficient to assess carbonate content of the sand fraction. Carbonate mud contents are generally <50% indicating a significant non-carbonate component. Only 4 samples contained gravel fraction large enough for carbonate analysis, and so there was insufficient data to assess carbonate composition of gravel for this province.

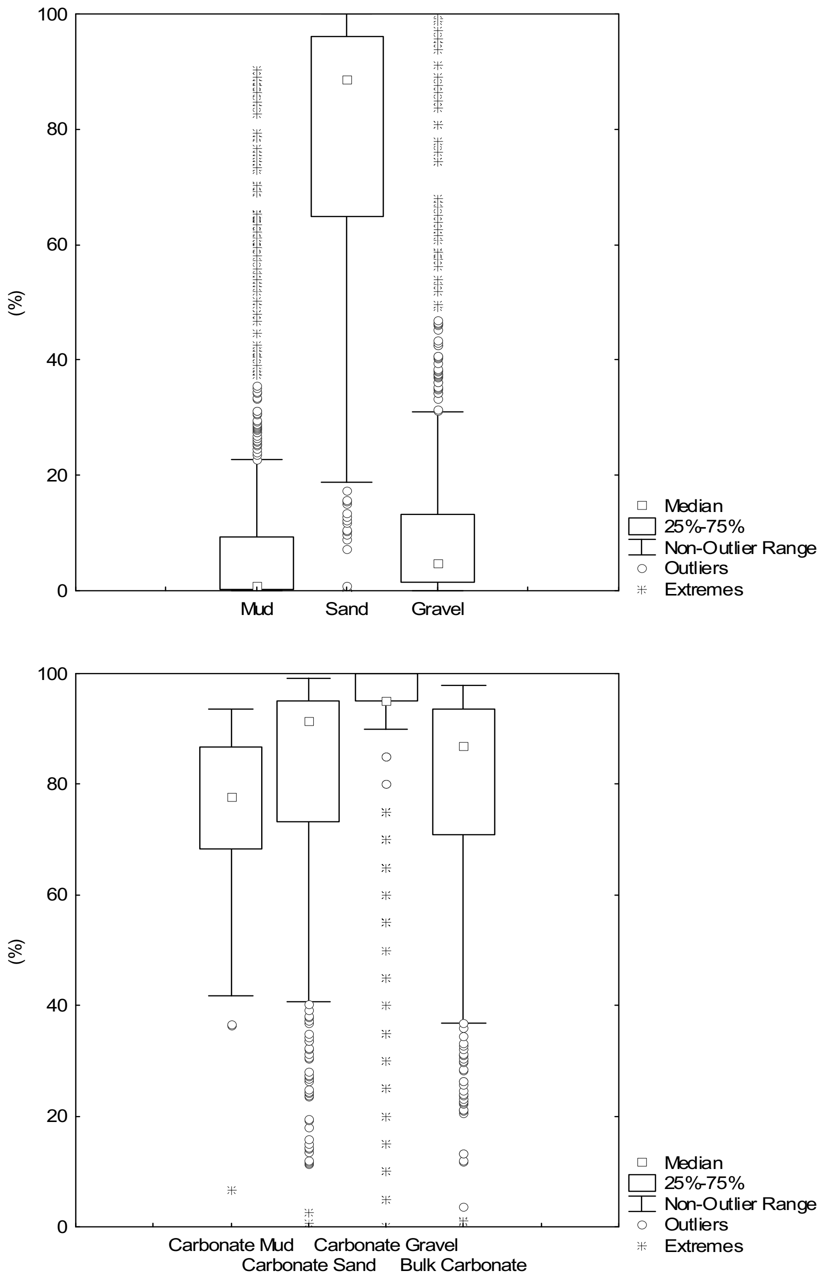


Figure 4.29. Box and whisker plots showing distribution of sediment properties for the shelf in the SWPR.

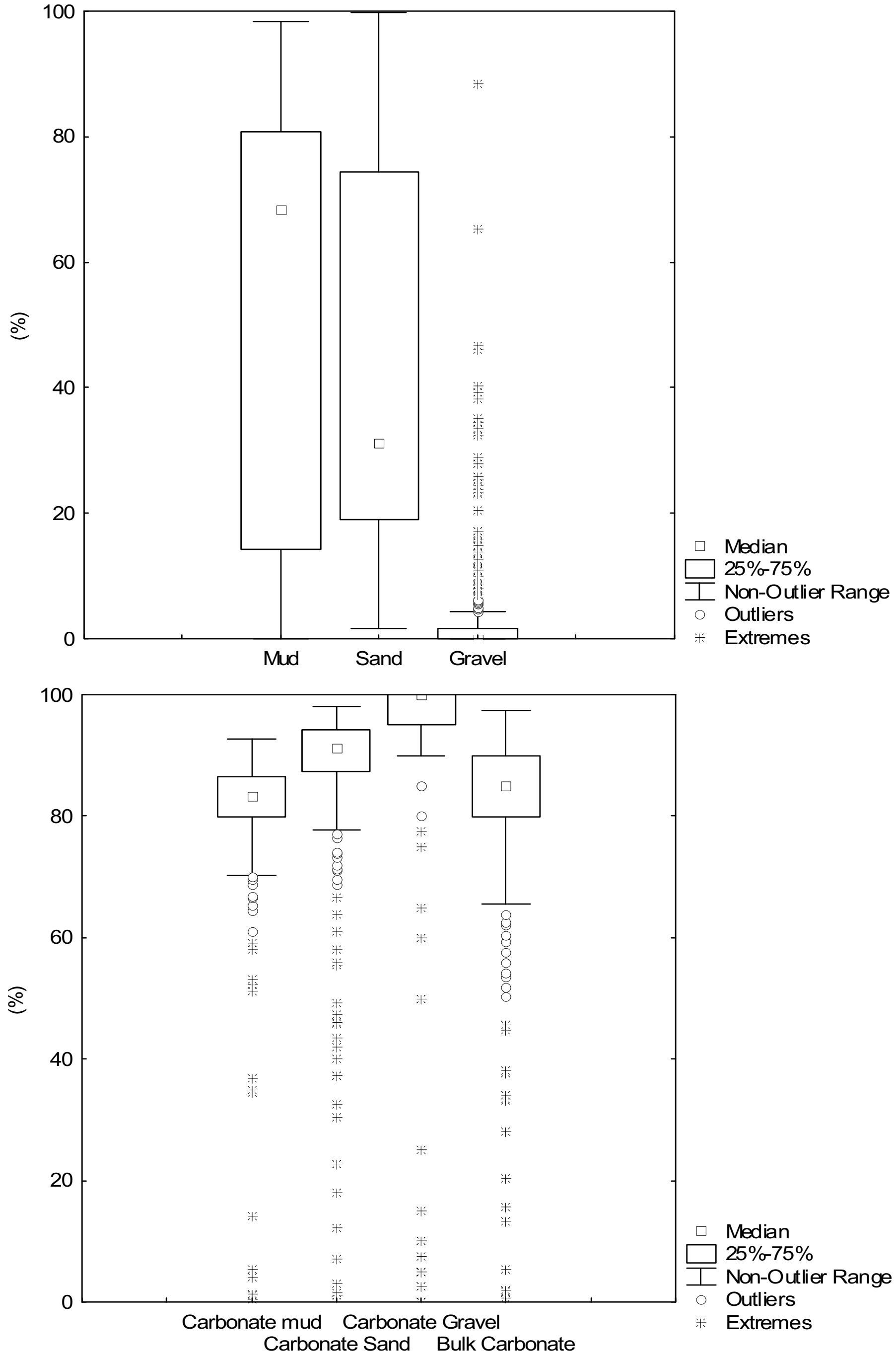
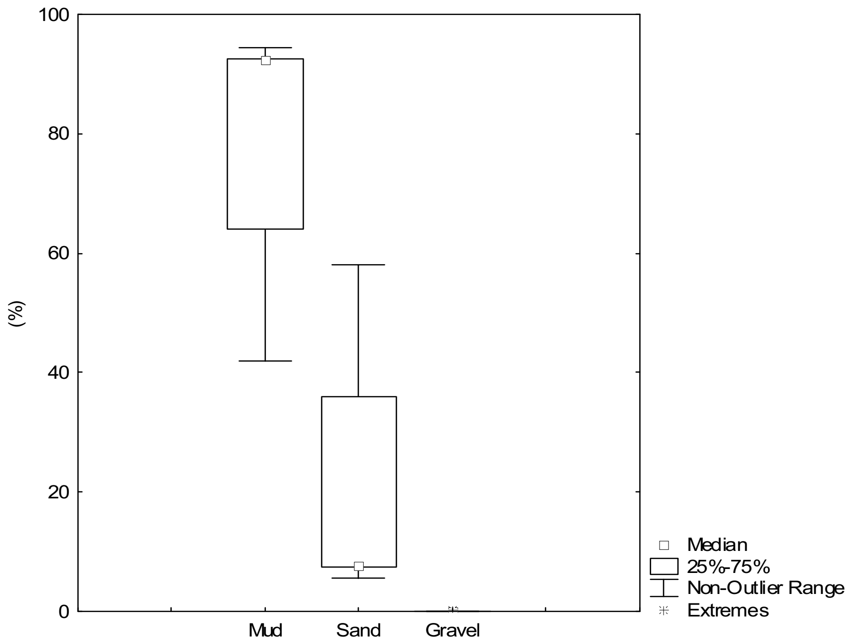


Figure 4.30. Box and whisker plots showing the distribution of sediment properties for the slope in the SWPR.



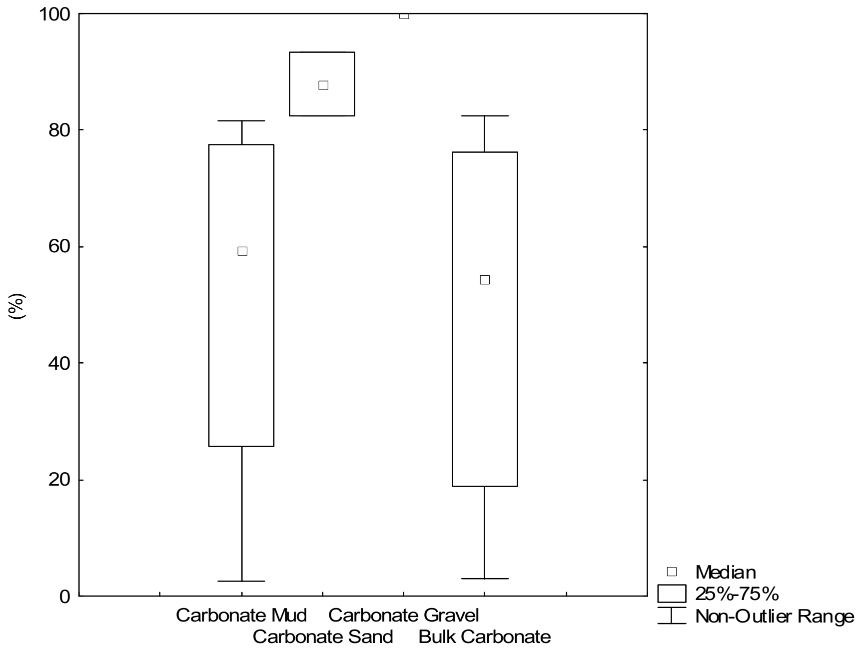
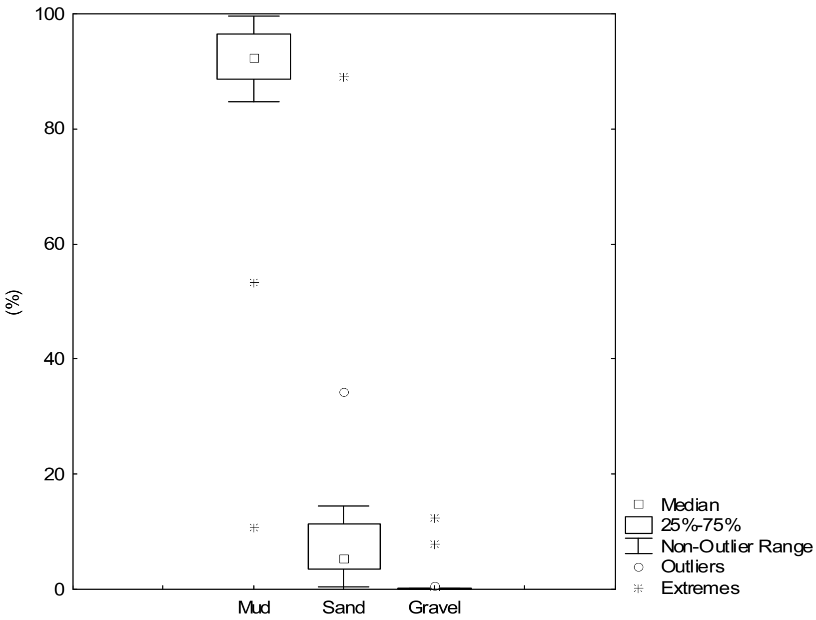


Figure 4.31. Box and whisker plots showing the distribution of sediment properties for the rise in the SWPR.



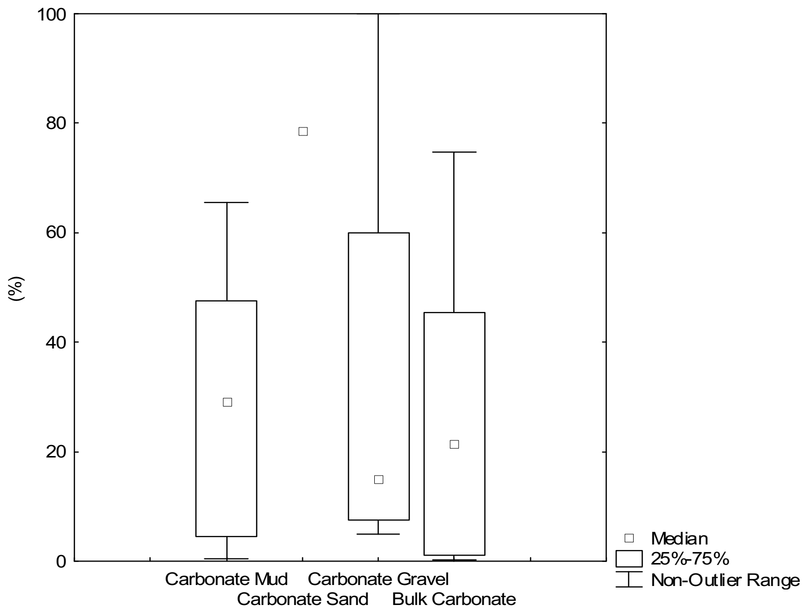


Figure 4.32. Box and whisker plots showing the distribution of sediment properties for the abyssal plain/deep ocean floor in the SWPR.

4.4.3. Sedimentology of the Geomorphic Features

4.4.3.1. Bank/shoal

A total of 40 samples were obtained from bank/shoal features (Fig. 4.33). Sand is the dominant fraction of the sediments in these features generally comprising between 40 to 100% and >75% in 30 of the 40 samples. Gravel contents generally attain 45%, with 30 of the 40 samples containing up to 25% gravel. However, at four locations on the inner shelf near Esperance bank/shoal features contained gravel contents of between 60 and 80%. Mud content in all samples is <5%, except in 5 samples where the content attains 25%. Carbonate content attains >60% in all fractions for 18 of the 20 samples assayed for carbonate. Carbonate gravel attains >95% in 7 out of 9 samples. Carbonate sand generally ranges between 25 and

95% and 6 out of 9 samples contain between 65 and 85% carbonate sand. Carbonate mud is not present in sufficient quantities to assess carbonate content of this fraction.

4.4.3.2. Deep/hole/valley

A total of 10 samples were obtained from deep/hole/valley features (Fig. 4.34). Sand is the dominant fraction of the sediments in these features comprising between 25 and 99%, with 8 of the 10 samples containing >65% sand. Gravel is the next most abundant fraction with contents attaining 35%, although 8 of the 10 samples contain less than 25% gravel. Mud content is <5% in 7 of the 10 samples, although 1 samples from the Gulf Vincent contained 30% mud. Bulk carbonate content of sediments was consistently >80% in all sediment fractions.

4.4.3.3. Canyon

A total of 79 samples were obtained from canyon features (Fig. 4.35). Mud is the dominant fraction of the sediments with contents generally ranging between 30 and 95% (Fig. 4.39). A total of 61 of the 79 samples contain >75% mud. Eight samples recovered from near the head of canyons off the southern margin contained slightly lower mud contents of between 10 and 45%. The remaining material in the sediments is sand which ranges in content from 5 to 45%, and up to 90% where low mud contents are observed. Sediments in canyons generally contain no gravel-sized clasts. However, gravel concentrations up to 10% (and a single site of 35%) are observed at locations distributed across the SWPR. Bulk carbonate content generally varied between 65 and 90%, although values as low as 1% were observed at some locations. Carbonate mud contents generally range between 70 and 90%, with 58 of the 73 samples containing >75% carbonate mud. A total of 2 samples contained >98% non-carbonate mud. These samples were recovered from the head of canyons in the Albany canyons in the south west of the SWPR. Carbonate sand contents generally range from 15 and 95%, with 41 of the 64 samples containing >75% carbonate sand. Low carbonate sand contents (<15%) occur in associated with low carbonate mud contents (<15%). Carbonate gravel contents range from 0 to 100%, although the small number of assays (33) for this fraction means that these contents probably do not accurately characterize the distribution of carbonate contents in this fraction for canyons.

4.4.3.4. Plateau

Only 4 samples were obtained from plateau features (Fig. 4.36). Sediments are principally composed of mud and sand, with contents ranging from 35 to 90% and 15 to 65% respectively (Fig. 4.40). Gravel is not present. Carbonate mud contents range from 85 to 92%.

4.4.3.5. Terrace

A total of 163 samples were obtained from terrace features (Fig. 4.37). Mud and sand are the dominant size fractions in the sediments ranging in content from 0 to 90% and 10 to 97%, respectively (Fig. 4.41). Mud content was found to be highly variable with 85 of the 163 samples containing >50% mud, but 33 samples contain <5%. Gravel contents were <5% for 126 of 145 samples, however concentrations attain 88% in 1 locations on the Ceduna Terrace on the southern margin. Carbonate contents exceed 75% for all but 3 of 144 samples.

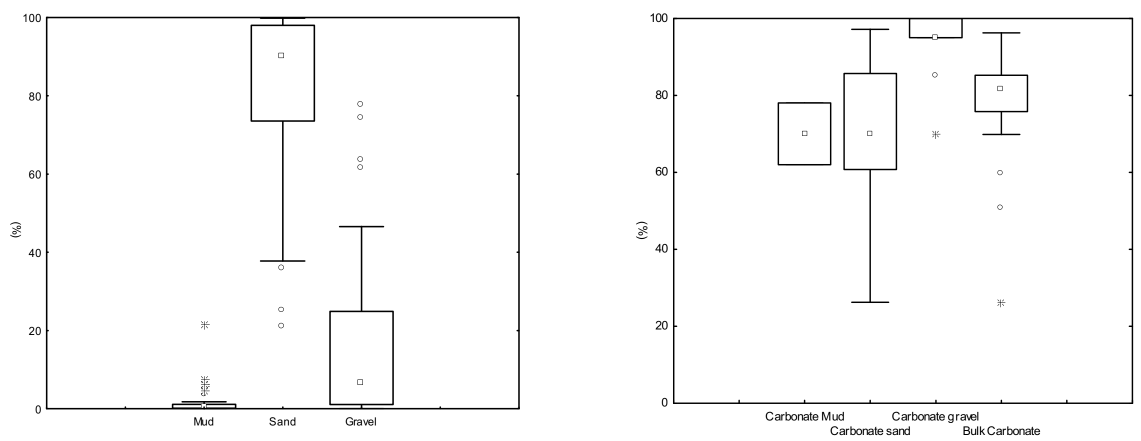
Carbonate gravel contents exceed 75% at all but 4 of the 79 locations where they were present.

4.4.3.6. Tidal sandwave/sand bank

A total of 17 samples were obtained from tidal sandwave/sand bank features (Fig. 4.38). Sand and mud are the dominant size fractions of the sediment with contents ranging between 25 to 95% and 2 to 75%, respectively (Fig. 4.42). Around 50% (8 of 17) samples contained >60% sand, while mud contents were slightly lower with 15 of the 17 samples containing <60% mud. Gravel content ranges from 0-40%, with 9 of the 17 samples containing <10% gravel. Bulk carbonate content of sediments ranges between 45 and 100%. Carbonate contents generally range from 75 to 100% for gravel (mean 92% from 17 samples), 45 to 93% for sand (mean 77% from 17 samples), and 58 to 80% for mud (mean 68% from 13 samples).

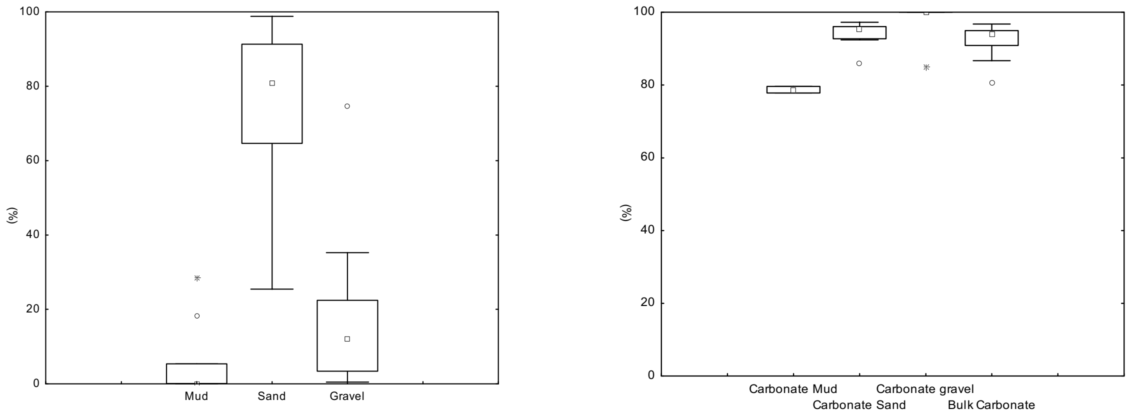
4.4.3.7. Areas not assigned to geomorphic features

The majority of the seabed in the SWPR consists of Shelf, Slope, Rise and AP/DOF areas where no geomorphic features have been identified. Sedimentology of this area for each primary bathymetric unit is described in Figures 4.39-4.42.



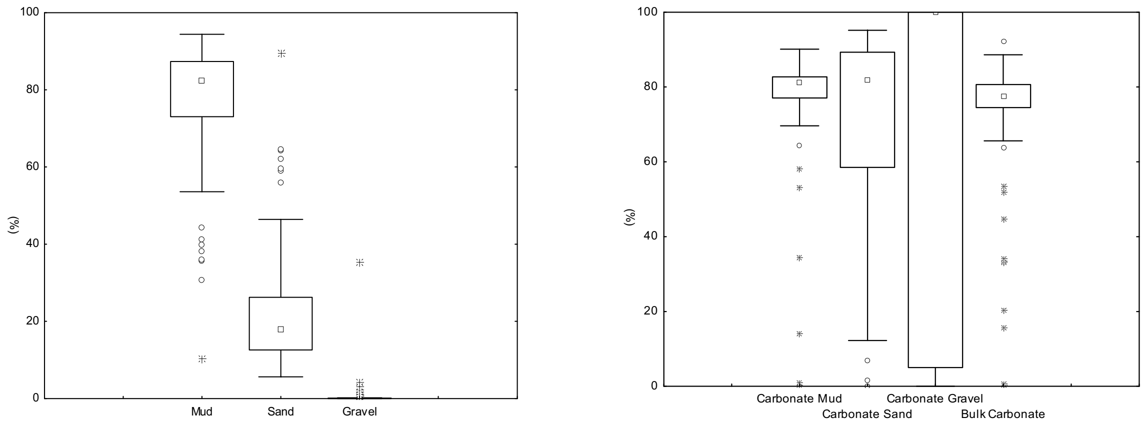
Bank/shoal

Figure 4.33. Box and whisker plots showing the distribution of sediment properties for bank/shoal geomorphic features in the SWPR.



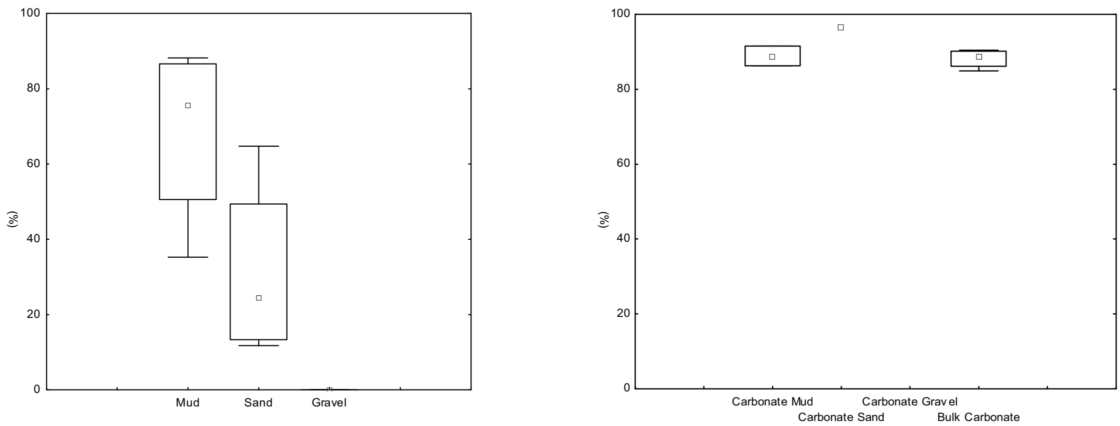
Deep

Figure 4.34. Box and whisker plots showing the distribution of sediment properties for deep/hole/valley geomorphic features in the SWPR.



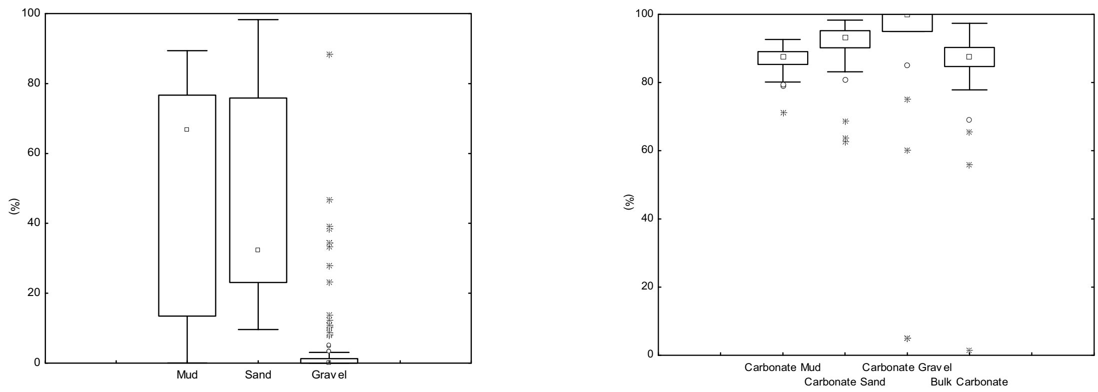
Canyon

Figure 4.35. Box and whisker plots showing the distribution of sediment properties for canyon geomorphic features in the SWPR.



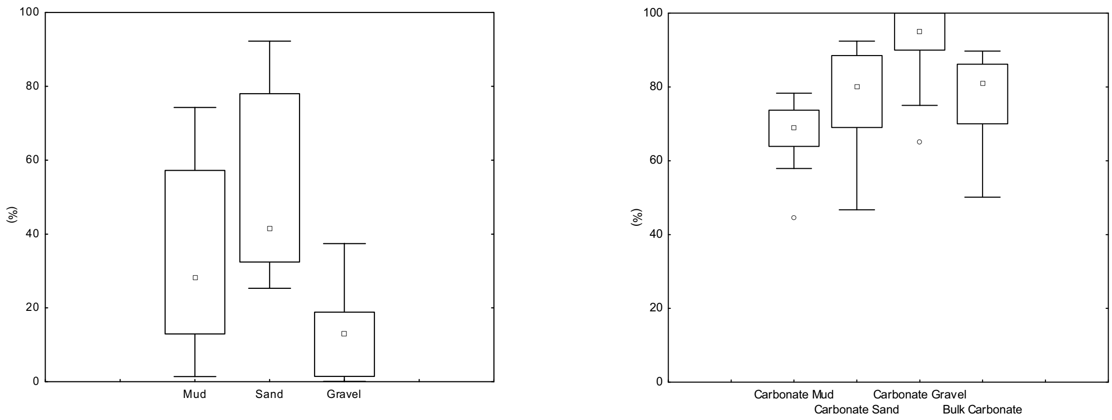
Plateau

Figure 4.36. Box and whisker plots showing the distribution of sediment properties for plateau geomorphic features in the SWPR.



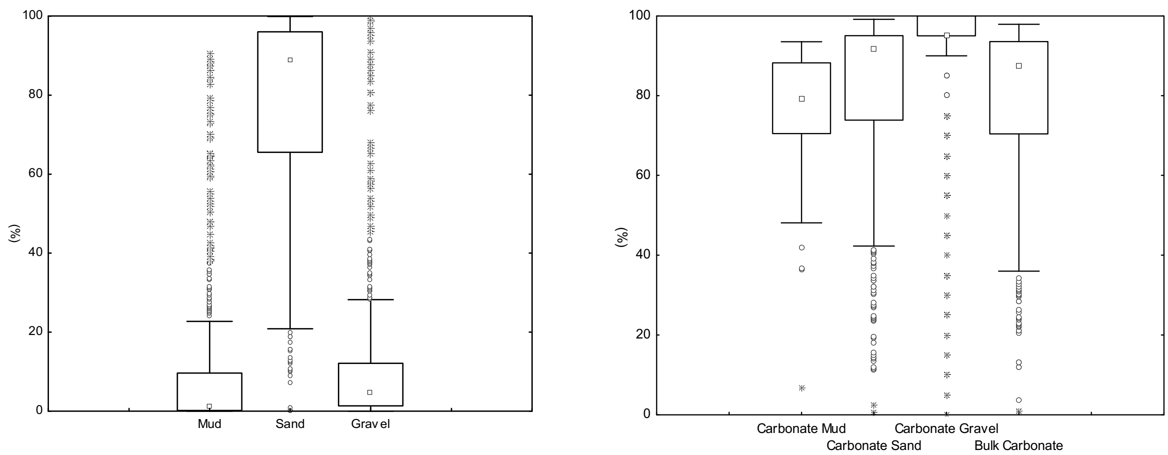
Terrace

Figure 4.37. Box and whisker plots showing the distribution of sediment properties for terrace geomorphic features in the SWPR.



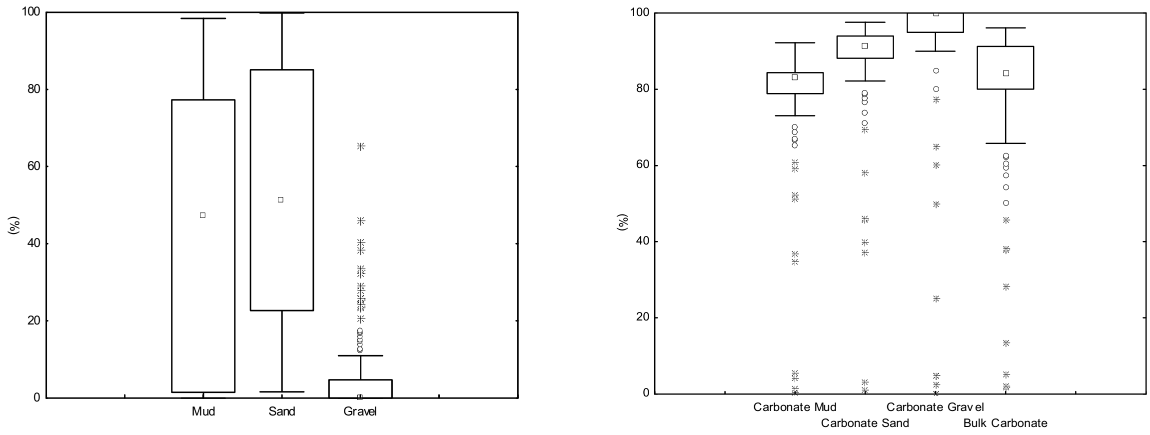
Tidal sand wave/sand bank

Figure 4.38. Box and Whisker plots showing the distribution of sediment properties for tidal sandwave/sand bank geomorphic features in the SWPR.



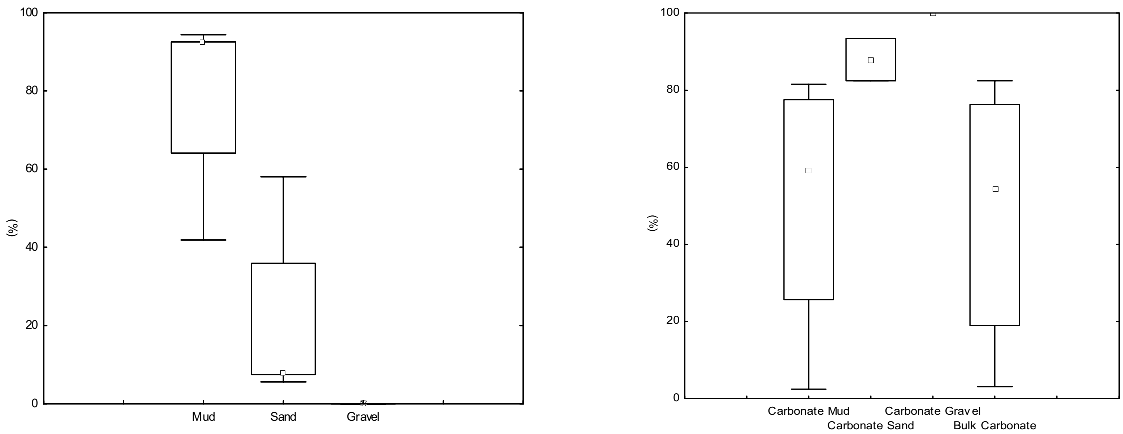
Shelf (unassigned)

Figure 4.39. Box and whisker plots showing the distribution of sediment properties for the area of shelf in the SWPR where no geomorphic features have been identified.



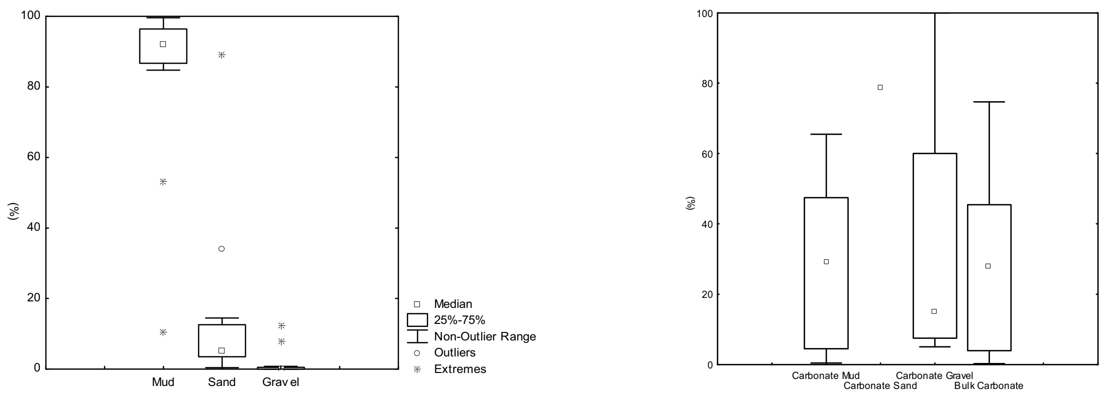
Slope (unassigned)

Figure 4.40. Box and whisker plots showing the distribution of sediment properties for the area of slope in the SWPR where no geomorphic features have been identified.



Rise (unassigned)

Figure 4.41. Box and whisker plots showing the distribution of sediment properties for the area of rise in the SWPR where no geomorphic features have been identified.



AP/DOF (unassigned)

Figure 4.42. Box and Whisker plots showing the distribution of sediment properties for the area of the AP/DOF in the SWPR where no geomorphic features have been identified

5. Bioregion Sedimentology and Geomorphology

5.1. 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. Appendix 1 provides a detailed analysis of the sedimentological and major physical characteristics of the seabed in each bioregion.

The four IMCRA Provinces and Transitions are located on the shelf. More than 95% of their combined area is on the shelf, with of the remaining 5% covering 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 because the seabed is more accessible. 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 Diamantian 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 the full range of statistical analyses.

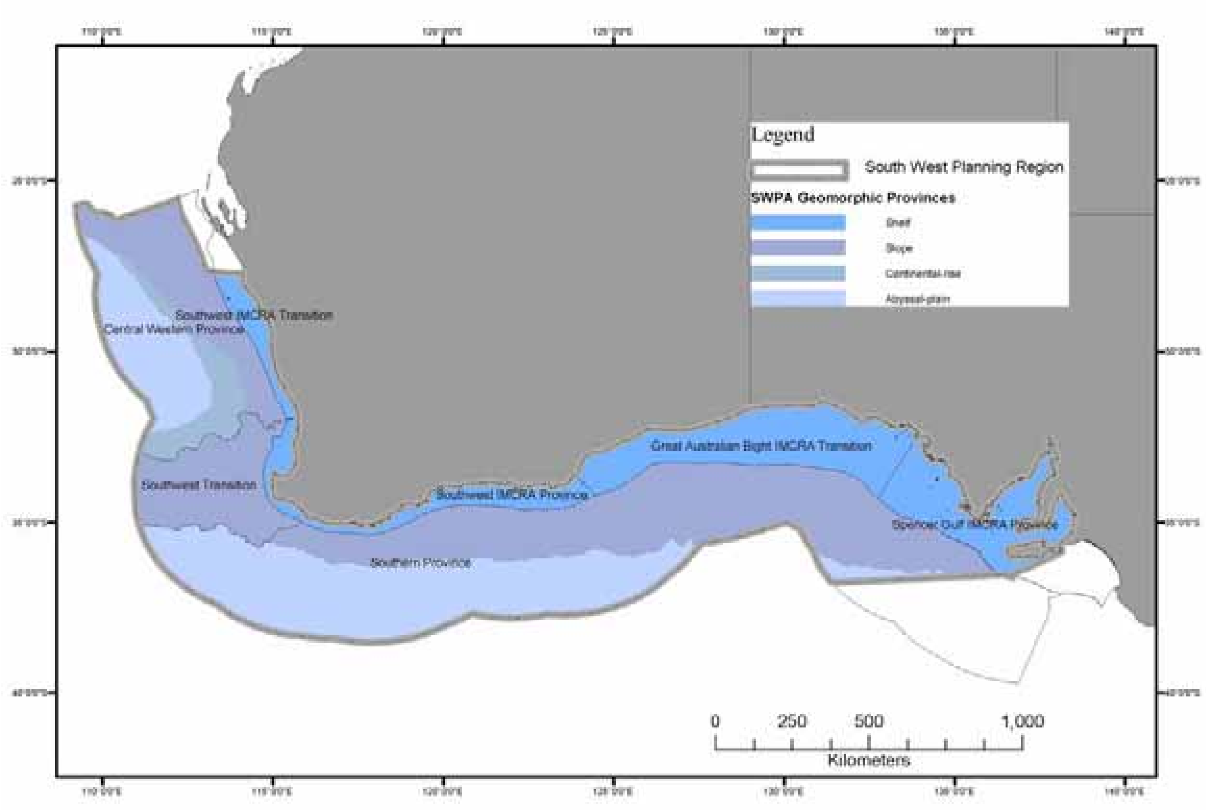


Figure 5.1. Map showing the boundaries of the provincial bioregions overlaid on to the geomorphic provinces for the SWPR.

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

6. Discussion and Summary

Our newly-created database of the texture and composition of the seabed sediments for the southern and western margins (SWPR) permits quantitative comparisons of the sedimentology to be made for the entire Australian margin. Significantly, these data also build on the mainly qualitative studies that currently exist for these margins. Previous work for these margins has focussed principally on the shelf, and so much of the following discussion is restricted to comparing our results with the findings of these studies. Where possible, we also comment on how our results compare with previous sedimentological models of the deep seabed.

6.1. COMPARISON TO PREVIOUS SEDIMENT MODELS

6.1.1. Margin Sedimentology

Across the SWPR, the seabed sediments show a broad zoning with water depth, and generally become finer with depth Also, 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 numerous environments associated with submarine canyons.

Sediments over the entire SWPR are dominated by carbonate grains. Sediments dominated by terrigenous grains are restricted to several 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.

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 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. Areas dominated by sandy sediments do occur in water depths of >4,000 m on the rise and abyssal plain/deep ocean floor regions. In most places, 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.

6.1.2. Shelf Sedimentology

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 significant 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 confirmed by 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.

The current sediment facies model for the southern Rottnest Shelf (Collins, 1988) shows that this region is 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, these 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 Rottenest and Recherché shelves, and the slope, rise and abyssal plain/deep ocean floor regions off Perth and around 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 are generally lower sand contents and higher mud contents than observed by these previous workers. Our results quantify the gradation from sand- to mud-dominated sediments in detail.

On the southern margin, the shelf sediments have been described by James et al. (2001). This region is the largest cool-water carbonate margin in 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 contents in the western bight attain 35%; elsewhere they are 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 contents attain 30% on the outer shelf and increase to between 80 and 100% on the upper slope, where they generally remain 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. Significantly, our data reveal that the 'Quartzose skeletal sand' facies of James et al. (1999) on the shelf north of Perth contains carbonate contents of between 0 and 20%. 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 contents on the southern Rottnest Shelf is much greater than depicted by the current sediment model (Collins, 1988), with regions most proximal to the coast generally containing <20% carbonate, and middle shelf regions containing between 40 to 60% in the north and 20 and 40% in the south.

On the southern shelf, our data generally agree with the interpretations 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 non-carbonate 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 results generally agree with the distribution of these facies, although the spatial variation in our data is greater than that 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. 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.

6.2.1. 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.

6.2.2. 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.

6.2.3. 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.

7. References

Bax, N.J. and Williams, A., 2001. Seabed habitat on the south-eastern Australian continental shelf: context, vulnerability and monitoring. *Marine and Freshwater Research* **52**, 491-512.

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

Beaman, R.J., Daniell, J.J. and Harris, P.T., 2005. Geology-benthos relationships on a temperate rocky bank, eastern Bass Strait, Australia. *Marine and Freshwater Research* **56**, 943-958.

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

Bolton B.R., Exon N.F., Otswald J. and Kubrass H.R., 1988. Geochemistry of ferromanganese crusts and nodules from the South Tasman Rise, southeast of Australia. *Marine Geology* **84**, 50-83.

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

Boyd, R., Ruming, K. and Roberts, J.J., 2004. Geomorphology and surficial sediments of the southeast Australian continental margin. *Australian Journal of Earth Sciences* **51**, 743-764.

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

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

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

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

Carrigy, M.A. and Faribridge, R.W., 1954. Recent sedimentation, physiography and structure of the continental shelves of Western Australia. *Journal of the Royal Society of Western Australia* **37**, 65-95.

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

Collins, L.B., France, R.E., Zhong, R.Z. and Wyrwoll, K.H., 1997. Warm-water platform and cool-water shelf carbonates of the Abrolhos Shelf, southwest Australia. *Cool-Water Carbonates Special Publication* **56**, 23-36.

Conolly, J.R., 1976. Interplay of continental margin and oceanic sediments between the Australian and Antarctic continents. *International Geological Congress, Abstracts-Congres Geologique Internationale, Resumes* **25**, 883.

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

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

Day, J.C. and Roff, J.C., 2000. *Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans*. World Wildlife Fund, Toronto.

Department of the Environment and Heritage, 2005a. *Great Australian Bight Marine Park (Commonwealth and State Waters): A description of Values and Users*. Department of the Environment and Heritage, Canberra.

Department of the Environment and Heritage, 2005b. *National marine bioregionalisation of Australia 2005*. Department of the Environment and Heritage (National Oceans Office), Hobart. DVD.

Exon N.F., 1979. *Deep sea sediments and manganese nodules from the Southern Tasman Sea*. Bureau of Mineral Resources, Record **1979/062**. Bureau of Mineral Resources, Canberra.

Exon N.F., 1997. Ferromanganese crust and nodule deposits from the continental margin south and west of Tasmania. *Australian Journal of Earth Sciences* **44**, 701-710.

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

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

Gagan, M.K., Chivas, A.R. and Herczeg, A.L., 1990. Shelf-wide erosion, deposition, and suspended sediment transport during cyclone Winifred, central Great Barrier Reef, Australia. *Journal of Sedimentary Petrology* **60**, 456-470.

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

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

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

Harris, P.T., 1995. Marine geology and sedimentology of the Australian continental shelf. *In*: Zann, L.P., (Ed.), *The State of the Marine Environment. Report for Australia. Technical Annex 1: The Marine Environment*, pp. 11–23. Department of the Environment, Sport and Territories: Canberra.

Harris, P.T., Baker, E.K. and Cole, A.R., 1991. *Physical Sedimentology of the Australian Continental Shelf*. Ocean Sciences Institute, Report 51. University of Sydney, Sydney.

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

Harris, P.T., Smith, R., Anderson, O., Coleman, R. and Greenslade, D., 2000. *GEOMAT; modelling of continental shelf sediment mobility in support of Australia's regional marine planning process*. Australian Geological Survey Organisation, Record **2000/41**. Australian Geological Survey Organisation, Canberra.

Hill, P.J. and De Deckker, P., 2004. *AUSCAN seafloor mapping and geological sampling survey on the Australian southern margin by RV Marion Dufresne in 2003: final project report*. Geoscience Australia, Record **2004/04**. Geoscience Australia, Canberra.

Hinde, A., Whiteway, T., Heap, A.D., Lucieer, V., Ruddick, R. and Harris, P.T., in press. *Creation of Ecological Seascapes for Australia's Seabed: Methodology and Results*. Geoscience Australia, Record **2006**. Geoscience Australia, Canberra.

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

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

James, N.P., Bone, Y., Von der Borch, C.C. and Gostin, V.A., 1992. Modern carbonate and terrigenous clastic sediments on a cool water, high energy, mid-latitude shelf:

Lacepede, southern Australia. *Sedimentology* **39**, pp 877-903.

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

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

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

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

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

Kostylev, V.E., Todd, B.J., Fader, G.B.J., Courtney, R.C., Cameron, G.D.M. and Pickrill, R.A., 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Marine Ecology Progress Series* **219**, 121-137.

Levinton, J.S., 1982. *Marine Ecology*, New Jersey: Prentice-Hall.

Long, B.G., Poiner, I.R. and Wassenberg, T.J., 1995. Distribution, biomass and community structure of megabenthos of the Gulf of Carpentaria, Australia. *Marine Ecology Progress Series* **129**, pp 127-139.

Muller, G. and Gastner, M., 1971. The "Karbonate-Bombe", a simple device for the determination of the carbonate cotent in sediments, soils, and other materials. *Neues Jahrbuch fuer Mineraliogie* **10**, 446-469.

Orpin, A.R., Brunskill, G.J., Zagorskis, I. and Woolfe, K.J., 2004. Patterns of mixed siliciclastic-carbonate sedimentation adjacent to a large dry-tropics river on the central Great Barrier Reef shelf, Australia. *Australian Journal of Earth Sciences* **51**, 665-683.

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

Porter-Smith, R., Harris, P.T., Andersen, O.B., Coleman, R., Greenslade, D. and Jenkins, C.J., 2004. Classification of the Australian continental shelf based on predicted sediment threshold exceedance from tidal currents and swell waves. *Marine*

Geology **211**, 1-20.

Post A.L., 2006. *Physical surrogates for benthic organisms in the southern Gulf of Carpentaria, Australia: Testing and application to the Northern Planning Area*. Geoscience Australia, Record **2006/09**. Geoscience Australia, Canberra.

Post, A.L., Wassenberg, T.J. and Passlow, V., 2006. Physical surrogates for macrofaunal distributions and abundance in a tropical gulf. *Marine and Freshwater Research* **57**, 469-483.

Remey, P.A. and Snelgrove, P.V.R., 2003. Spatial patterns in sedimentary macrofaunal communities on the south coast of Newfoundland in relation to surface oceanography and sediment characteristics. *Marine Ecology Progress Series* **262**, 215-227.

Richardson, L., Mathews, E. and Heap, A.D., 2005. *Geomorphology and Sedimentology of the South Western Planning Area of Australia*. Geoscience Australia, Record **2005/11**. Geoscience Australia, Canberra.

Roberts, J.J. and Boyd, R., 2004. Late Quaternary core stratigraphy of the northern New South Wales continental shelf. *Australian Journal of Earth Sciences* **51**, 141-156.

Roff, J.C. and Taylor, M.E., 2000. National frameworks for marine conservation – a hierarchical geophysical approach. *Aquatic Conservation: Marine and Freshwater Ecosystems* **10**, 209-223.

Roff, J.C., Taylor, M.E. and Laughran, J., 2003. Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**, 77-90.

Ruddick, R., 2006. *Data Interpolation Methods in the Geoscience Australia Seascapes Maps*. Geoscience Australia Internal Report (unpublished). Geoscience Australia, Canberra.

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

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

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

Snelgrove, P.V.R. and Butman, C.A., 1994. Animal-sediment relationships revisited; cause verses effect. *Ocean and Marine Biology: An Annual Review* **32**, 111-177.

Solan, M., Raffanellli, D.G., Paterson, D.M., White, P.C.L. and Pierce, G.J., 2006. Marine biodiversity and ecosystem function: empirical approaches and future research needs. *Marine Ecology Progress Series* **311**, 175-178.

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

Ward, T.J., Vanderklift, M.A., Nicholls, A.O. and Kenchington, R.A., 1999. Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity. *Ecological Applications* **9**, 691-698.

Waters, C., 1982. *Dynamics of Sedimentation in a Shallow Gulf*. Flinders University of South Australia, PhD Thesis.

8. Appendices

8.1. APPENDIX A: SEDIMENTOLOGY AND GEOMORPHOLOGY OF THE SWPR BIOREGIONS

8.1.1. Spencer Gulf IMCRA Province

8.1.1.1. Introduction

The Spencer Gulf IMCRA Province (SG IMCRA) covers a total area of 132,200 km^2 (Fig. 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 lies on the shelf (Fig. 8.1; Table 8.1). 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 (Fig. 8.2).

A total of 10 geomorphic features are represented in the Spencer Gulf IMCRA Province (Table 8.1). 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 8.2). 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.

8.1.1.2 Sample Coverage

A total of 216 data points occur in the Spencer Gulf IMCRA Province, and all of these are located on the shelf geomorphic province (Table 8.3). A significant number fall in the area designated as non-marine (water depth <10 m) and could not be used in analyses (Fig. 8.3). Approximately 80% of remaining samples were collected in water depths <50 m (Fig. 8.4).

40% 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. 4.11).

A total of 170 data points are located in the Spencer and St Vincent Gulfs, with concentrations in the northern Spencer Gulf (Fig. 4.5). Elsewhere in the bioregion data coverage is relatively sparse, with the distance between samples as much as 50-100 km, but the distribution of the points gives relatively even coverage of inner and outer shelf.

Table 8.1. Details of the geomorphology of the Spencer Gulf IMCRA Province.

Feature	Total number of features	% 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	77	99.93	17.48	
Slope		<0.01	<0.01	
Geomorphic Feature				
Shelf (unassigned)	17	97.76	32.00	7.89
Slope (unassigned)	1	<0.01	<0.01	<0.01
Bank/shoal	44	0.34	18.38	0.67
Deep/hole/valley	1	0.52	15.63	0.32
Basin	1	0.51	100	0.08
Reef	6	0.02	1.04	0.03
Canyon	2	<0.01	<0.01	<0.01
Knoll/abyssal-hills/hills/peak	3	0.06	0.10	0.05
Terrace	2	<0.01	<0.01	<0.01
Tidal sandwave/sand bank	5	0.79	99.00	3.30
TOTAL	82			

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

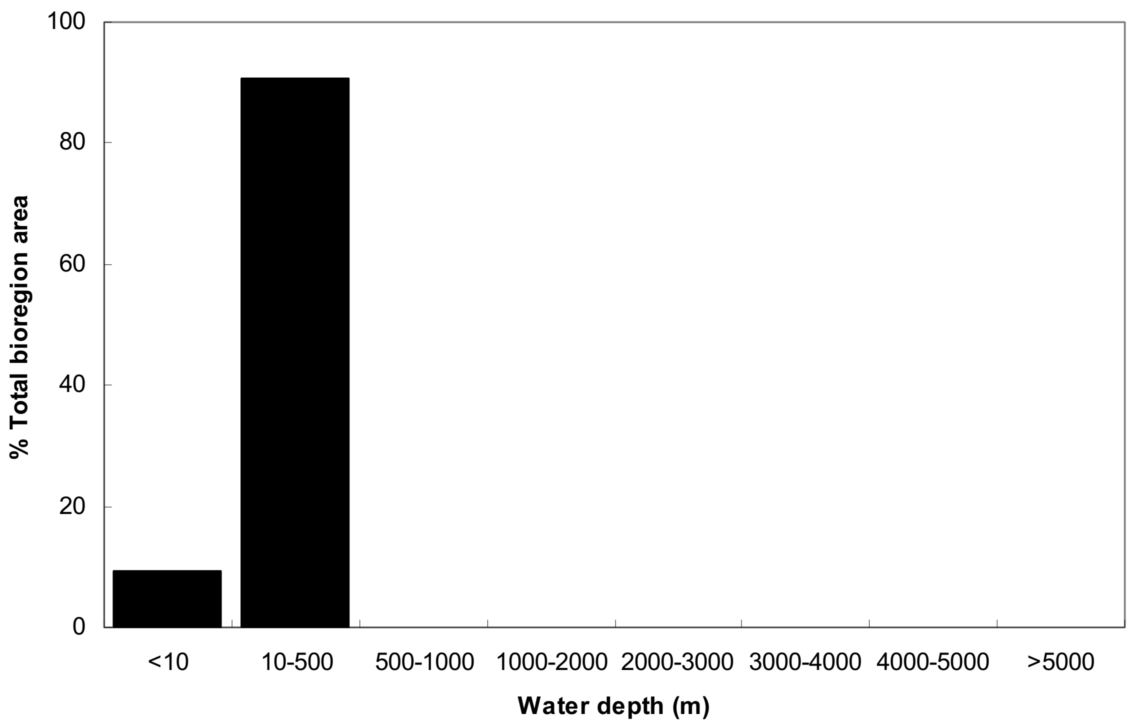


Figure 8.1. Graph showing the distribution of water depths for the Spencer Gulf IMCRA Province. Note that >99% of the seabed is in water shallower than 500 m. Also ~10% of the province is in water depths <10 m and is not included in the analyses. This is depth frequency distribution is unique to this province.

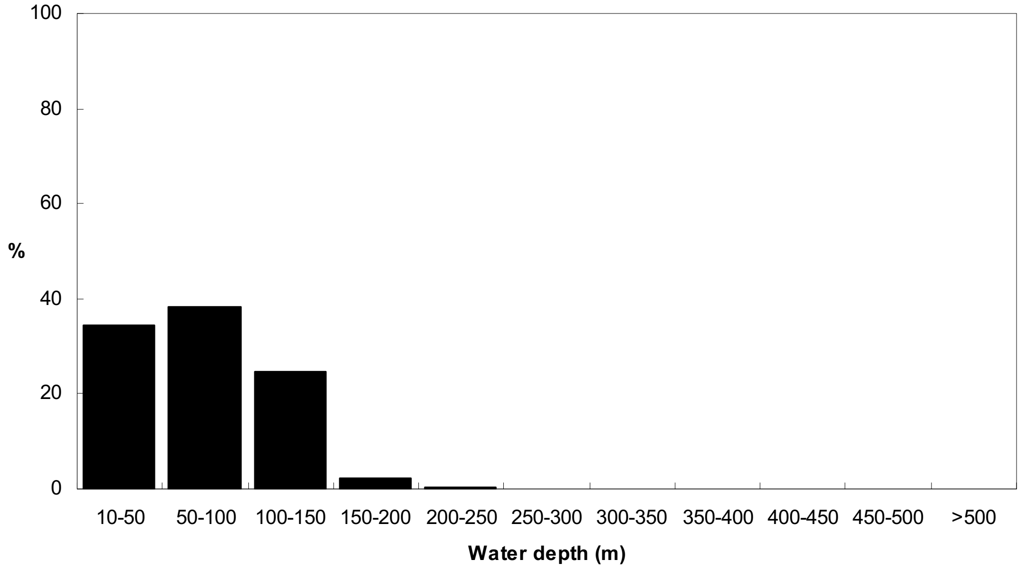


Figure 8.2. Graph showing the distribution of water depth on the continental shelf for the Spencer Gulf IMCRA Province.

Table 8.2. 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 8.3. Sample coverage by geomorphic provinces and features for the Spencer Gulf IMCRA Province.

Feature	**No. of Samples**	**Features covered/Total number of features**	**Average data density (sample:km^2)**
Geomorphic Provinces			
Shelf	216	77	~1:450
Geomorphic features			
Shelf (unassigned)	189	1/17	~1:500
Bank/shoal	8	4/44	~1:50
Deep/hole/valley	2	1/1	~ 1:250
Tidal sandwave/sand bank	17	2/5	~1:50

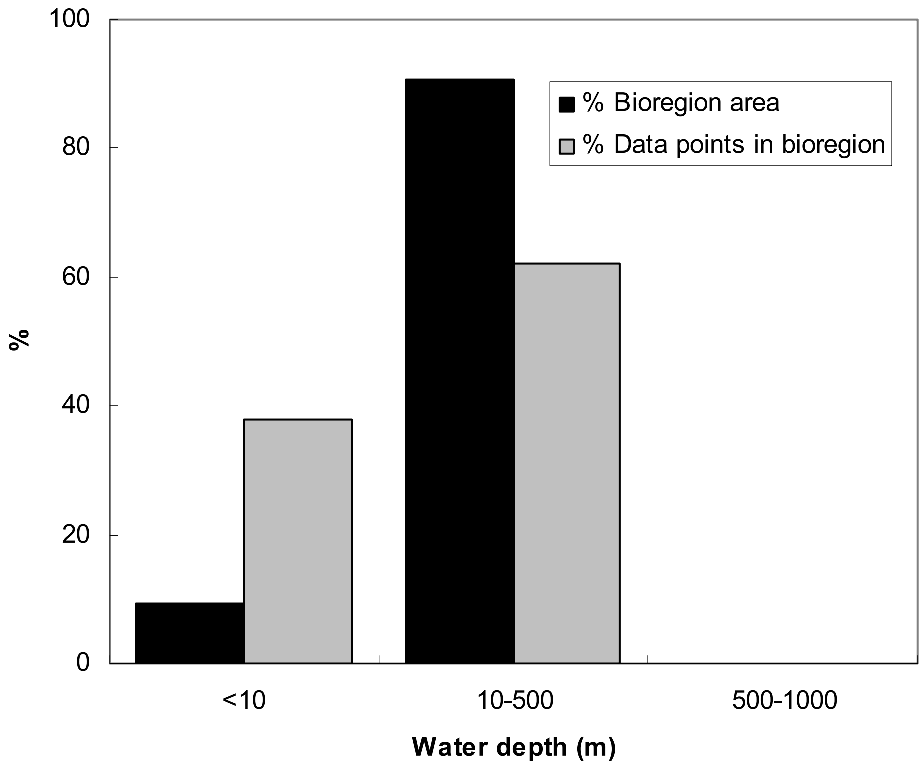


Figure 8.3 Graph of sample coverage distributed by water depth in the Spencer Gulf IMCRA Province. Note that a significant number of samples fall in <10 m water depth and thus were not included in the analysis.

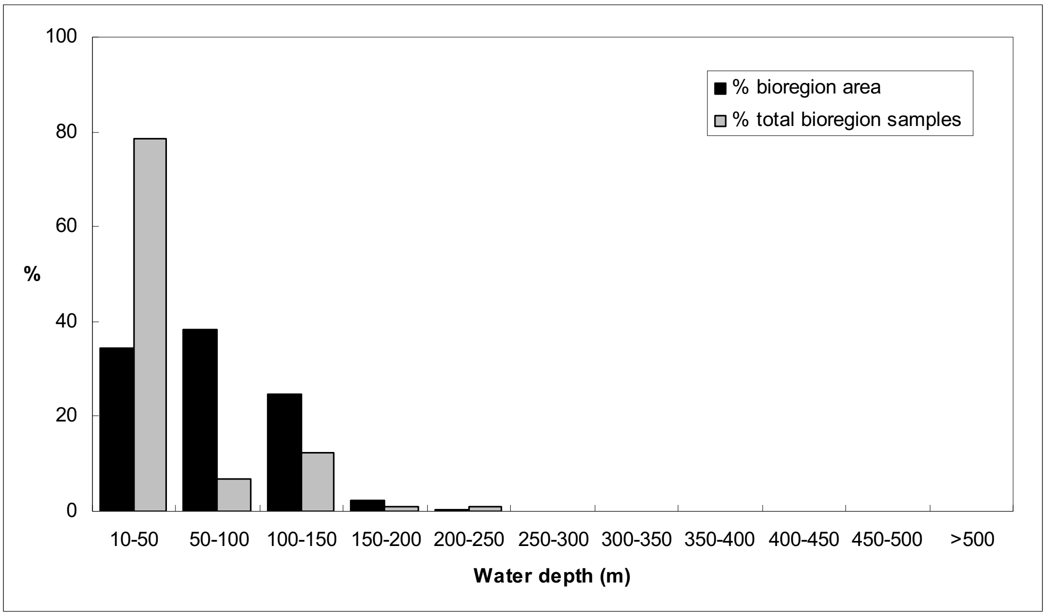


Figure 8.4. Graph of sample coverage distributed by water depth on the shelf in the Spencer Gulf IMCRA Province.

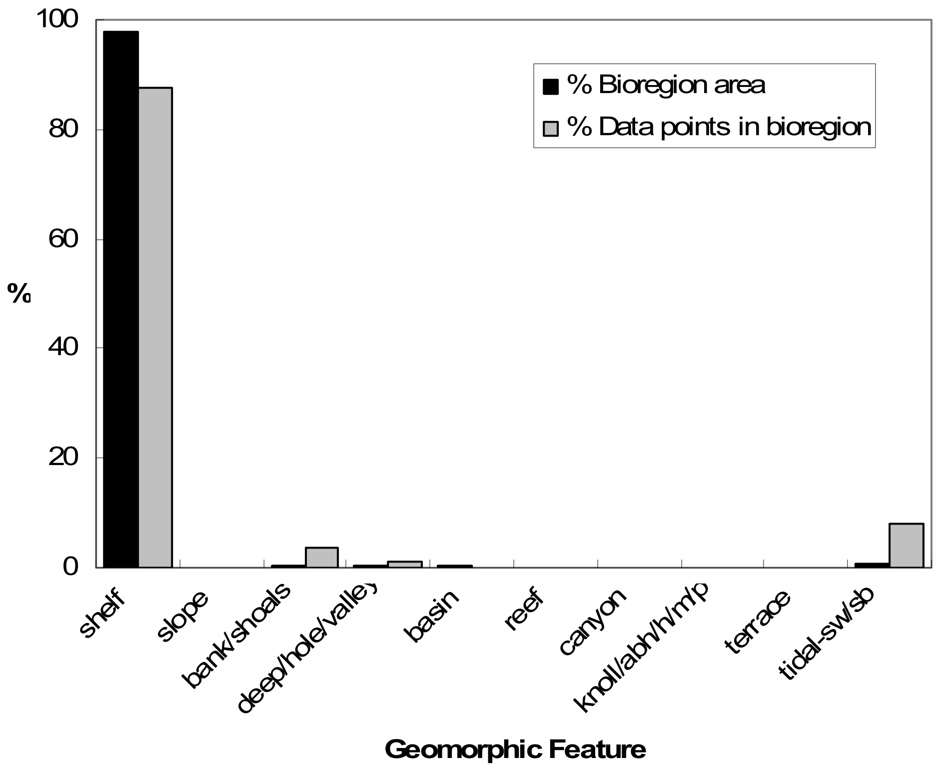


Figure 8.5. Graph of sample coverage distributed by geomorphic features in the Spencer Gulf IMCRA Province.

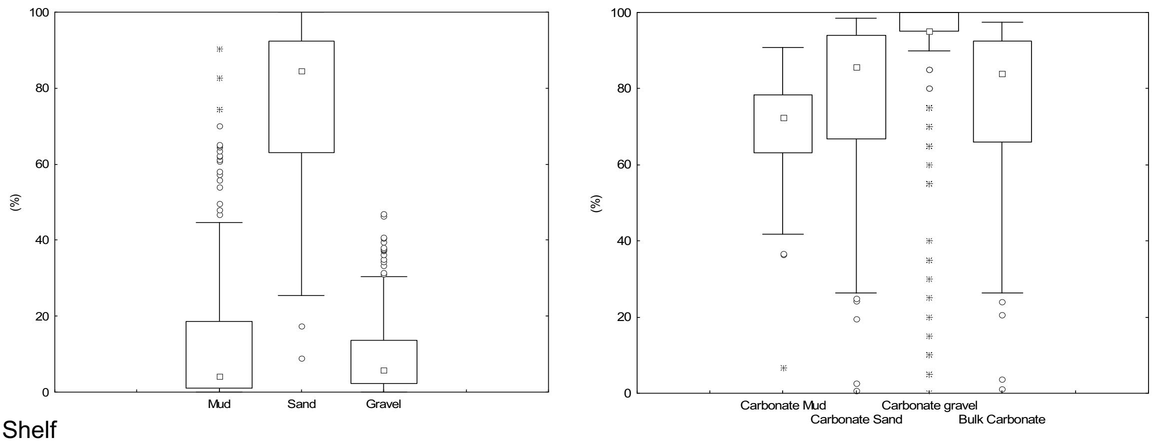
Samples cover 4 of the 10 geomorphic features represented in this bioregion (Fig. 8.5; Table 8.3). Bank/shoals and tidal sandwaves/sand banks occur in shallow water and are covered by 8 and 17 samples, respectively, which is proportional to their area, giving a sample density of >1:50 km for both features. Samples only occur on the tidal sand waves/sand banks in the northern Spencer Gulf, with tidal sandwaves/sand banks off Kangaroo Island covered by no samples.

8.1.1.3. Sedimentology

Sand is the dominant sediment type across the entire bioregion, with 169 of the 230 samples (75%) containing >60% sand (Fig. 8.6). Mud and gravel generally comprise <20% by weight. Areas comprising up to 90% mud and 50% gravel occur in the Spencer and St Vincent Gulfs.

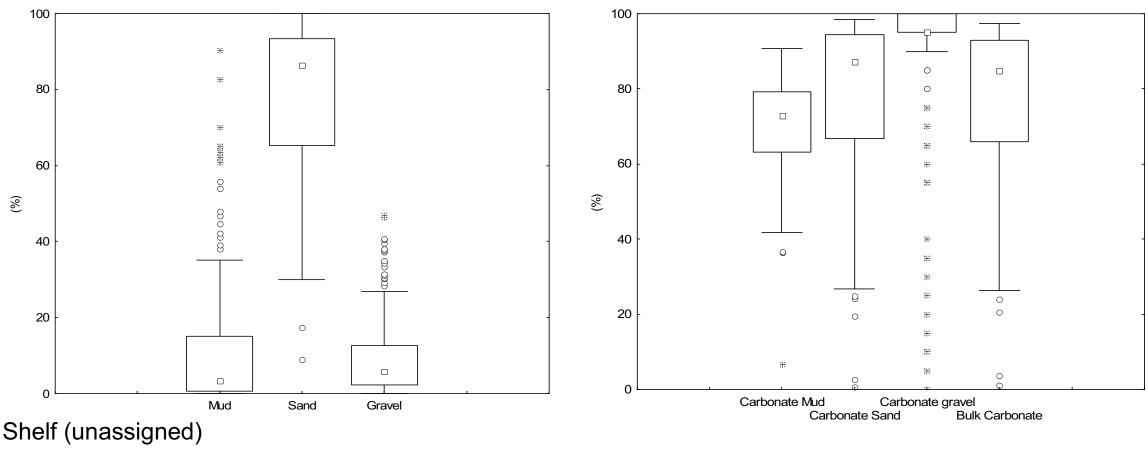
Mud content is relatively high on the tidal sandwave/sand banks in the Northern Spencer Gulf reaching >20% in 12 out of 17 samples. The highest mud contents (>60%) occur in 1 sample located on the outer shelf and in 2 samples from the northern Spencer Gulf. Muddy sediments occur in the St Vincent Gulf, although surrounding sites have relatively low mud contents indicating that areas of muddy substrate have limited spatial extent.

Sediments in bank/shoals comprise between 75 and 100% sand, with the sand content for these features varying between 30 and 95% carbonate (Fig. 8.8). Sand content was significantly lower in tidal sandwave/sand banks than other geomorphic features, varying between 25 and 95% (mean 55%) (Fig. 8.9). Carbonate content of sediments was relatively high for all fractions, with bank/shoals and tidal sandwave/ sand banks comprising >90% carbonate gravel. Gravels attain >90% carbonate across most of the shelf area, although terrigenous gravels are present locally in St Vincent Gulf.



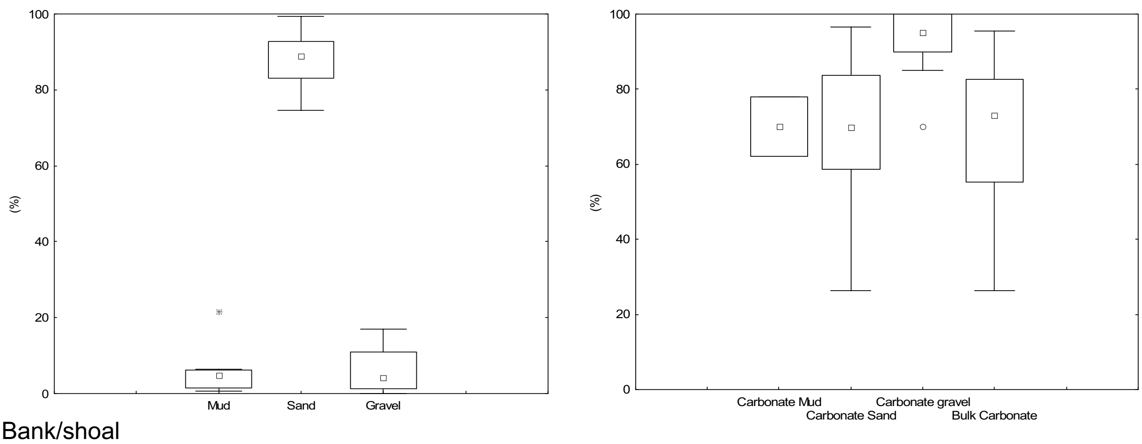
Shelf

Figure 8.6. Box and whisker plots showing the distribution of sediment properties for shelf of the Spencer Gulf IMCRA Province.



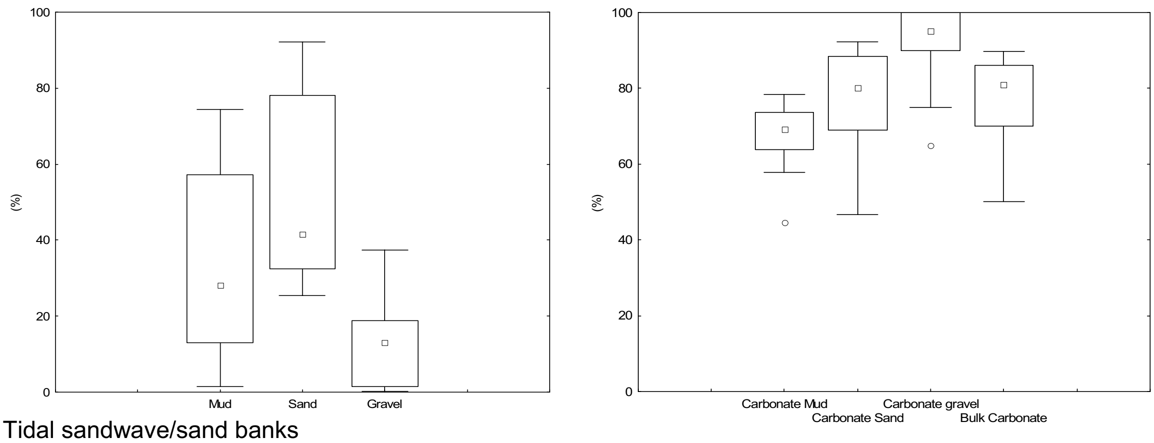
Shelf (unassigned)

Figure 8.7. Box and whisker plots showing the distribution of sediment properties for the shelf where no geomorphic features have been identified for the Spencer Gulf IMCRA Province.



Bank/shoal

Figure 8.8. Box and whisker plots showing the distribution of sediment properties for bank/shoal features in the Spencer Gulf IMCRA Province.



Tidal sandwave/sand banks

Figure 8.9. Box and whisker plots showing the distribution of sediment properties for tidal sandwave/sand bank features in the Spencer Gulf IMCRA Province.

8.1.2. South West IMCRA Transition

8.1.2.1 Introduction

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 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. 8.10), and 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. 8.11).

Eight geomorphic features are represented in the South West IMCRA Transition (Table 8.4). 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 are rare in the cooler water types found in the SWPR.

8.1.2.2 Sample Coverage

The South West IMCRA Transition contains 38 samples (Table 8.6). 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 (Figs. 8.12 & 8.13).

Although samples are distributed evenly across the bioregion, many geomorphic

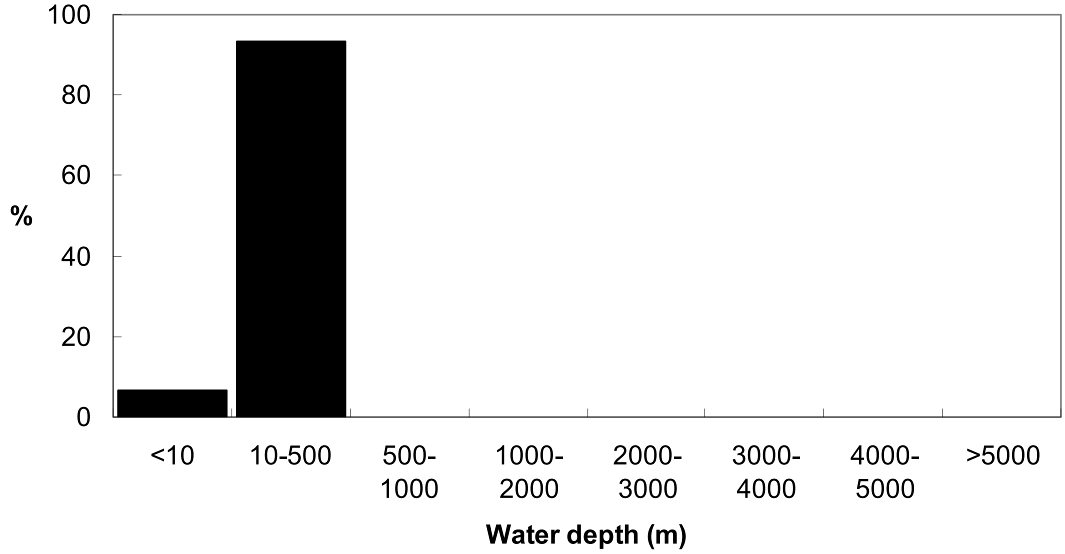


Figure 8.10. Graph showing the distribution of water depth for the South West IMCRA Transition. Note that all of the seabed is in water shallower than 500 m. A significant area (>1,800 km^2) of this province is located in water shallower than 10 m and is not included in the analyses. This is depth frequency distribution is similar to that found in the Spencer Gulf IMCRA Province and South West IMCRA Province.

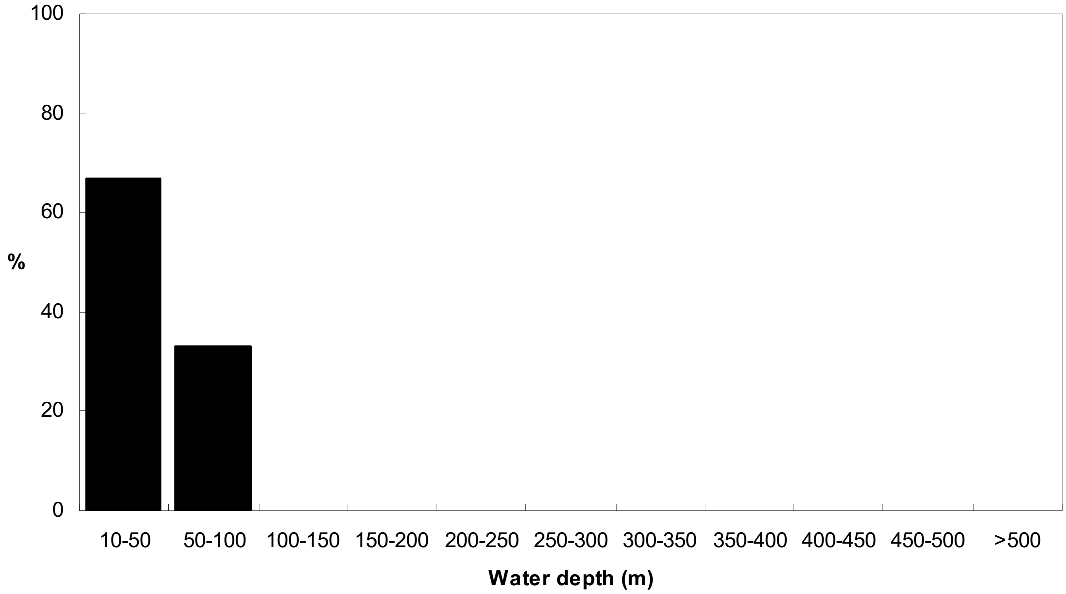


Figure 8.11. Graph showing the distribution of water depth for the shelf in the South West IMCRA Transition.

features cover relatively small areas and contain few data (Fig. 8.14). Bank/shoals achieve an average sample density of 1 sample per 400 km^2 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 km^2) but poor coverage of polygons with data covering only two of the seven that occur in the bioregion. Owing to the close proximity and similar bathymetry, all seven of these geomorphic features are likely to contain similar environments. Reefs contain no data.

Table 8.4. Details of the geomorphology of the South West IMCRA Transition.

Feature	Total number of features	% 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	30	99.74	8.08	1.37
Slope	4	0.26	0.01	<0.01
Geomorphic Feature				
Shelf (unassigned)	1	91.61	8.10	2.0
Slope (unassigned)	3	<0.01	<0.01	<0.01
Bank/shoals	11	1.62	23.86	0.87
Deep/hole/valley	7	2.06	16.58	0.34
Reef	5	3.39	63.80	1.97
Pinnacle	5	0.15	5.83	0.80
Apron/fan	1	0.90	0.08	<0.01
Terrace	1	0.26	0.04	0.01
Total	38			

Table 8.5. 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 8.6. Sample coverage by geomorphic provinces and features for the South West IMCRA Transition.

Feature	No. of Samples	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Province			
Shelf	38	4/30	~1:700
Geomorphic Feature			
Shelf (unassigned)	35	1/1	~1:700
Bank/shoal	1	1/11	~1:400
Deep/hole/valley	2	2/7	~1:300

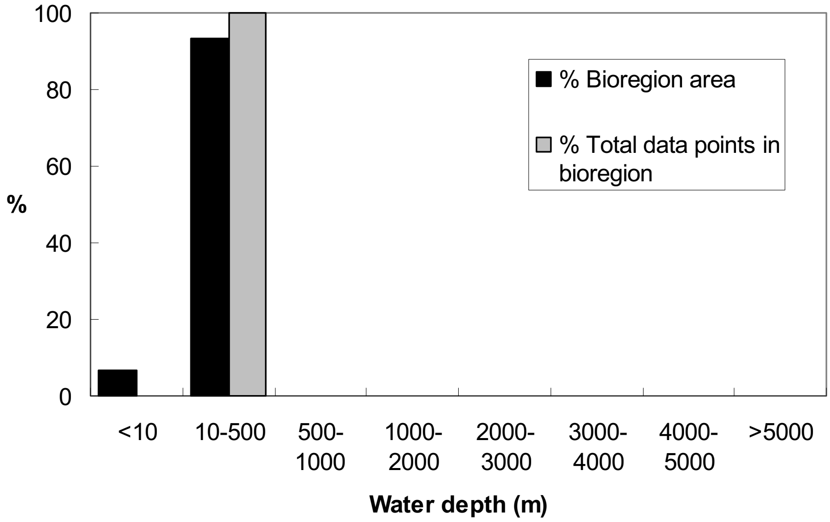


Figure 8.12. Graph of sample coverage distributed by water depth in the South West IMCRA Transition.

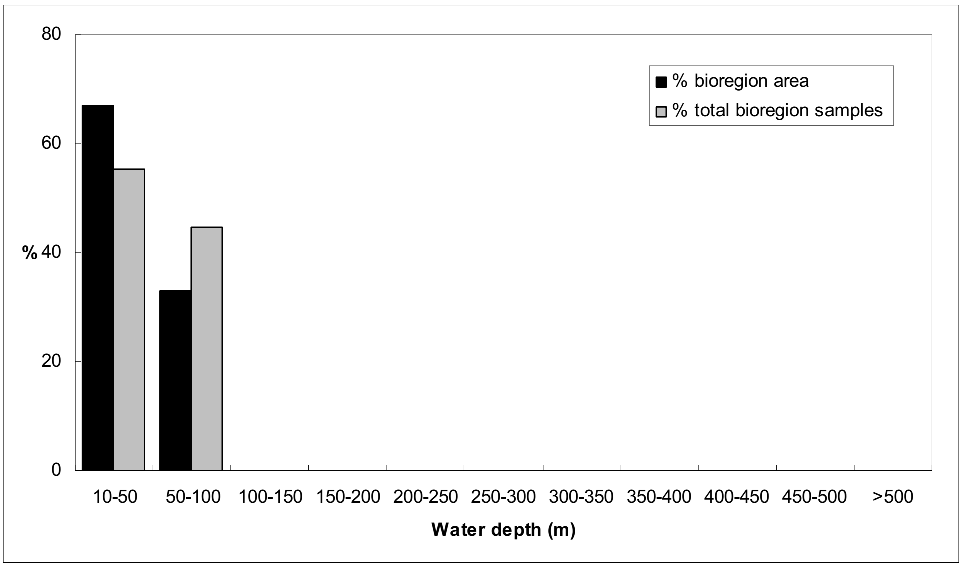


Figure 8.13. Graph of sample coverage distributed by water depth on the shelf in the South West IMCRA Transition.

8.1.2.3. Sedimentology

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. These cover almost the same area and therefore the results for each are almost identical (Figs. 8.15 & 8.16).

Sediments in this bioregion are dominated by sand (>75% in 33 of 38 samples) with <15% gravel in 32 of 38 samples (Fig. 8.15). Mud is generally absent or present 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.

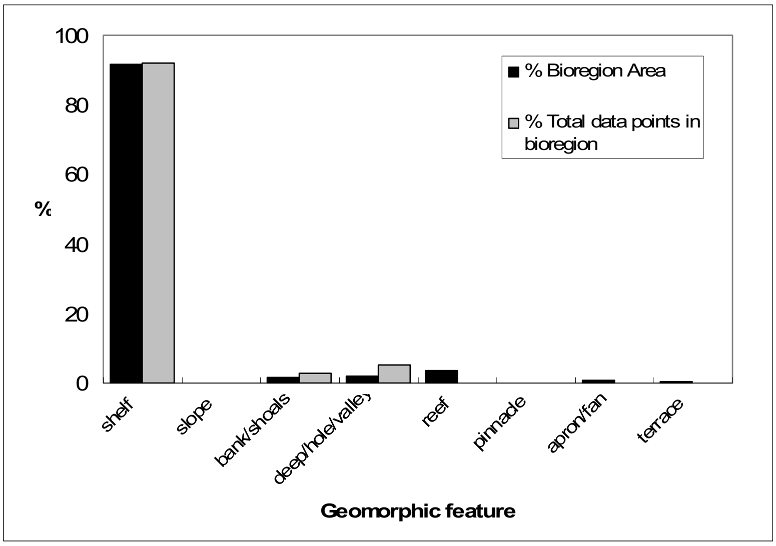
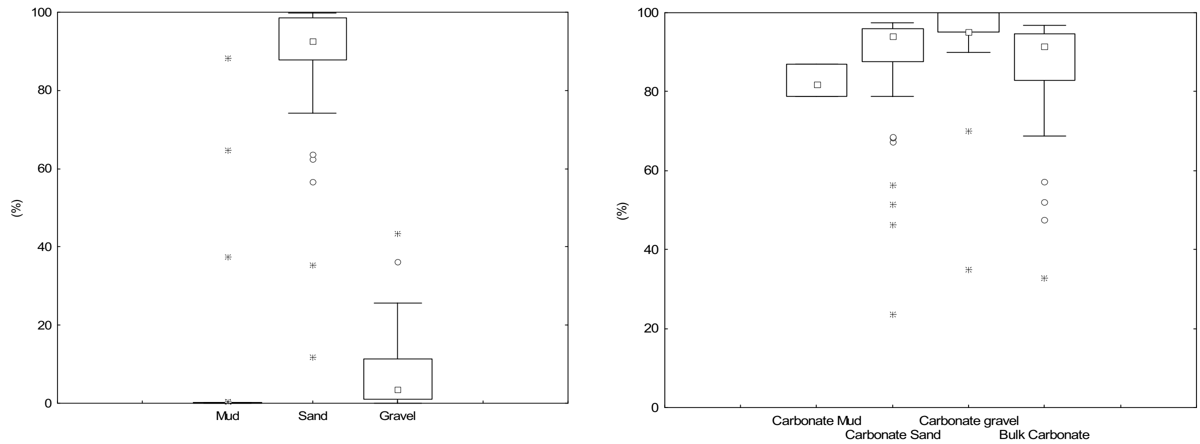
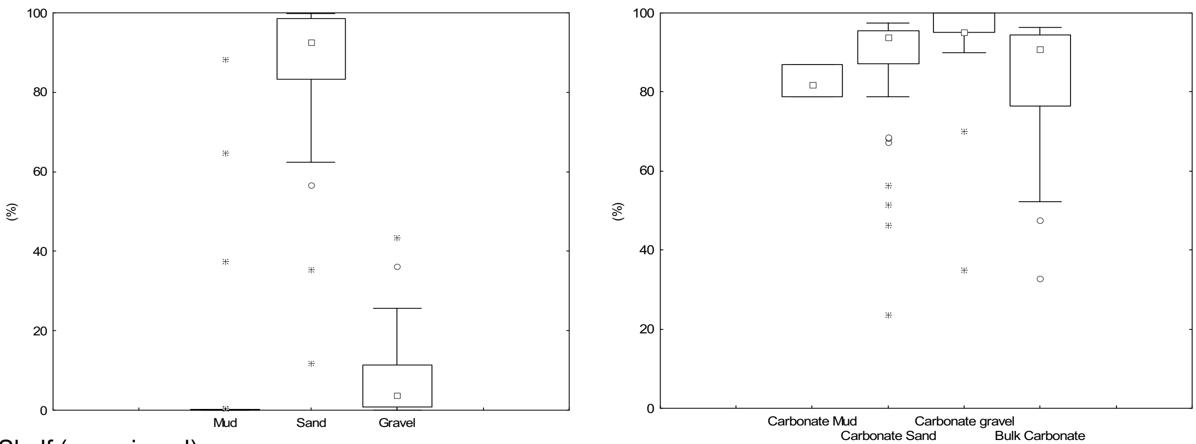


Figure 8.14. Graph of sample coverage distributed by geomorphic features in the South West IMCRA Transition.



Shelf

Figure 8.15. Box and whisker plots showing the distribution of sediment properties for the shelf of the South West IMCRA Transition.



Shelf (unassigned)

Figure 8.16. Box and whisker plots showing the distribution of sediment properties for the shelf where no geomorphic features have been identified for the South West IMCRA Transition.

8.1.3. South West IMCRA Province

8.1.3.1 Introduction

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 South Western IMCRA Province 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. 4.3). 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. 8.17). Water depths across 60% of this area are 50-100 m, with 35% of the area in 10-50 m water depth (Fig. 8.18).

A total of 7 geomorphic features occur in this bioregion (Table 8.3.1). 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 8.7), 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 8.8). 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

8.1.3.2 Sample Coverage

The SWP IMCRA contains 296 samples (Table 8.9). Approximately 10% of the samples occur in water of <10 m and have been excluded from the analysis (Figs. 8.19 & 8.20). More than 85% of the remaining data points (262) lie within the shelf geomorphic feature (average data density=~1:250 km²). Although by area, the data achieves better coverage for banks/shoals (average density=1:30 km²) and deep/holes/valleys (average density=1:100 km²) (Fig. 8.21; Table 8.9).

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. 4.5). 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.

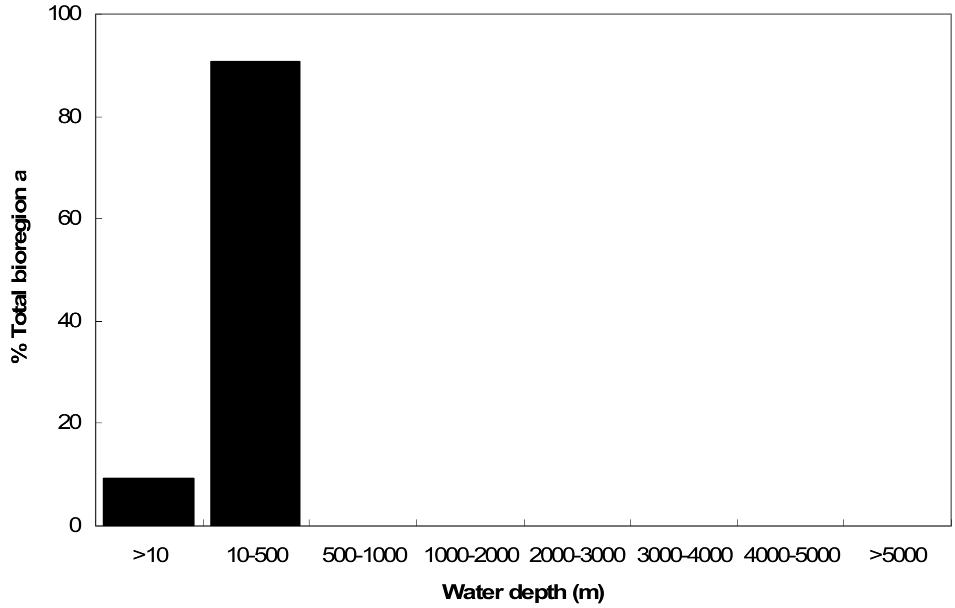


Figure 8.17. Graph showing the distribution of water depth for the South West IMCRA Province. Note that >99% of the seabed is in water depths shallower than 500 m. A significant area of this province is in water shallower than 10 m and is not included in the analyses. This is depth frequency distribution is similar to that found in the Spencer Gulf IMCRA Province.

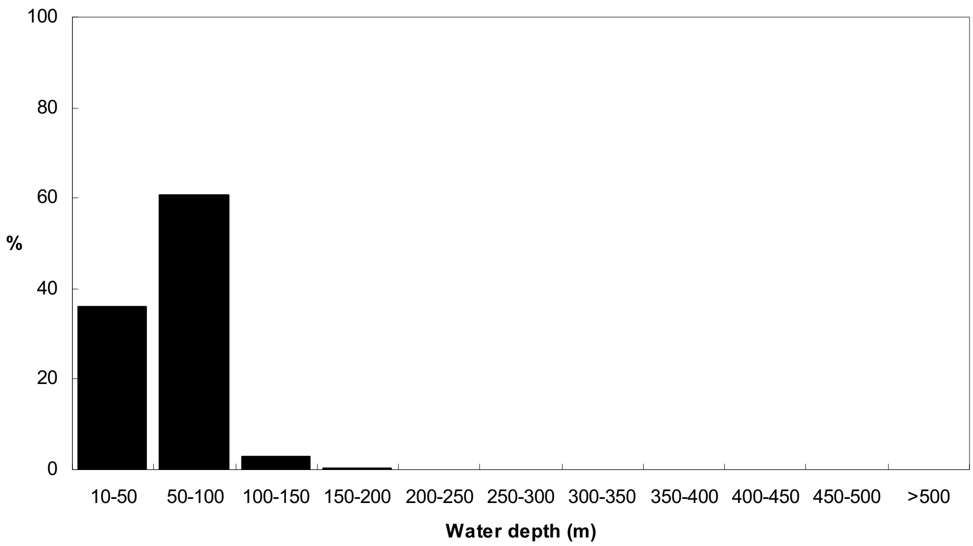


Figure 8.18. Graph showing the distribution of water depth for the shelf of the South West IMCRA Province.

8.1.3.3 Sedimentology

Sample coverage is adequate to assess sedimentology for shelf, bank/shoals and deep/hole/valley features (Figs. 8.22-8.25).

Sediment composition varies significantly across the bioregion. Sand dominates with 198 of 262 samples containing over 50% sand (Fig. 8.22). Sand is most abundant in shallower water on the inner shelf. Gravel is more common in sediments than mud with 120 of 262 samples containing >5% gravel, and 78 samples containing >5% mud.

Table 8.7. Details of the geomorphology of the South West IMCRA Province.

Feature	Total number of features	% 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	50	99.82	10.64	-
Slope	3	<0.01	<0.01	-
Geomorphic Feature				
Shelf (unassigned)	8	96.77	19.28	4.75
Slope (unassigned)	2	<0.01	<0.01	<0.01
Bank/shoal	8	1.37	45.34	1.66
Deep/hole/valley	1	0.95	17.23	0.35
Reef	12	0.78	33.22	1.03
Pinnacle	21	0.13	10.95	1.5
Terrace	1	<0.01	<0.01	<0.01
Total	53			

Table 8.8. 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 8.9. 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	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Province			
Shelf	296	3/50	~1:200
Geomorphic Feature			
Shelf (unassigned)	262	1/8	~1:250
Bank/shoal	28	1/8	~1:30
Deep/hole/valley	6	1/1	~1:100

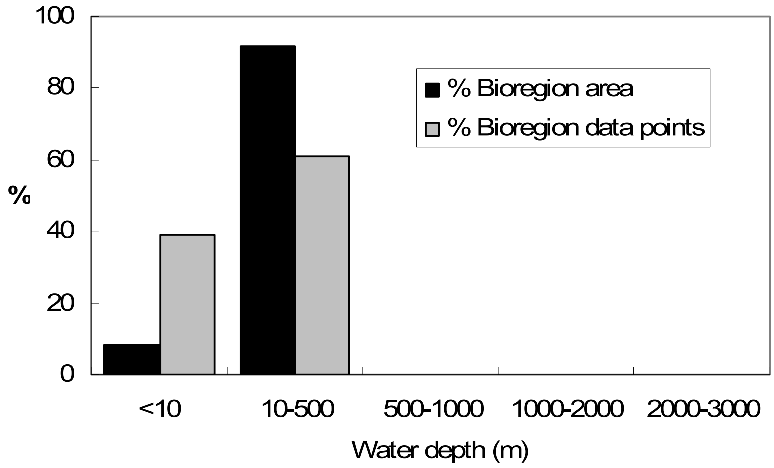


Figure 8.19. Graph of sample coverage distributed by water depth in the South West IMCRA Province. Note that a significant number of samples fall in the area with water depth <10 m.

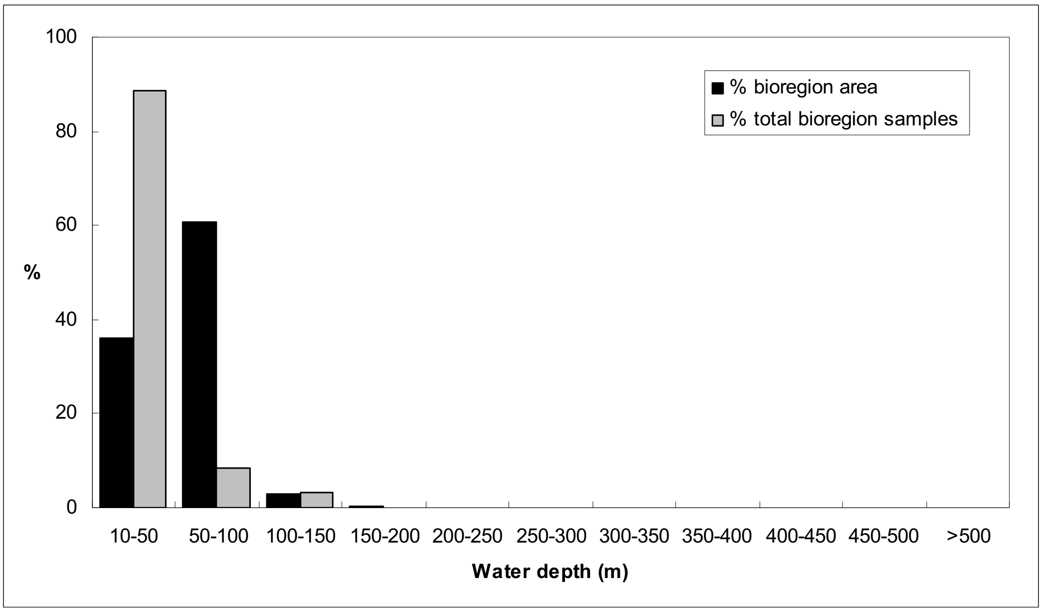


Figure 8.20. Graph of sample coverage distributed by water depth on the shelf in the South West IMCRA Province.

Areas of very coarse sediment (up to 100% gravel) and very fine sediment (up to 90% mud) occur locally (Fig. 8.22). Muddy sediments occur on the outer shelf near the shelf break. Gravels, with a non-carbonate component of up to 90%, occur in water depths of <50 m on the inner shelf north of Casurina Point. Carbonate gravel occurs at one location on the inner Recherche Shelf near Esperance.

In the South West IMCRA Province, the carbonate content of the sediment is also highly variable (Fig. 8.22). Carbonate appears to be zoned with water depth with samples in proximity to the coast containing a non-carbonate component as great as 85% in the sand fraction and 50% in gravel fraction. Sediments with the lowest bulk carbonate content (<40%) occur in Geographe Bay to the north of Cape Naturaliste, and on the inner shelf north of Casurina Point. Samples containing carbonate 40-60% occur along the inner shelf between

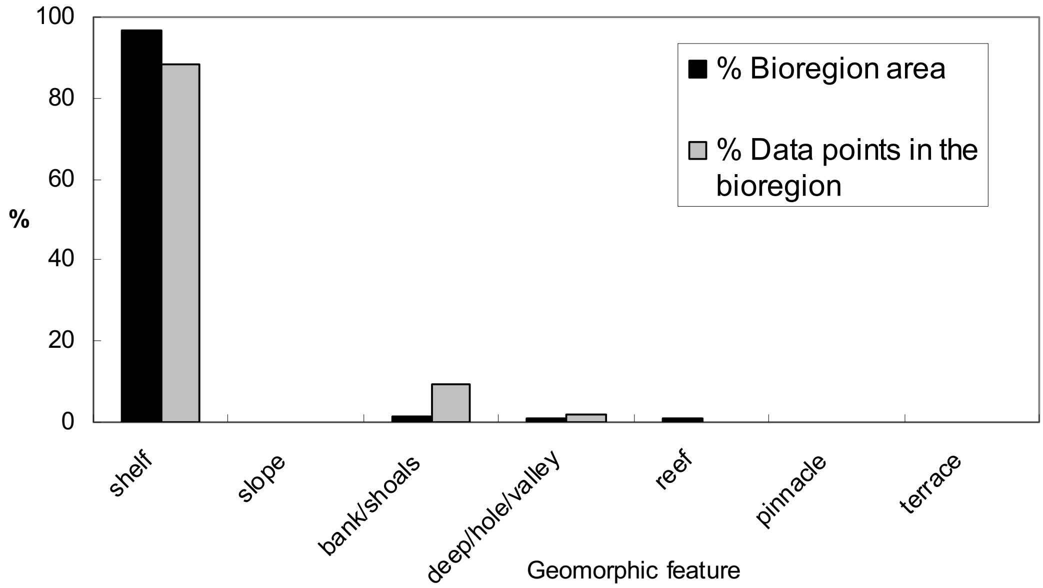
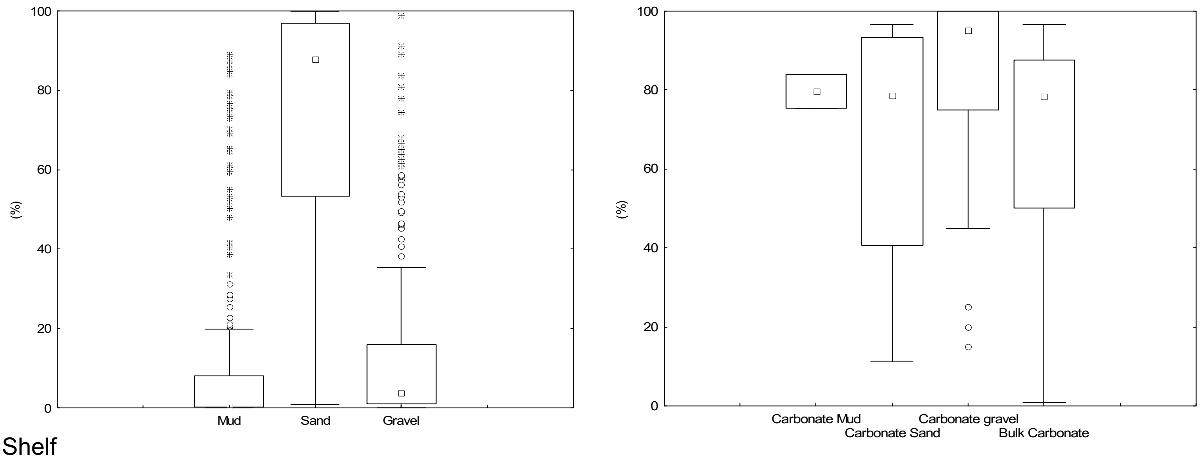
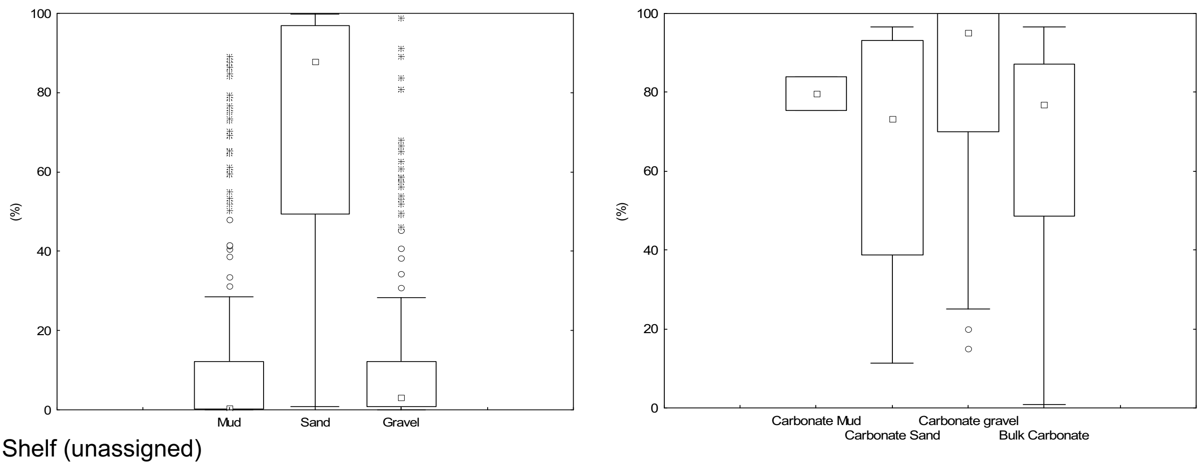


Figure 8.21. Graph of sample coverage distributed by geomorphic features in the South West IMCRA Province.



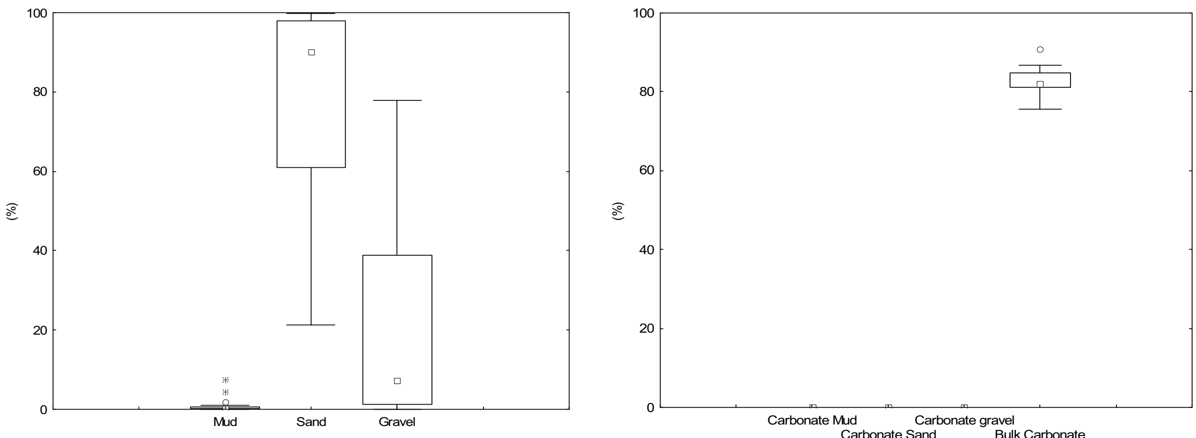
Shelf

Figure 8.22. Box and whisker plots showing the distribution of sediment properties for shelf of the South West IMCRA Province.



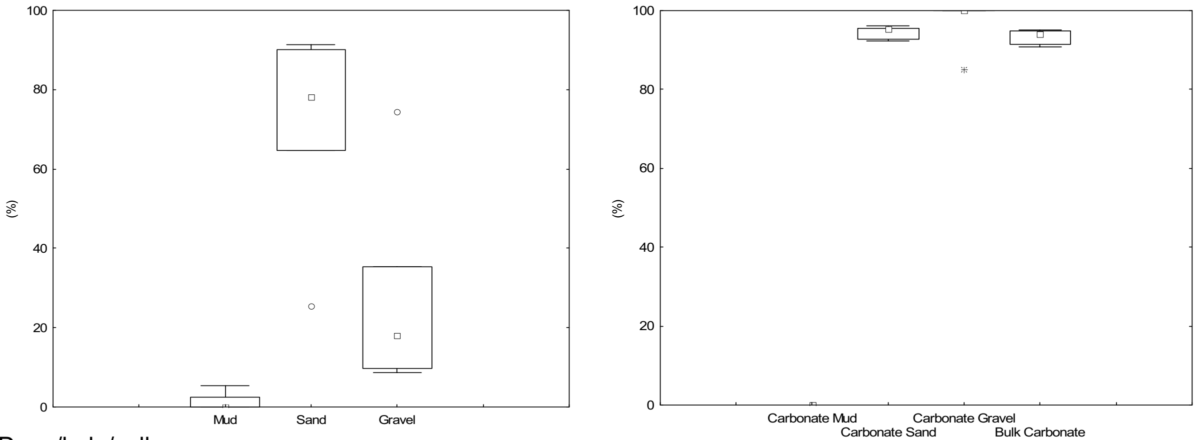
Shelf (unassigned)

Figure 8.23. Box and whisker plots showing the distribution of sediment properties for the shelf where no geomorphic features have been identified for the South West IMCRA Province.



Bank/shoals

Figure 8.24. Box and whisker plots showing the distribution of sediment properties for bank/shoal features in the South West IMCRA Province.



Deep/hole/valley

Figure 8.25. Box and whisker plots showing the distribution of sediment properties for deep/hole/valley features in the South West IMCRA Province.

Cape Leeuwin and Albany. Sediments on the middle and outer shelf contain mainly carbonate grains (60-100%) except off Albany where non carbonate grains form around 50% of sediment.

Samples from banks/shoals were dominated by sand and gravel, and contained little or no mud (Fig. 8.24). A total of 21 of the 28 samples contained >60% sand. The gravel component attains >35% in 8 of the samples. Deep/hole/valleys are also dominated by sand and gravel, with relatively minor mud content (Fig. 8.25). 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%.

8.1.4. Great Australian Bight IMCRA Transition

8.1.4.1 Introduction

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

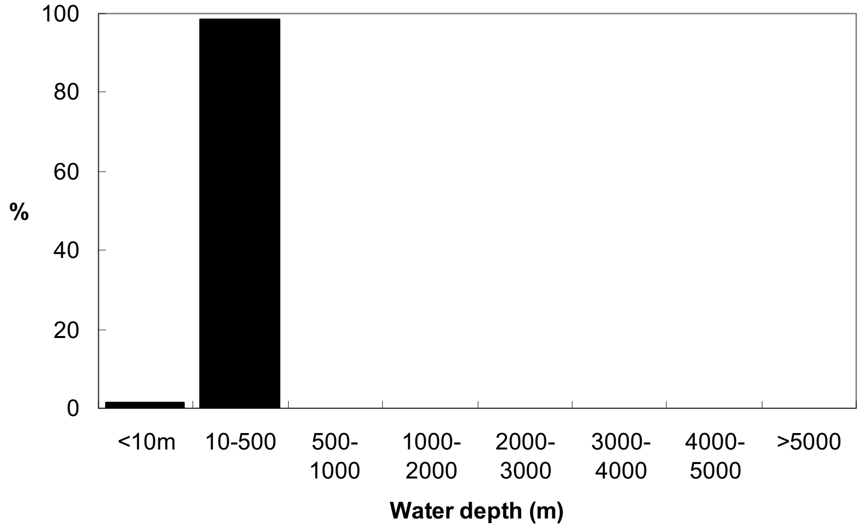


Figure 8.26. Graph showing the distribution of water depth for the Great Australian Bight IMCRA Transition.

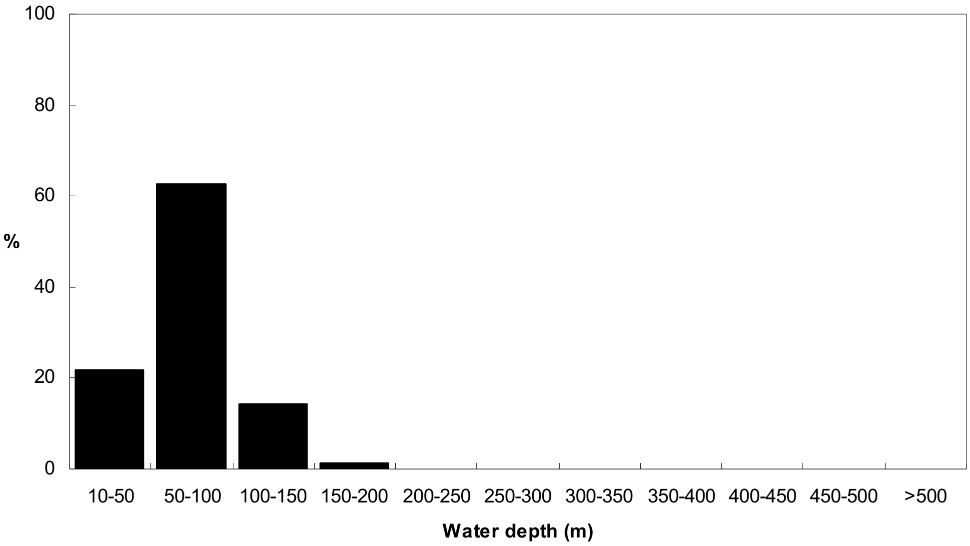


Figure 8.27. Graph showing the distribution of water depth on the shelf for the Great Australian Bight IMCRA Transition.

Table 8.10. 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

Table 8.11. Details of the geomorphology of the Great Australian Bight IMCRA Transition.

Feature	Total number of features	% 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	12	100	43.29	7.33
Slope	2	<0.01	<0.01	<0.01
Geomorphic Feature				
Shelf (unassigned)	3	85.31	40.30	9.93
Reef	8	0.01	1.25	0.04
Terrace	3	14.68	11.45	3.67
Total	14			

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 (Fig. 8.26; Table 8.10). A total of 2,000 km^2 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 (Fig. 8.27).

A total of 123,150 km^2 (85%) of the shelf area has no other geomorphic features identified within it (Table 8.11). The Eyre Terrace on the inner shelf in the centre of the GAB covers most of the remaining 21,400 km^2 (15%) of the bioregion. A very small area of reefs covering <15 km^2 (<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.

8.1.4.2 Sample Coverage

The Great Australian Bight IMCRA Transition contains 141 samples (Table 8.12). 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 (Figs. 8.28 & 8.29).

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 km^2 for the shelf and 1:2,100 km^2 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. 8.30).

Table 8.12. Sample coverage by geomorphic provinces and features for the Great Australian Bight IMCRA Transition.

Feature	No. of Samples	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Province			
Shelf	141	2/12	~1:1,000
Geomorphic Feature			
Shelf (unassigned)	131	1/3	~1:1,000
Terrace	10	1/3	~1:2,100

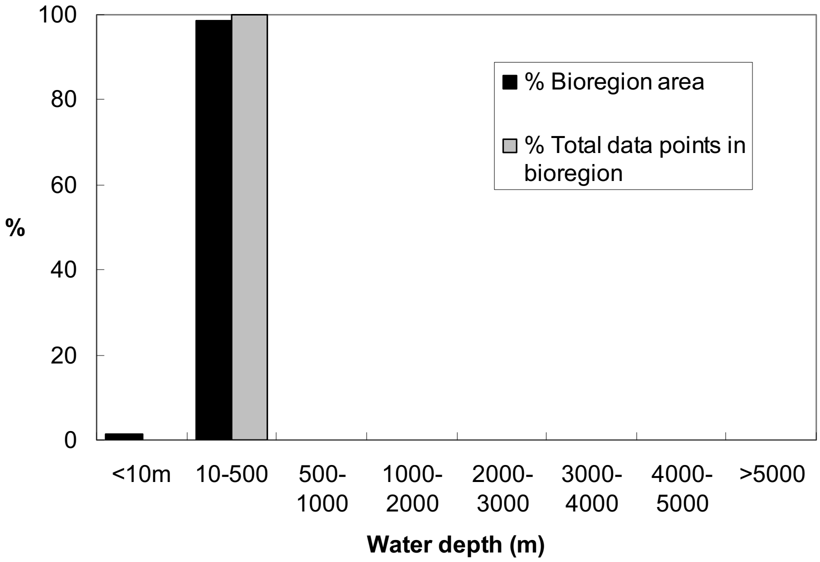


Figure 8.28. Graph of sample coverage distributed by water depth in the Great Australian Bight IMCRA Transition.

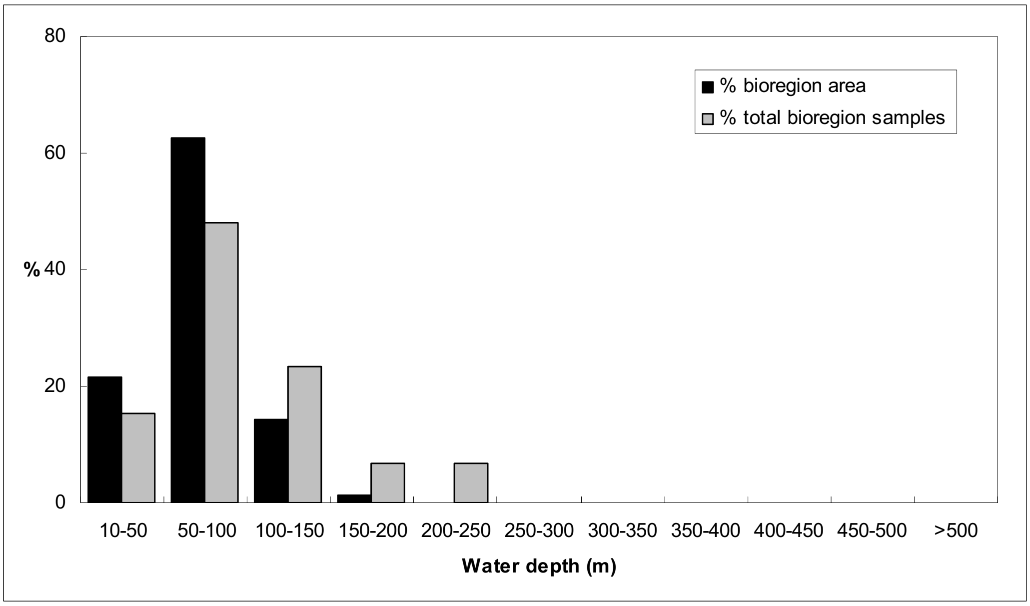


Figure 8.29. Graph of sample coverage distributed by water depth on the shelf in the Great Australian Bight IMCRA Transition.

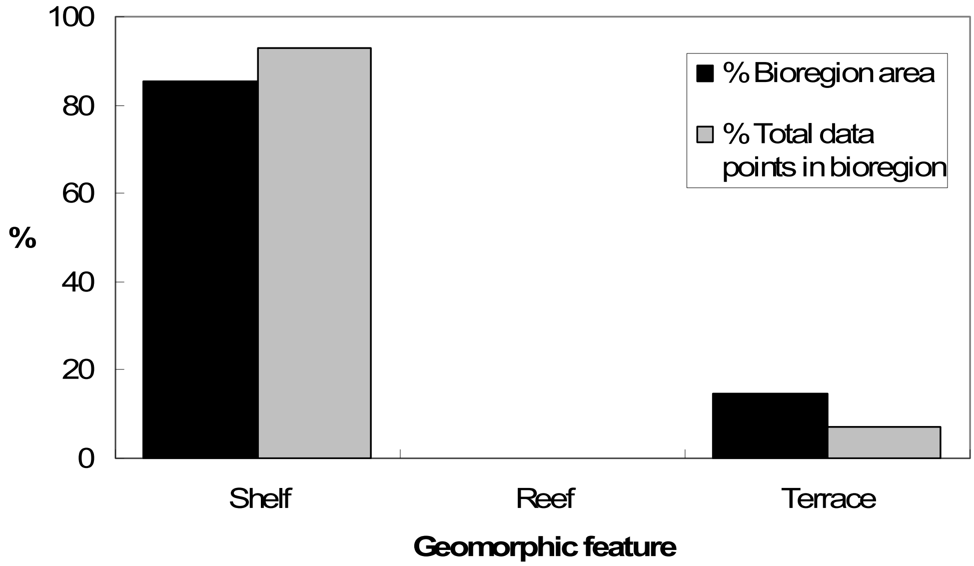


Figure 8.30. Graph of sample coverage distributed by geomorphic features in the Great Australian Bight IMCRA Transition.

8.1.4.3 Sedimentology

Sediments for the entire bioregion and shelf show similar characteristics (Fig. 8.31). 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.

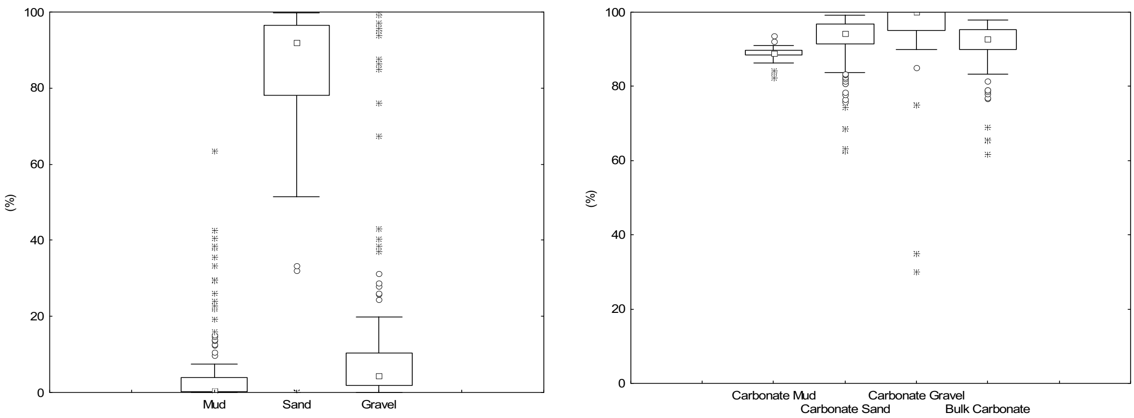
Sample coverage was adequate to assess sedimentology within the shelf and terrace geomorphic features (Figs. 8.32 & 8.33).

Carbonate content of all fractions is consistently >80% (Fig. 8.31). The non-carbonate fraction attains 65% for gravels and 30% for sands at 8 locations on inner shelf. Seabed sediments on the terraces have similar textures and compositions to other areas of the shelf, although the carbonate content of the sediments, particularly sands, showed slightly greater variability. The non-carbonate component attains >20% in 3 of the 10 samples.

8.1.5. Southern Province

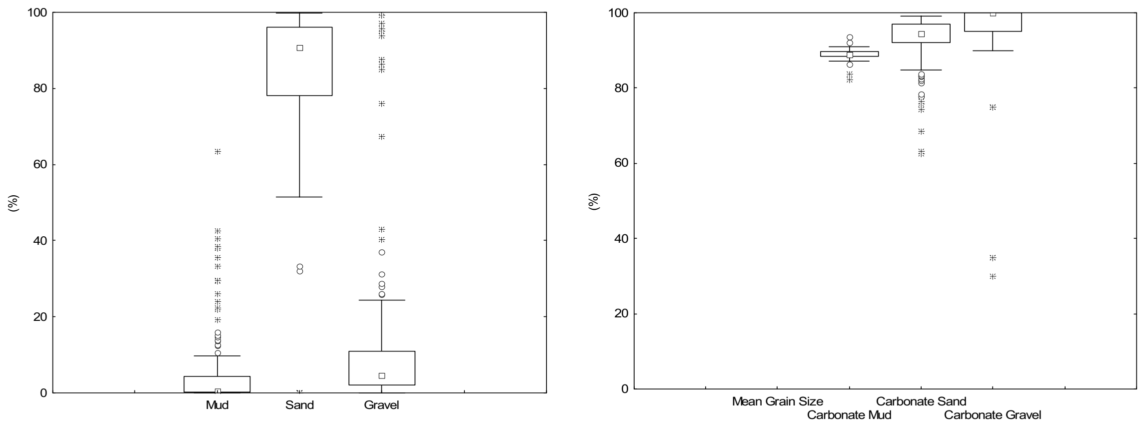
8.1.5.1. Introduction

The Southern Province covers a total area of 770,596 km^2 (Fig. 5.1), and all of this area except for 115,590 km^2 (15%) lies within 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 bounded to the north by the Spencer Gulf IMCRA



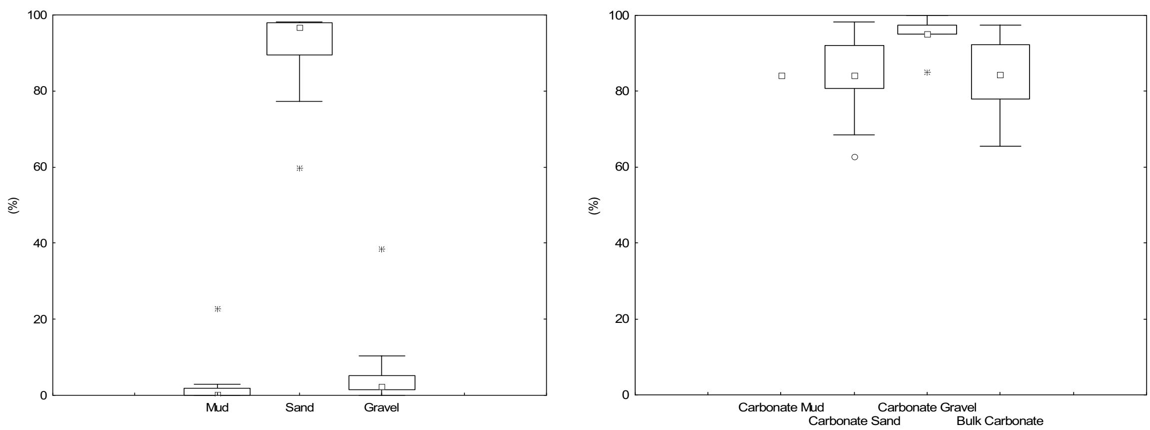
Shelf

Figure 8.31. Box and whisker plots showing the distribution of sediment properties for shelf of the Great Australian Bight IMCRA Transition.



Shelf (unassigned)

Figure 8.32. Box and whisker plots showing the distribution of sediment properties for the shelf where no geomorphic features have been identified for the Great Australian Bight IMCRA Transition.



Terrace

Figure 8.33. Box and whisker plots showing the distribution of sediment properties for bank/shoal features in the Great Australian Bight IMCRA Transition.

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 8.13). 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 8.14). 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 (Figs. 8.34 & 8.35).

A total of 11 geomorphic features occur in the Southern Province (Table 8.13). 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 a 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 8.13). 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 canyons head on 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 8.13). 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 (Fig 8.35). Trench/troughs in water depths greater than 5,000 m are rare across the SWPR and EEZ.

Table 8.13. Details of the geomorphology of the Southern Province.

Feature	Total number of features	% 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	10	<0.01	<0.01	<0.01
Slope	101	53.00	60.43	8.55
AP/DOF*	91	47.00	74.54	10.67
Geomorphic Feature				
Shelf (unassigned)	10	<0.01	<0.01	<0.01
Slope (unassigned)	19	30.49	58.72	14.53
AP/DOF* (unassigned)	3	30.63	65.88	8.14
Bank/shoal	2	<0.01	3.04	0.11
Deep/hole/valley	4	0.07	13.23	0.27
Trench/trough	2	0.24	14.86	0.90
Canyon	69	3.04	68.24	18.65
Knoll/abyssal-hills/hills/peak	11	10.19	99.90	56.30
Ridge	54	6.05	100	35.56
Pinnacle	26	0.06	55.33	7.60
Terrace	2	19.22	67.81	21.72
Total	202			

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

Table 8.14. 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

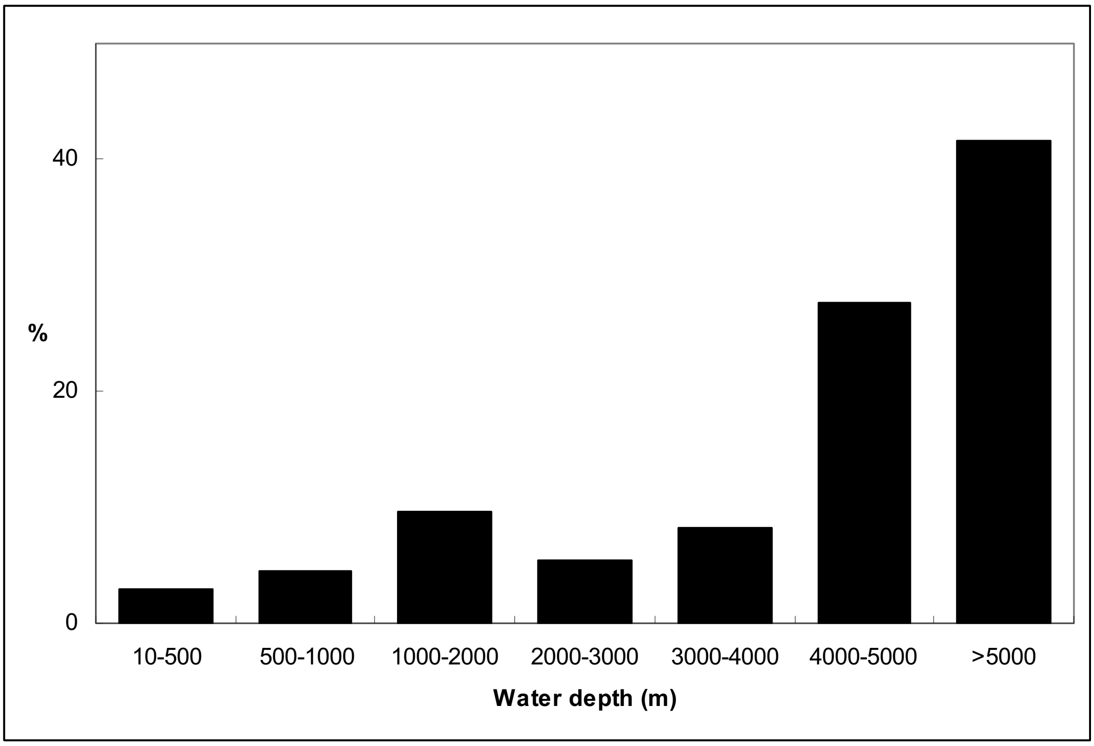


Figure 8.34. Graph showing the distribution of seabed depth for the Southern Province. Note the relatively large areas of seabed below 4,000 m (70%). This is depth frequency distribution is unique to this province.

8.1.5.2. Sample Coverage

The Southern Province contains a total of 279 samples (Fig. 8.36; Table 8.15). Of this total, 267 (96%) are located on the slope, corresponding to an average sample density of 1:1,300 km^2 (Fig. 8.37; Table 8.15). 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 (Fig. 8.38; Table 8.15). 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 ridges samples may not be representative of the range of sediments occurring in this feature within the Southern Province.

At total of 49 samples are contained within 19 canyons representing an average sample density of 1:400 km^2 for this feature (Fig. 8.38). 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.

8.1.5.3. Sedimentology

Samples achieve adequate coverage to assess sedimentology for the slope, abyssal plain/deep ocean floor, canyon, and terrace features (Figs. 8.39-8.45).

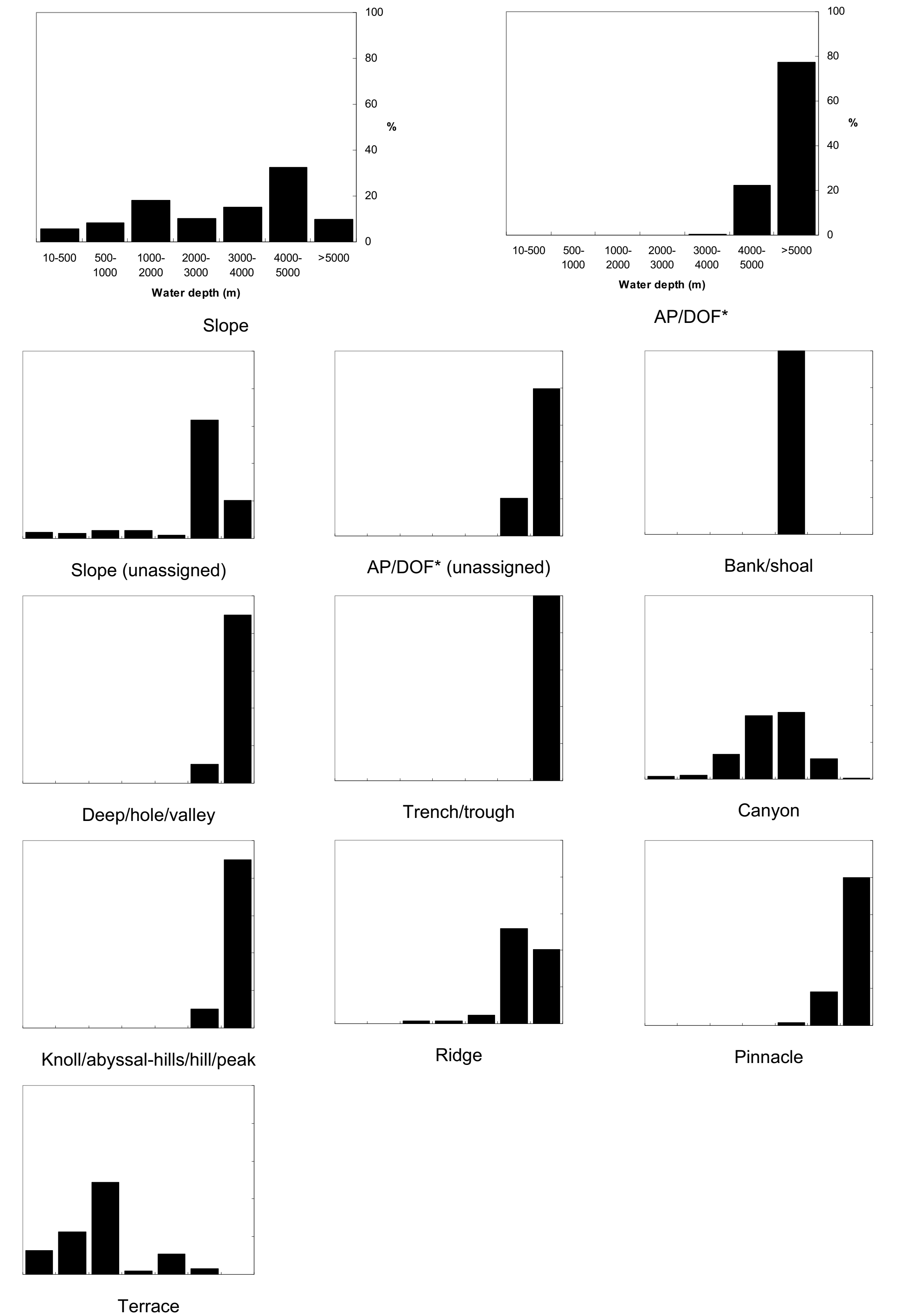


Figure 8.35. Frequency histograms showing the distribution of water depth for the geomorphic provinces and features in the Southern Province.

Table 8.15. Sample coverage by geomorphic provinces and features for the Southern Province.

Features	No. of Samples	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Provinces			
Slope	267	26/101	~1:1300
AP/DOF	12	3/91	~1:25,500
Geomorphic Features			
Slope (unassigned)	86	4/19	~1:2,500
AP/DOF* (unassigned)	10	2/3	~1:20,000
Canyon	49	19/69	~1:400
Knoll/abyssal-hills/hills//peak	2	1/11	~1:33,500
Ridge	2	2/54	~1:20,000
Terrace	130	1/2	~1:1,000

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

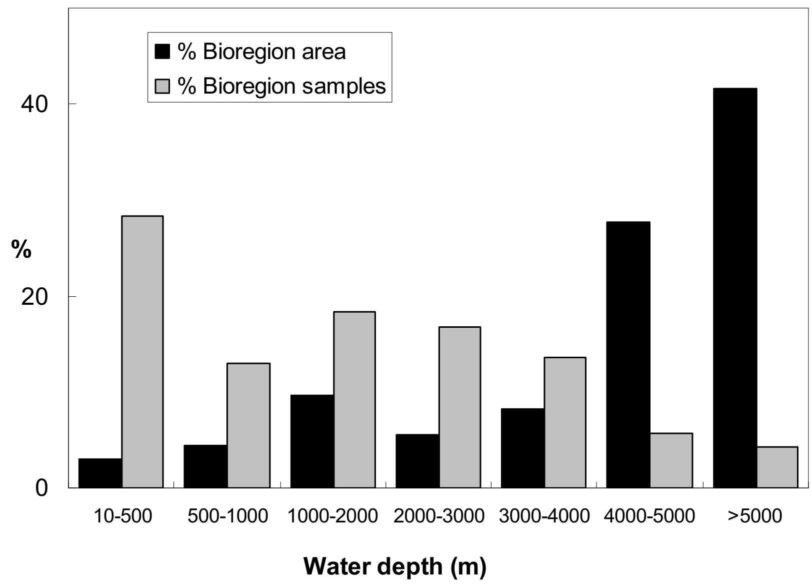


Figure 8.36. Graph of sample coverage distributed by water depth in the Southern Province. Note the inverse relationship between water depth area and number of samples expressed as a percentage. Samples occur in all bathymetric classes, although >40% of the samples occur in water depths of <500 m, and <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 between 0 and 100%, and with 163 of 259 samples containing >50% mud (Fig. 8.39). Sand is the next dominant size fraction, with ranges between 0 and 100% (mean 42%) with 90 samples containing >50% sand. Gravel is a minor component, with contents mainly <5%, although isolated samples in shallower water areas on the slope and terrace contain as much as 80% gravel.

Sediment on the slope is principally composed of sand (range 0-100%), with 98 of 248 samples containing >50% sand, and mud (range 0-100%), with 153 samples containing >50%

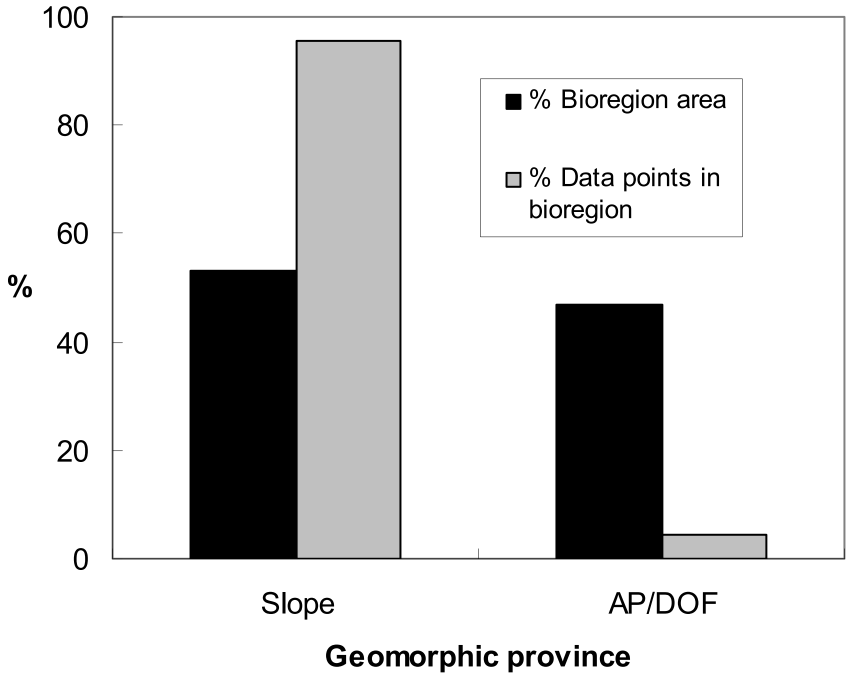


Figure 8.37. Graph of sample coverage distributed by geomorphic provinces in the Southern Province.

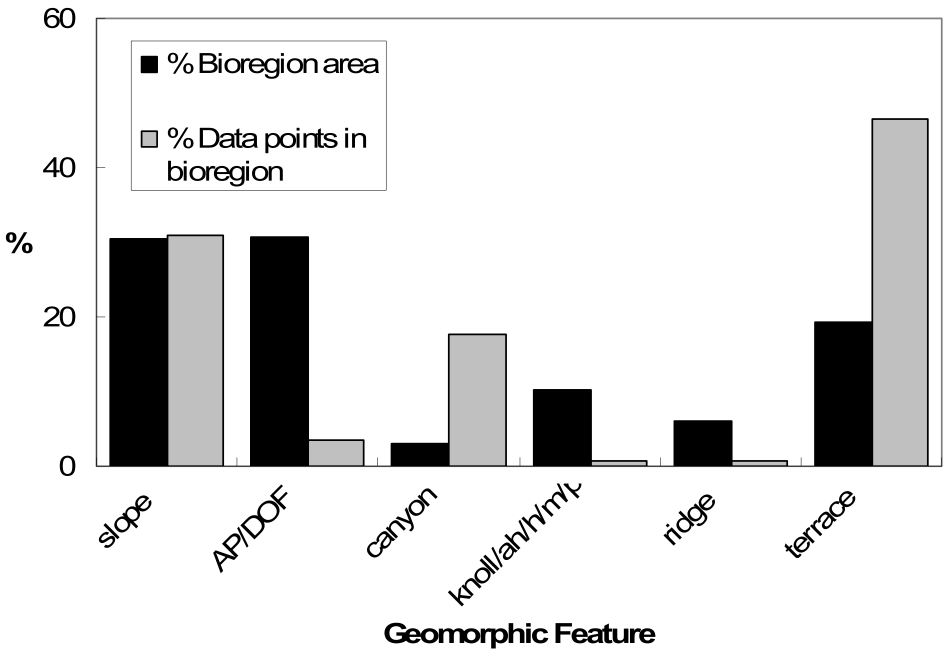
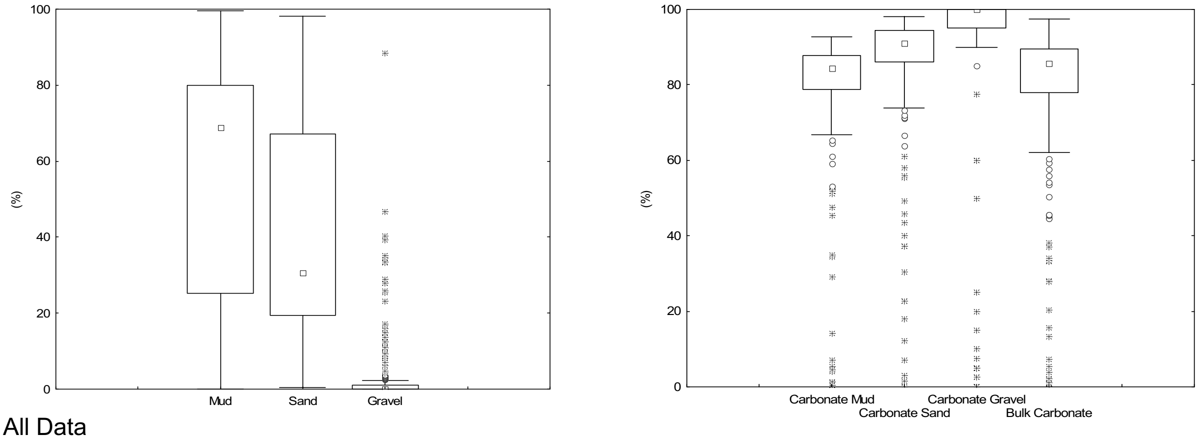


Figure 8.38. Graph of sample coverage distributed by geomorphic features in the Southern Province.

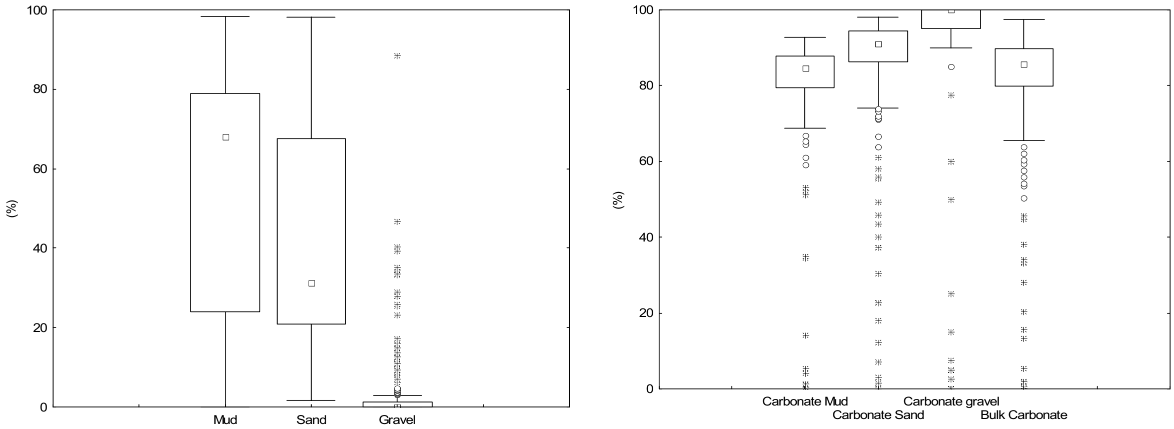
mud. Mud formed >90% of sediment in 6 of 11 samples recovered from the abyssal plain/deep ocean floor.

Bulk carbonate contents exceed 75% for a total of 203 of 256 samples in the Southern Province. Similar carbonate content occurred in all features except the Abyssal Plain/Deep Ocean Floor, where non carbonate component attained >90% in 6 of 12 samples.



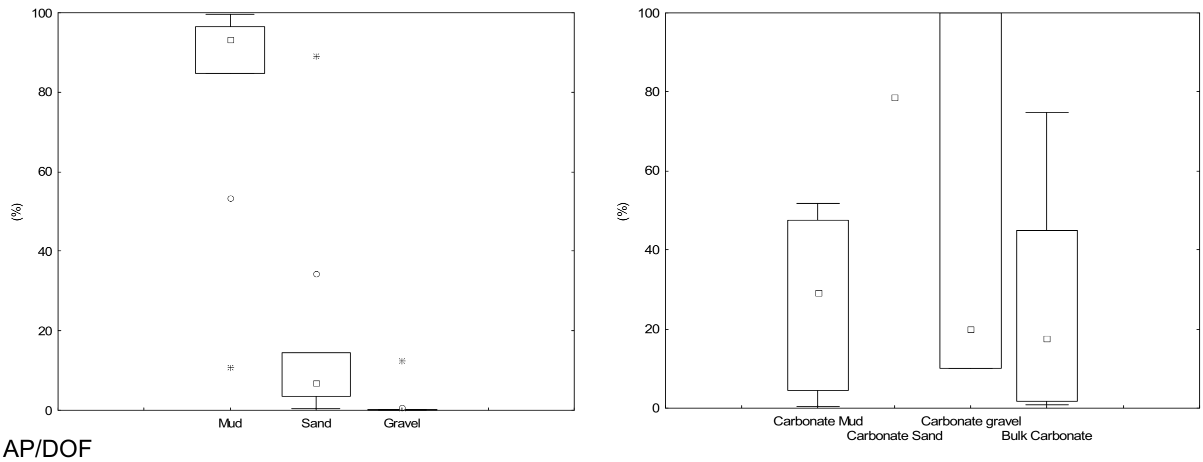
All Data

Figure 8.39. Box and whisker plots showing the distributions of sediment properties for the Southern Province.



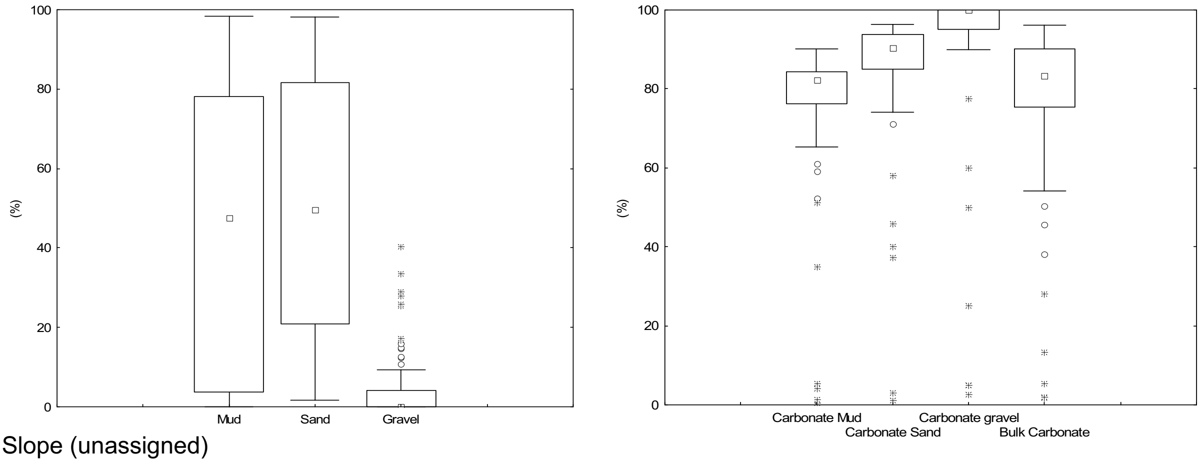
Slope

Figure 8.40. Box and whisker plots showing the distributions of sediment properties for samples recovered from the slope in the Southern Province.



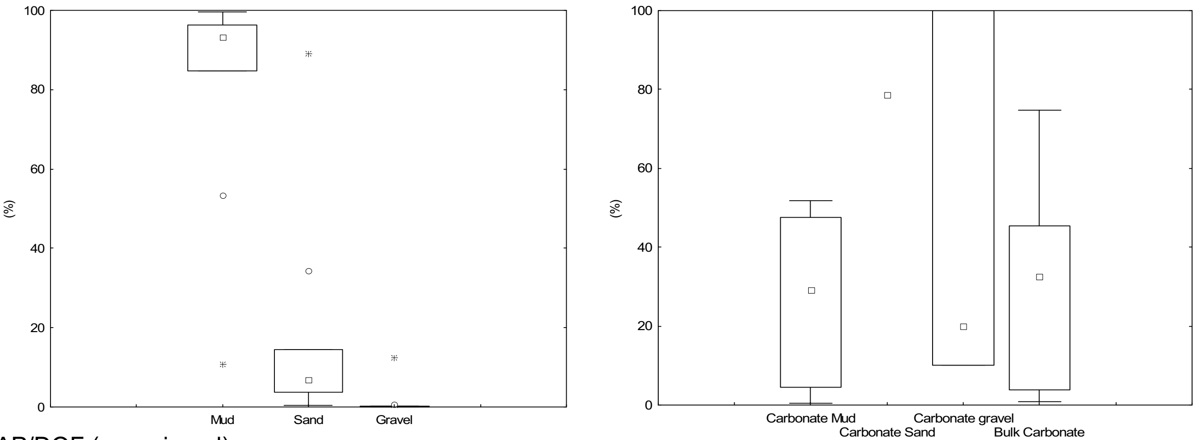
AP/DOF

Figure 8.41. Box and whisker plots showing distributions of sediment properties for the abyssal plain/deep ocean floor in the Southern Province.



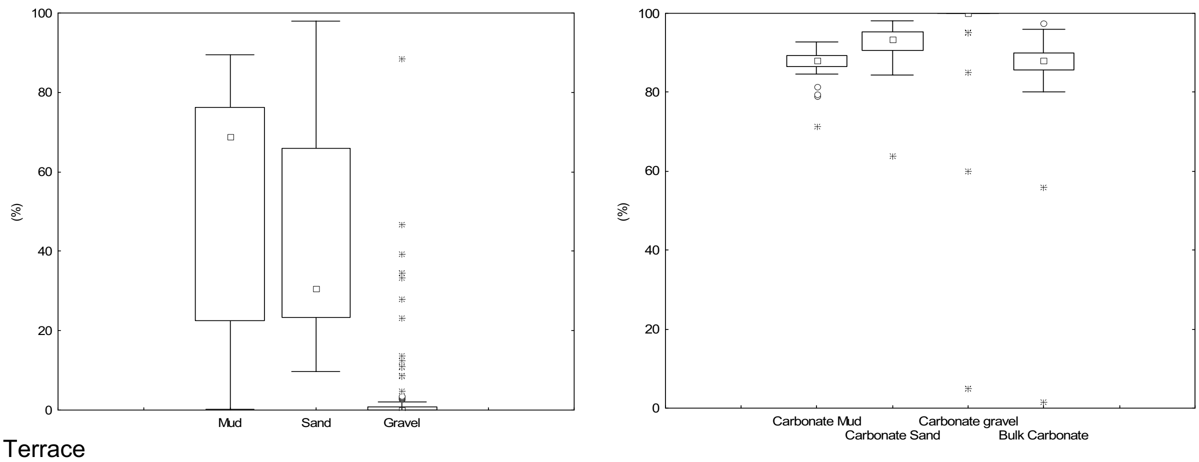
Slope (unassigned)

Figure 8.42. Box and whisker plots showing the distributions of sediment properties for regions of the slope in the Southern Province where no other geomorphic features have been identified.



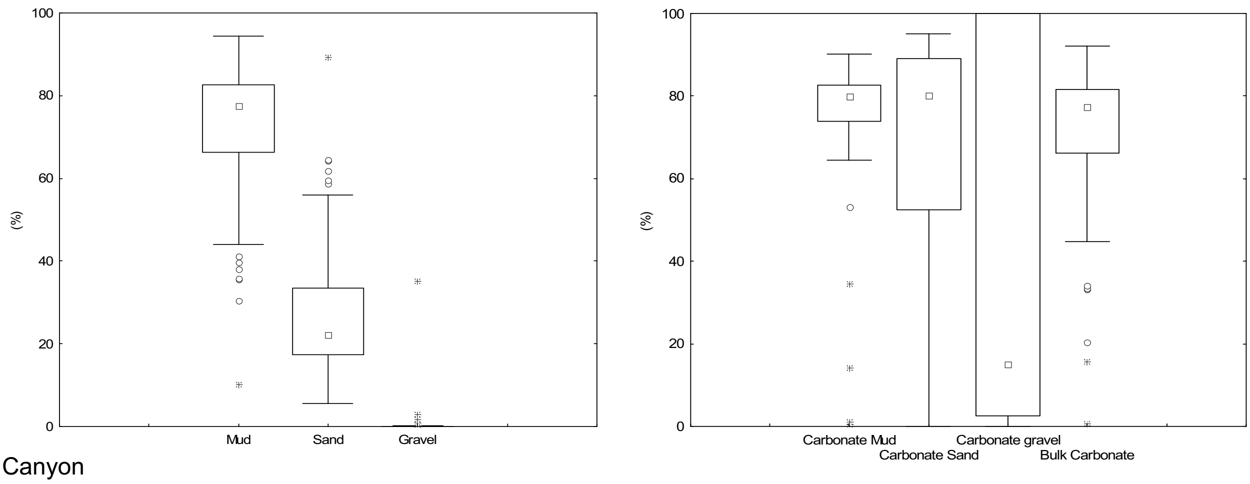
AP/DOF (unassigned)

Figure 8.43. Box and whisker plots showing the distributions of sediment properties for the abyssal plain/deep ocean floor in the Southern Province where no other geomorphic features have been identified.



Terrace

Figure 8.44. Box and whisker plots showing the distributions of sediment properties for terrace features in the Southern Province.



Canyon

Figure 8.45. Box and whisker plots showing the distributions of sediment properties for canyon features in the Southern Province.

Canyons are dominated by mud, with 31 of 49 samples comprising greater than 70% mud. Sand is the next most abundant size fraction with contents generally ranging between 10 and 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%.

8.1.6. South West Transition

8.1.6.1. Introduction

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 8.16). 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. 8.46; Table 8.17).

The slope contains nine types of geomorphic feature (Table 8.16). However, geomorphic features could not be identified over 53,000 km^2 (48%) of the total area. Two terraces run parallel to the shelf break on the upper slope in water depths of between 150 and 1,500 m (Fig. 8.47), 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.

8.1.6.2. Sample Coverage

The South West Transition contains 77 samples, with more than 80% of these clustered on

Table 8.16. Details of the geomorphology of the South West Transition.

Feature	Total number of features	% 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	1	<0.01	<0.01	<0.01
Slope	39	99.99	19.25	2.72
AP/DOF*	11	<0.01	<0.01	<0.01
Geomorphic Feature				
Shelf (unassigned)	1	<0.01	<0.01	<0.01
Slope (unassigned)	1	47.51	15.45	3.82
AP/DOF* (unassigned)	11	<0.01	<0.01	<0.01
bank/shoals	3	0.15	8.73	0.32
Trench/trough	1	8.07	85.14	5.14
Canyon	14	1.70	6.43	1.76
Pinnacle	17	0.10	15.22	2.09
Plateau	1	26.97	100	1.99
Terrace	2	15.51	9.24	2.96

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

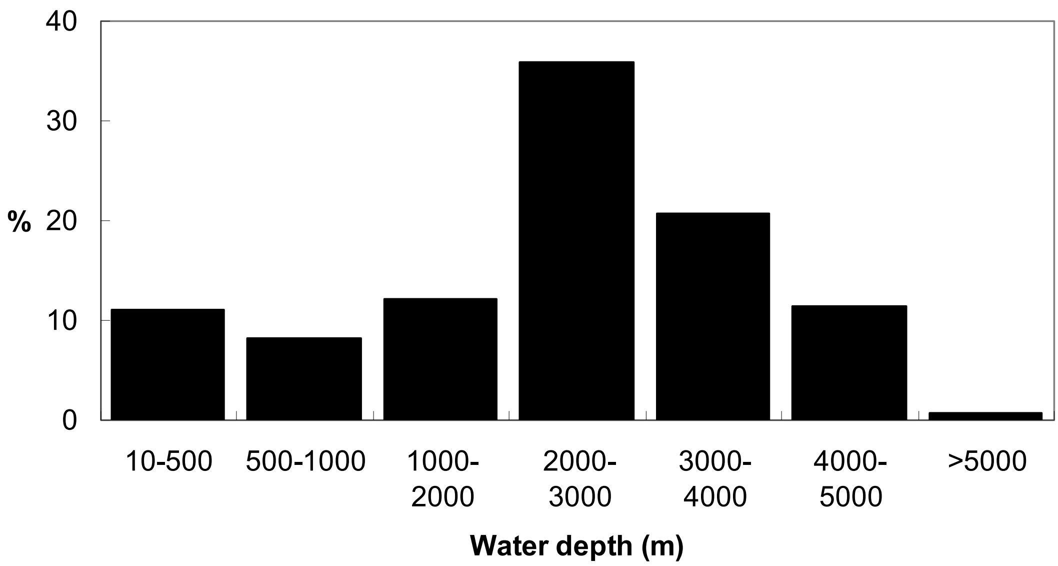


Figure 8.46. Graph showing the distribution of water depths for the South West Transition.

the upper slope, where no geomorphic features have been identified (Table 8.18; Fig. 8.48). 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 (Fig. 8.49).

Samples cover five out of 9 geomorphic features in the bioregion (Table 8.18; Fig. 8.48). Average sample density across the bioregion is 1:1,500 km^2. However, sample density is

Table 8.17. 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

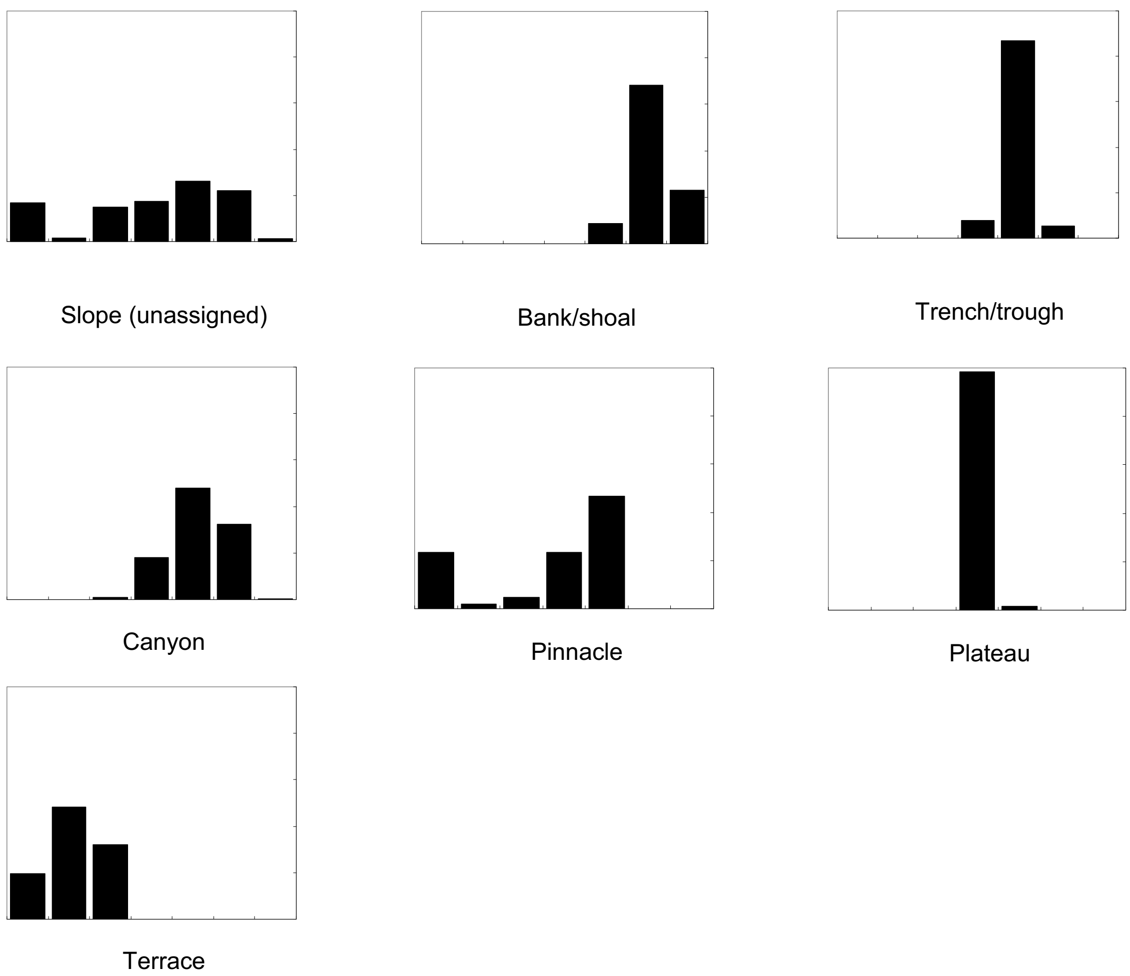


Fig. 8.47. Frequency histograms showing the distribution of water depths for geomorphic features for the South West Transition. See Fig. 8.35 for graph axes labels.

Table 8.18. Sample coverage by geomorphic provinces and features for the South West Transition.

Feature	No. of samples	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Provinces			
Slope	77	6/39	~1:1,500
Geomorphic features			
Slope (unassigned)	*62*	1/1	~1:900
Canyon	2	1/14	~1:1,000
Pinnacle	1	1/17	~1:100
Plateau	*4*	1/1	~1:7,500
Terrace	8	2/2	~1:2,100

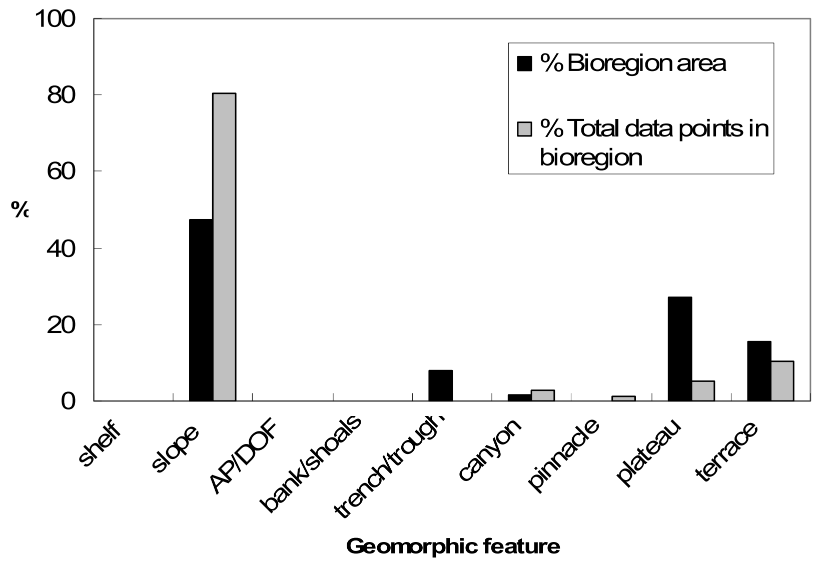


Figure 8.48. Graph showing sample coverage distributed by geomorphic feature in the South West Transition.

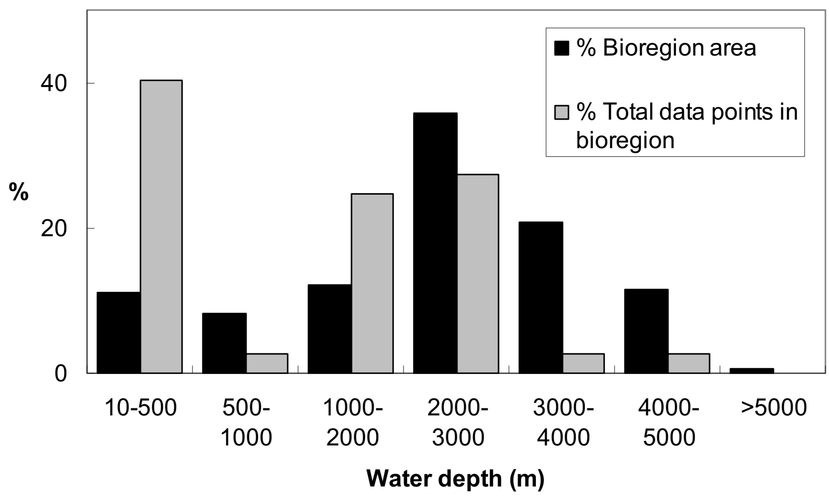


Figure 8.49. Graph showing sample coverage distributed by water depth in the South West Transition.

lower for the geomorphic features: 1:7,500 km² for plateaus and 1:2,100 km² for terraces. There are no data points located in trench/trough features

8.1.6.3. Sedimentology

Samples achieve adequate coverage to assess the sedimentology of the slope and terraces (Figs. 8.50-8.53). The sedimentology is broadly similar across these geomorphic features.

Sand is the dominant size fraction in the sediments in the South West Transition, ranging from 2 to 100%, and with 36 of 77 samples containing >50% sand, with all but 2 samples containing >5% sand (Fig. 8.50). Mud is the next dominant size fraction, ranging from 0 to 97%. A total of 41 of 77 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%.

Sand and mud contents vary greatly across the province. Sand comprises up to 90% of samples on the upper slope, while mud content attains 80% on the lower slope. The large number of samples on the upper slope and shallow water terraces mean that average sand content of sediment across the bioregion is likely to be lower than suggested by our results. The carbonate content exceeds 70% in all except 1 of 77 samples.

8.1.7. Central Western Province

8.1.7.1. Introduction

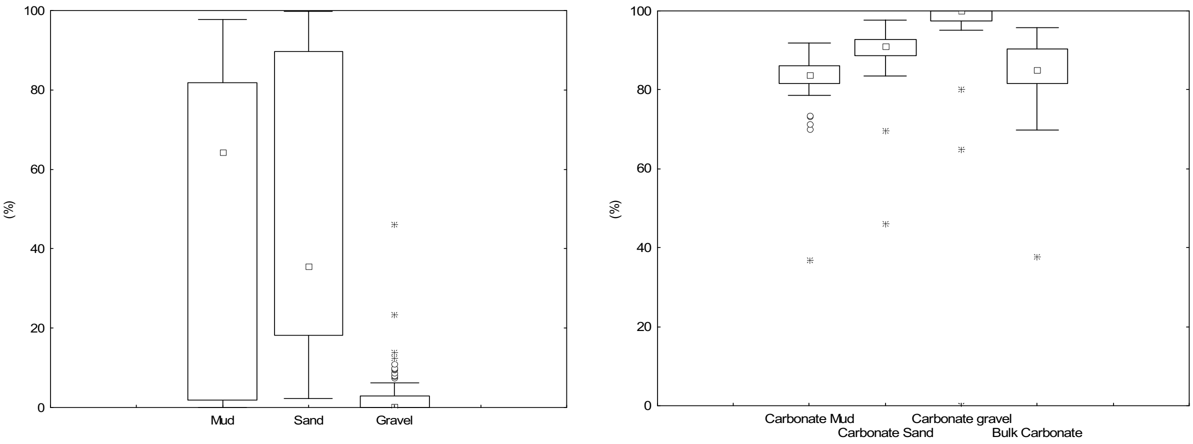
The Central Western Province covers a total area of 286,400 km² (Fig. 5.1), which represents 20% of the total area of the SWPR and 3% of total area of the EEZ. All except 4% of this area (11,460 km²) lies within the SWPR. The Central Western Province is located at the northernmost boundary of the SWPR 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 8.19). 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. 8.53).

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.

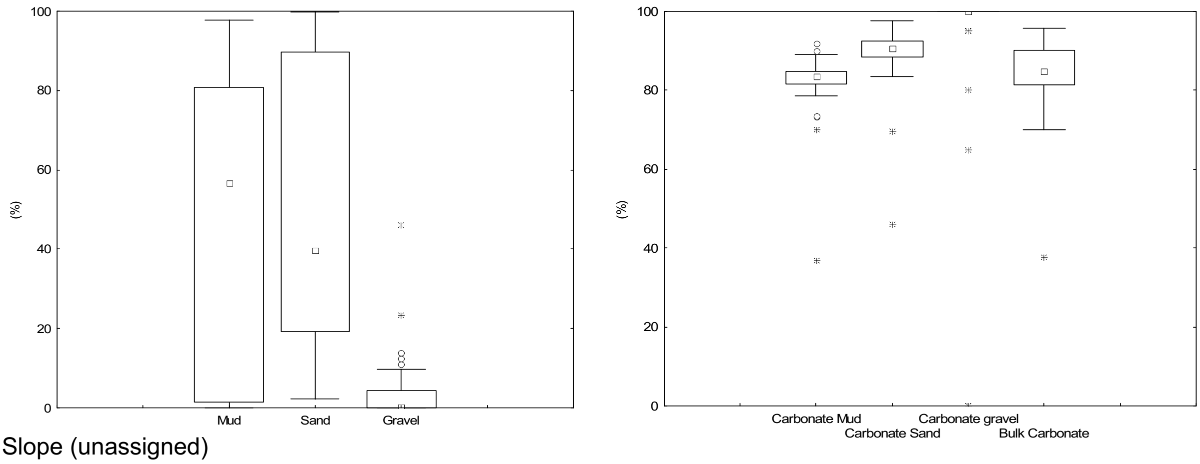
Canyons and terraces cover the greatest area of the Central Western Province, covering 7,700 km² (2.7%) and 22,000 km² (7.7%), respectively. Although this is a deep-water bioregion, the terraces occur in water depths of between 200 and 1,500 m, and are not representative of the range of water depths over which terraces occur in the SWPR (10->5,000 m) (Fig. 8.54; Table 8.20).

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). 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.



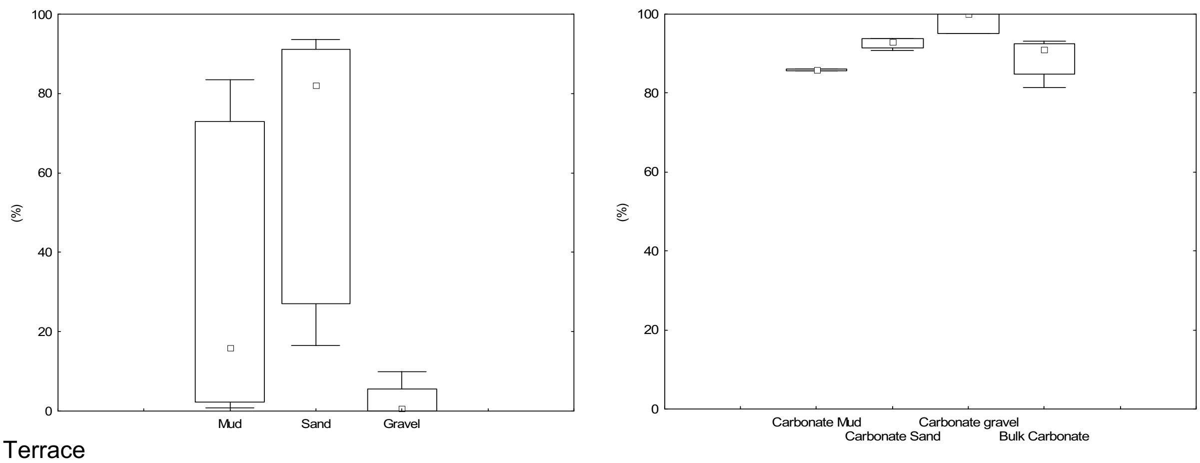
All Data

Figure 8.50. Box and whisker plots showing the distributions of sediment properties for the South West Transition.



Slope (unassigned)

Figure 8.51. Box and whisker plots showing distributions of sediment properties for the slope in the South West Transition where no geomorphic features have been identified.



Terrace

Figure 8.52. Box and Whisker plots showing the distribution of sediment properties for terrace features in the South West Transition.

Table 8.19. Details of the geomorphology of the Central Western Province.

Feature	Total number of features	% 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)	2	<0.01	<0.01	<0.01
Slope (unassigned)	1	32.06	25.83	6.39
Rise (unassigned)	1	19.04	100	54.49
AP/DOF* (unassigned)	1	37.92	34.12	4.21
Deep/hole/valley	2	0.46	37.34	0.76
Canyon	44	2.70	25.32	6.92
Pinnacle	11	0.03	12.66	1.74
Escarpment	1	0.09	100	1.19
Terrace	2	7.70	11.37	3.64
TOTAL	65			

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

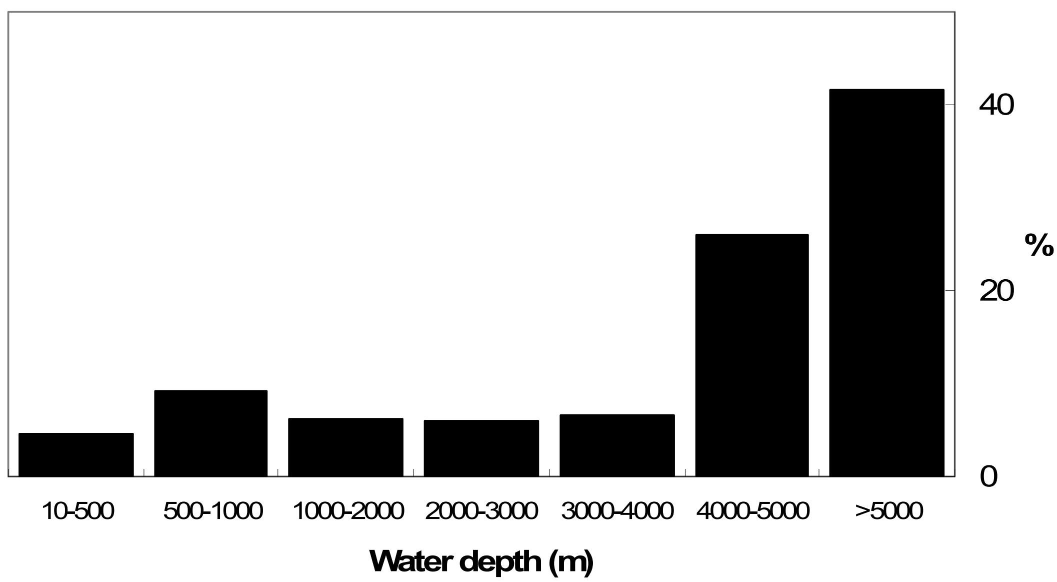


Figure 8.53. Graph showing the distribution of water depths for the Central Western Province. Note the relatively large areas of seabed below 4,000 m (70%). This is depth frequency distribution is unique to this province.

Table 8.20. 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
TOTAL	10 – 5,940	3,970

8.1.7.2. Sample Coverage

A total of 139 samples are located in the Central Western Province giving an average sample density of <1 sample for every 2,000 km^2 (Table 8.21). 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 (Figs. 8.55 & 8.56). Samples are sparse on the lower slope, rise and abyssal plain/deep ocean floor (average densities 1:9,000 – 1:35,000 km^2).

The Central Western Province includes 25% of all canyons in the SWPR. Water depths for canyons (range 50-5,000 m) (Fig. 8.57) suggest that these are likely to be 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. Of the 44 separate canyons present in this bioregion only 4 contain data.

8.1.7.3. Sedimentology

Samples achieve adequate coverage to assess sedimentology for the slope, rise, canyons and terraces (Figs. 8.58–8.63).

Sediments in the Central Western Province are dominated by sand and mud. Sand contents range from 0 to 100%, with 74 (50%) samples containing between 15 and 75% sand. Mud contents range from 0 to 96%, with 72 (50%) samples containing between 5 and 85%

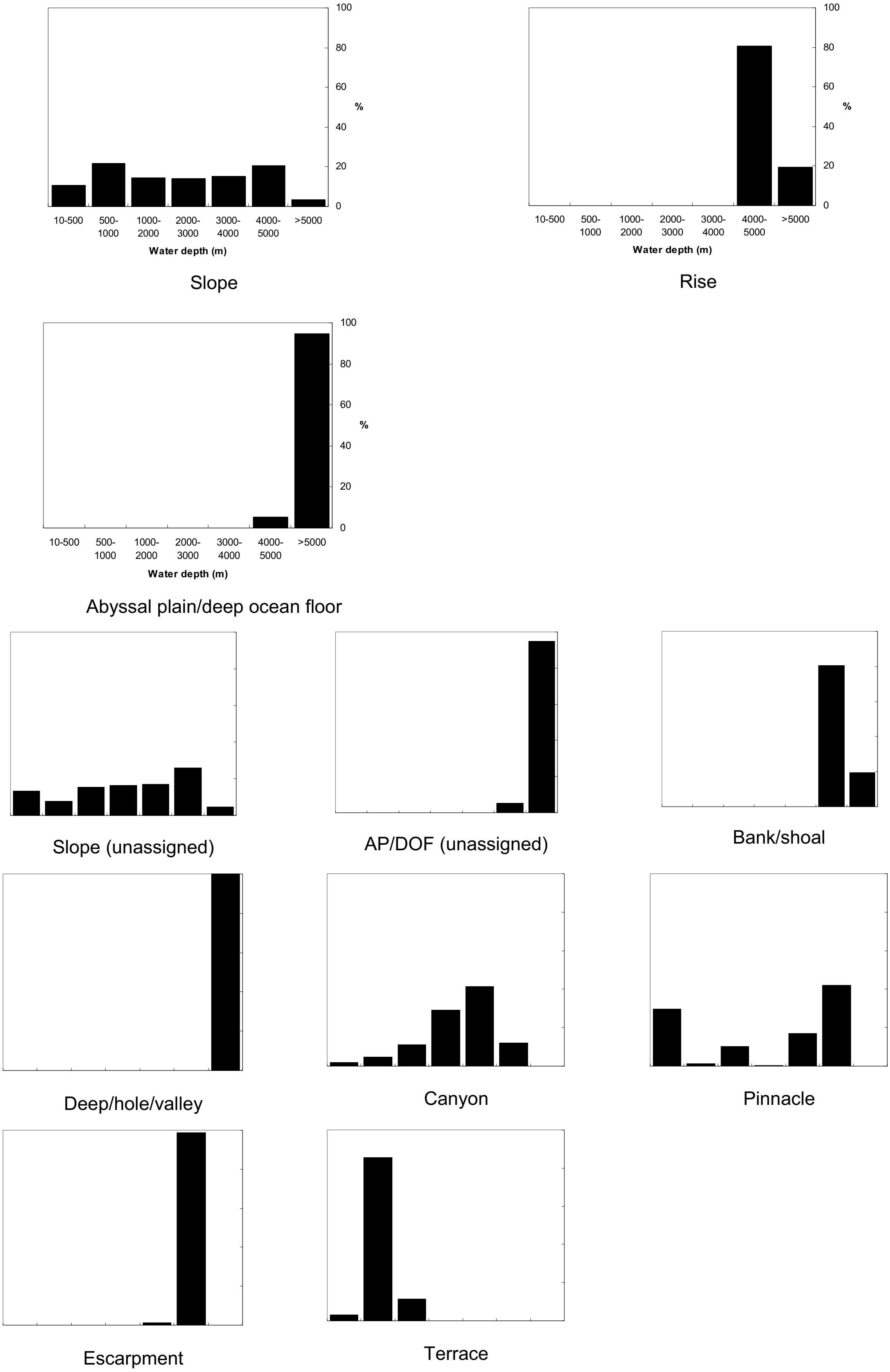


Figure 8.54. Frequency histograms showing the distribution of water depths for the geomorphic provinces and features for the Central Western Province.

Table 8.21. Sample coverage by geomorphic provinces and features for the Central Western Province.

Feature	No. of Samples	Features covered/Total number of features for unit	Average data density (sample:km^2)
Geomorphic Provinces			
Slope	130	8/56	~1:900
Rise	6	1/3	~1:9,000
AP/DOF	3	1/2	~1:35,000
Geomorphic features			
Slope (unassigned)	87	1/5	~1:1,000
Rise (unassigned)	6	1/1	~1:1,500
AP/DOF* (unassigned)	3	1/1	~1:35,000
Canyon	28	4/44	~1:250
Terrace	15	1/2	~1:1,000

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

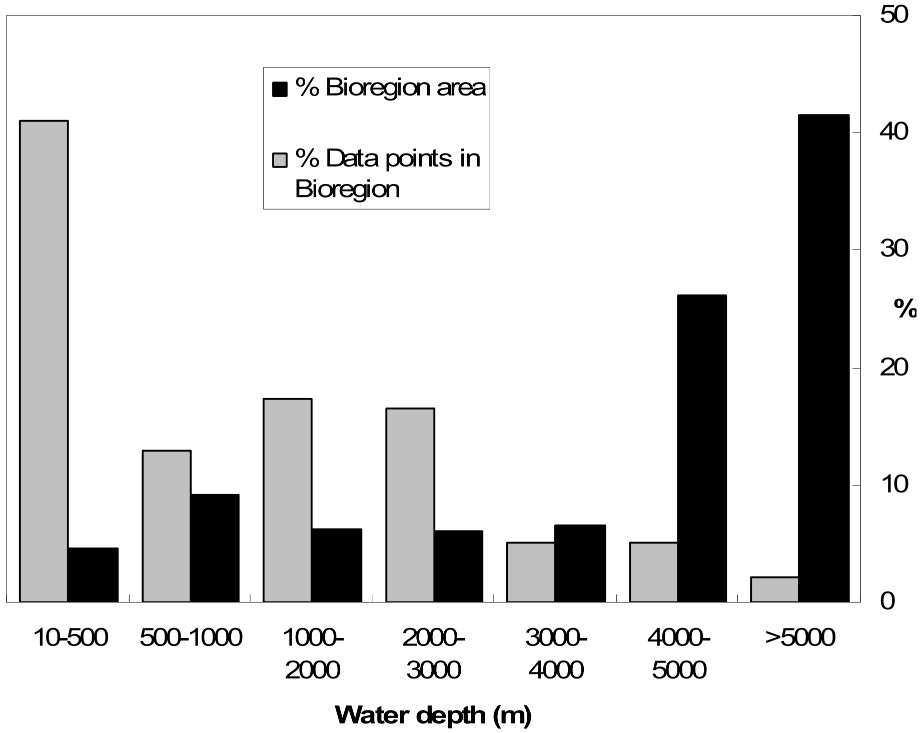


Figure 8.55. Graph showing sample coverage distributed by water depth in the Central Western Province. Note the inverse relationship between water depth area and percent number of samples. Samples occur in all bathymetric classes, although >40% of the samples occur in water depths of <500 m, and <2% 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.

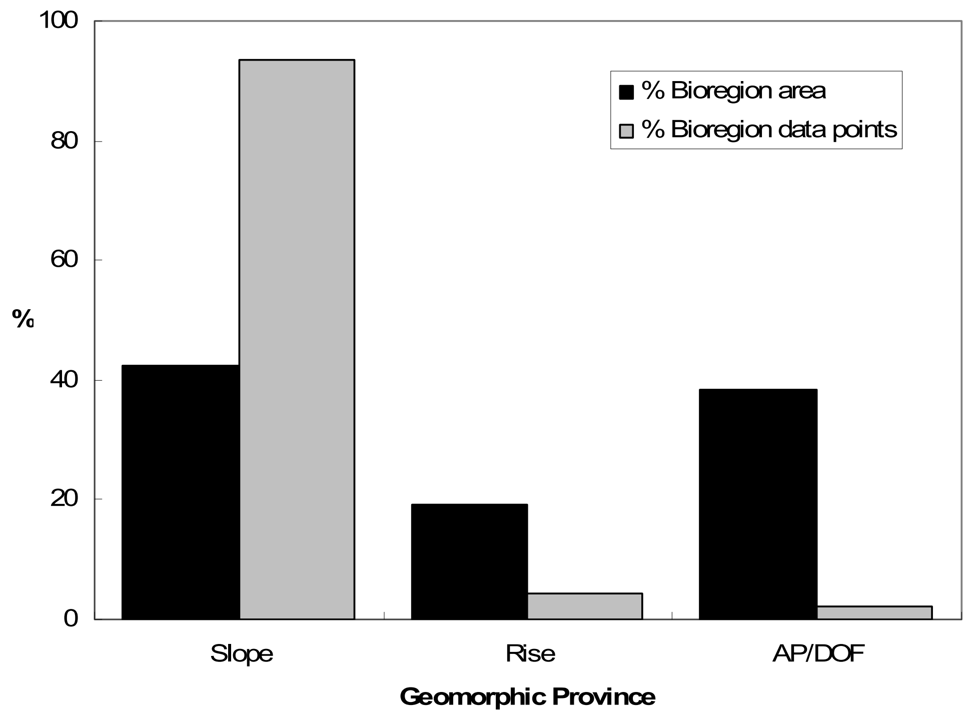


Figure 8.56. Graph showing sample coverage distributed by geomorphic province in the Central Western Province.

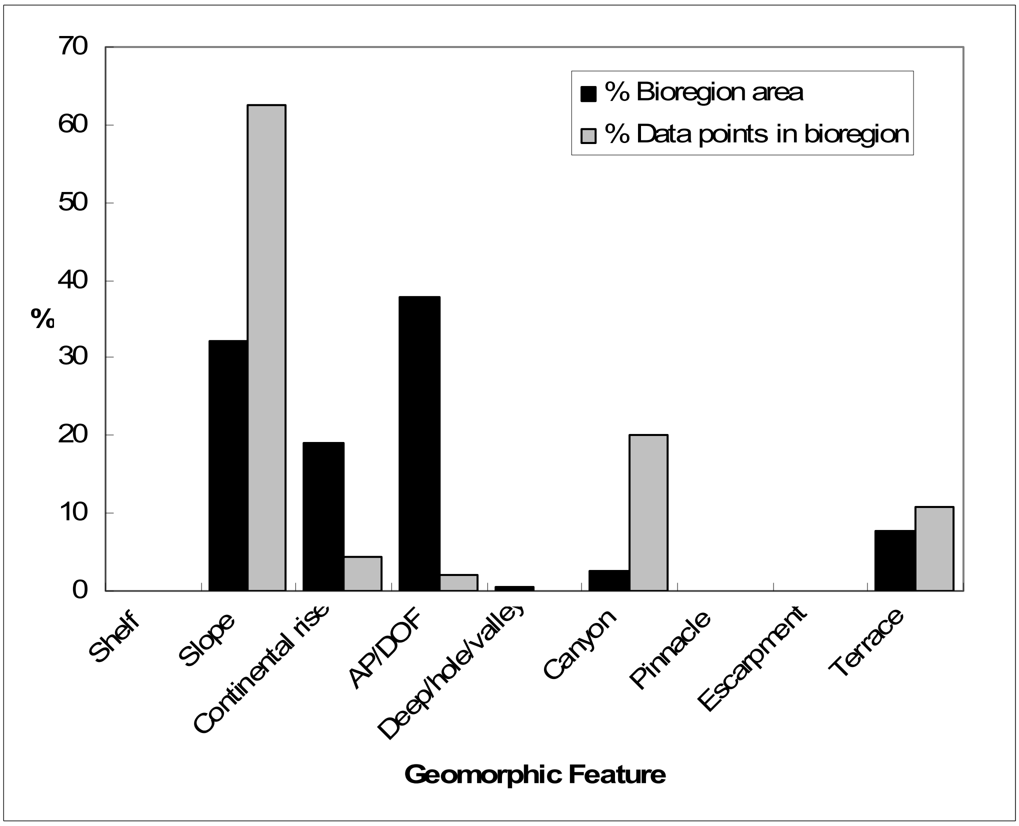


Figure 8.57. Graph showing sample coverage distributed by geomorphic features in the Central Western Province.

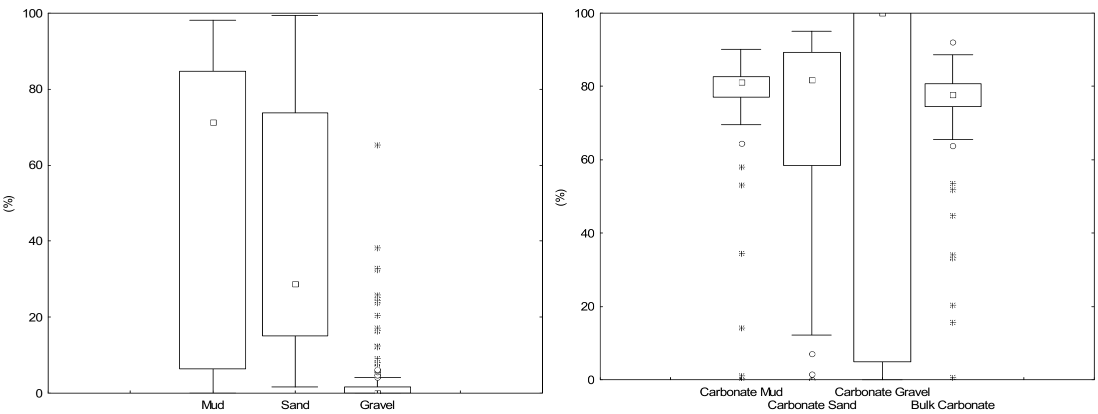
mud. Gravel is a minor constituent comprising <5% in 112 (75%) samples. Although, gravel contents attain 30% at 4 locations on the upper slope near the shelf break. Carbonate grains dominate all size fractions, with a total of 78 samples (50%) containing >80% carbonate in all fractions.

Areas of slope where no other geomorphic features could be defined contain similar sediment characteristics to those for the entire Bioregion. Differences include slightly lower average mud (48%) and higher average sand (55%) contents. Carbonate content for all fractions exceed 60%, with 77 (75%) samples containing >80% carbonate.

The rise is dominated by mud, with contents ranging from 40 to 95% and 5 (>75%) samples containing >65% mud. The remainder of the samples at all locations on the rise was sand. Carbonate mud contents are range between 3 and 83%, with 4 (>65%) samples containing between 25 and 78% carbonate mud. Carbonate sand for all samples exceeded 80%.

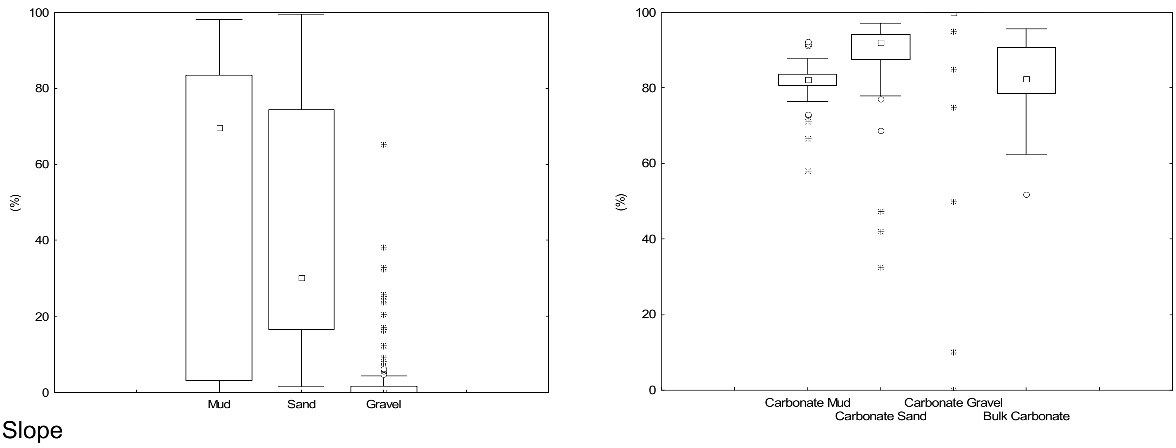
All samples from in the canyons occur in the Perth Canyon (Fig. 8.62). Mud is the dominant sediment type in this canyon, ranging from 77 to 95%, with 12 (50%) samples containing between 85 and 90% mud. The remainder of sample in most cases is sand, although gravel is present in amount of <5% in 14 samples. Carbonate exceed 75% in 25 (>75%) samples.

Terrace sediments are dominated by mud, with contents ranging from 30 to 88% and 8 (50%) samples containing between 60 and 85% mud. Sand content ranges from 10 to 95% and 7 (50%) samples contain between 15 and 35% sand. Gravel contents are generally <3% for all samples. Carbonate content exceeds 75% in all samples.



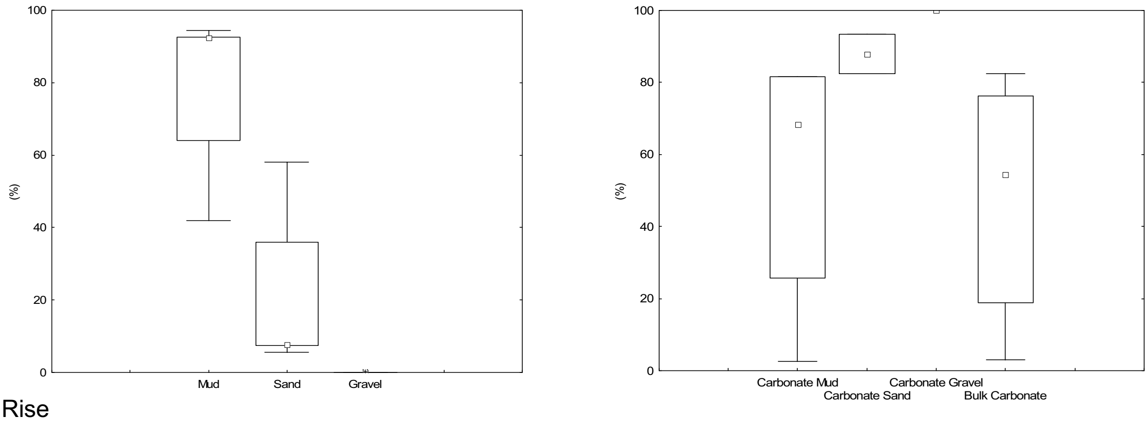
All Data

Figure 8.58. Box and whisker plots showing distributions of sediment properties for the Central Western Province.



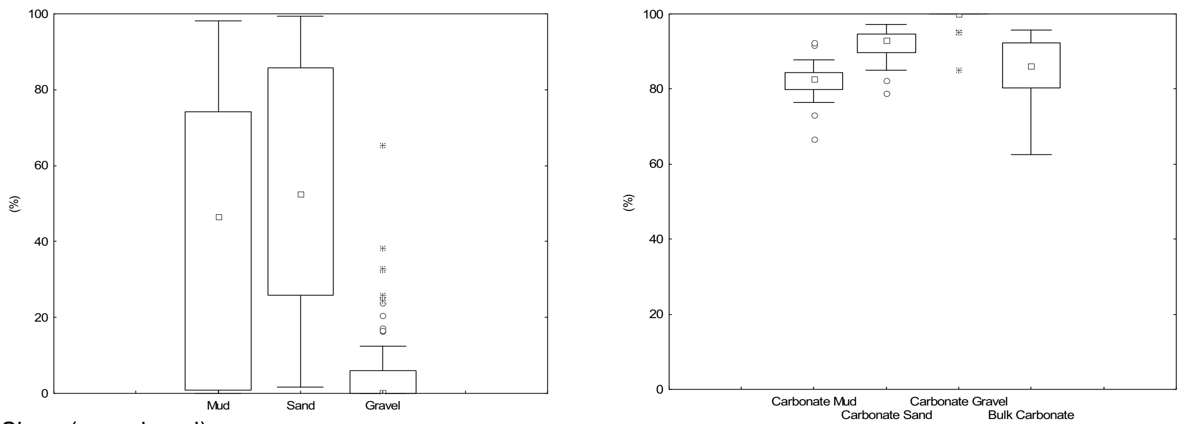
Slope

Figure 8.59. Box and whisker plots showing distributions of sediment properties for areas of the slope in the Central Western Province.



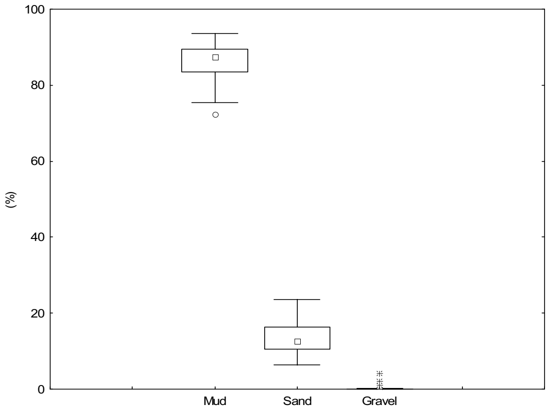
Rise

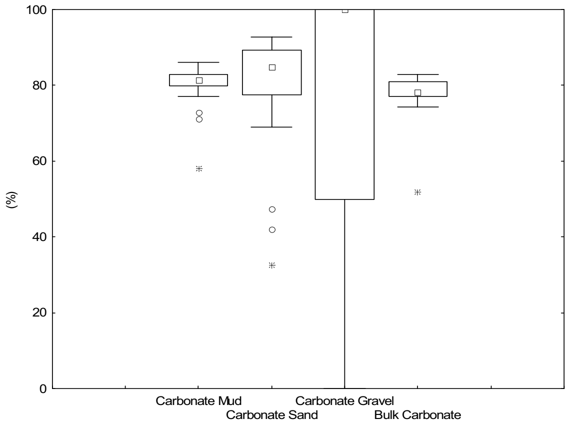
Figure 8.60. Box and whisker plots showing distributions of sediment properties for areas of the rise in the Central Western Province.



Slope (unassigned)

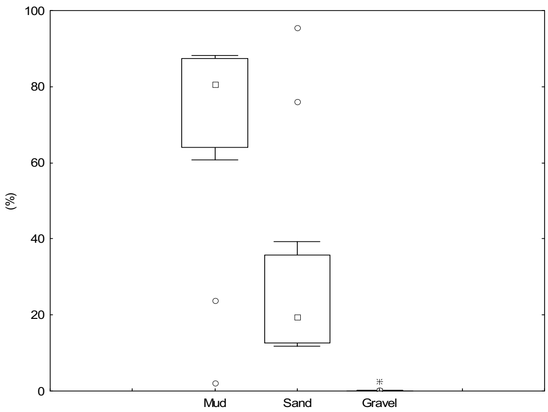
Figure 8.61. Box and whisker plots showing distributions of sediment properties for areas of the slope in the Central Western Province where no geomorphic features could be identified.

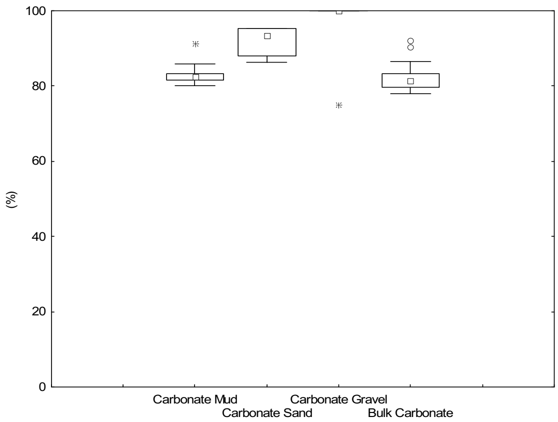




Canyon

Figure 8.62. Box and whisker plots showing distributions for sediment properties for canyon features in the Central Western Province.





Terrace

Figure 8.63. Box and whisker plots showing distributions of sediment properties for terrace features in the Central Western Province.

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
Tony Watson	Laboratory Manager
Christian Thun	Laboratory Manager
Billie Poignand	Laboratory Officer
Haylee Martin	Laboratory Officer
Keith Henderson	Laboratory Officer

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 & 5 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 features: The total number of polygons used to map occurrences of this feature within the SWPR.

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.

Number of features covered: The number of the polygons for this feature ('Total number of features') that contain sample points.

Average density (samples per km²): 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 km².

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.

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.

8.4.2. Appendix A Tables

E.g. Table 8.1

Feature	Total number of features	% 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 8.3.

Feature	No. of Samples	Features covered/Total number of features	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.

Features covered/Total number of features: The number of the polygons used to characterise this feature within the bioregion that is included in the SWPR / the total number of sample points located within the area covered by this feature in this bioregion.

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.

8.5. APPENDIX E: GRAVEL-RICH SEABED ENVIRONMENTS IN THE SWPR

When sediment assays were analysed at a SWPR scale, 114 outliers were identified in the gravel textural fraction. Outliers were defined as sites where gravel formed >25% of sediments. These occurred across the SWPR, restricted mainly to the continental shelf (Fig. 8.64). More detailed summaries distribution and composition of gravel outliers in each bioregion are given below.

8.5.1. Spencer Gulf IMCRA Province

Fourteen gravel outliers were identified for the Spencer Gulf IMCRA Province (Fig. 8.6; Table 8.22). Outliers were defined as points with Gravel content >25%. These are located dominantly in the northern Spencer Gulf (Fig. 8.65). Single samples with high gravel content are located in the Gulf St Vincent and on the northern side of Kangaroo Island.

Carbonate content of the gravel fraction in these samples varies from 25-100%. Carbonate in the northern Spencer Gulf is biogenic in origin, consisting of skeletal carbonate grains including molluscs, bryozoans, bivalves & coralline algae (Hails et al., 1984; Fuller et al., 1994). Carbonate sediments in the Gulf St Vincent and off Kangaroo Island are composed of bivalves, bryozoans, coralline algae and relict carbonate grains (James et al., 1997)

Previous work in the Spencer Gulf has identified the non-carbonate component in that area as terrigenous input including material eroded from the nearby Flinders Ranges and introduced into the Gulf by drainage (Burne and Colwell, 1982; Fuller et al., 1994). Terrigenous components include quartz grains & lithic fragments. Non-carbonate material identified at the site near Kangaroo Island is most likely quartz. A significant terrigenous quartz component was identified in this area by James et al. (1997).

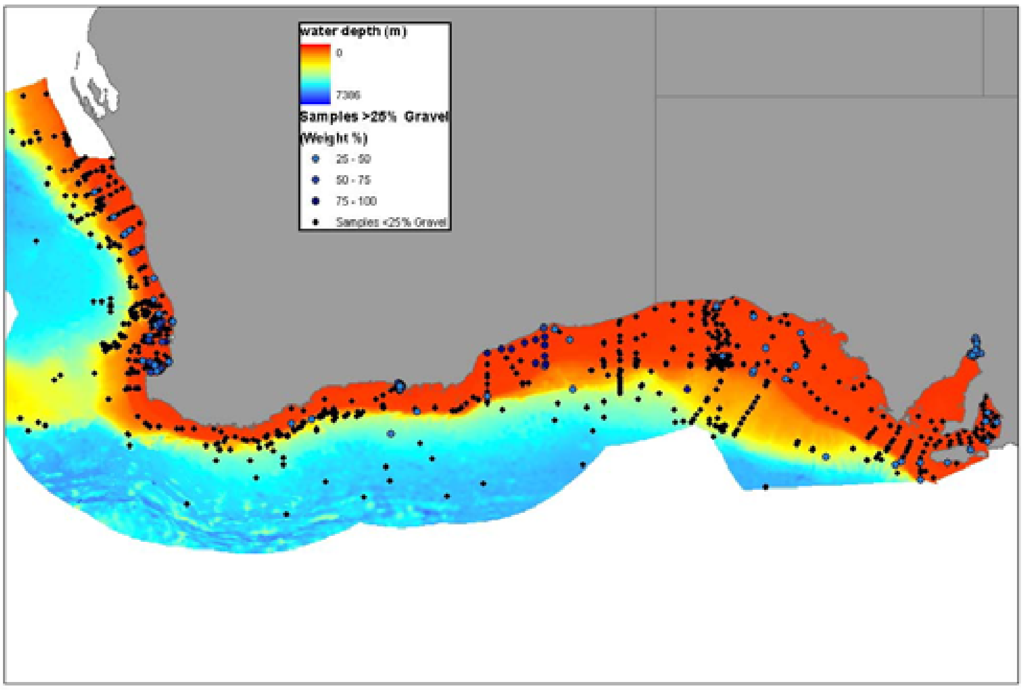


Figure 8.64. Distribution of SWPR gravel content outliers (Gravel >25 weight %).

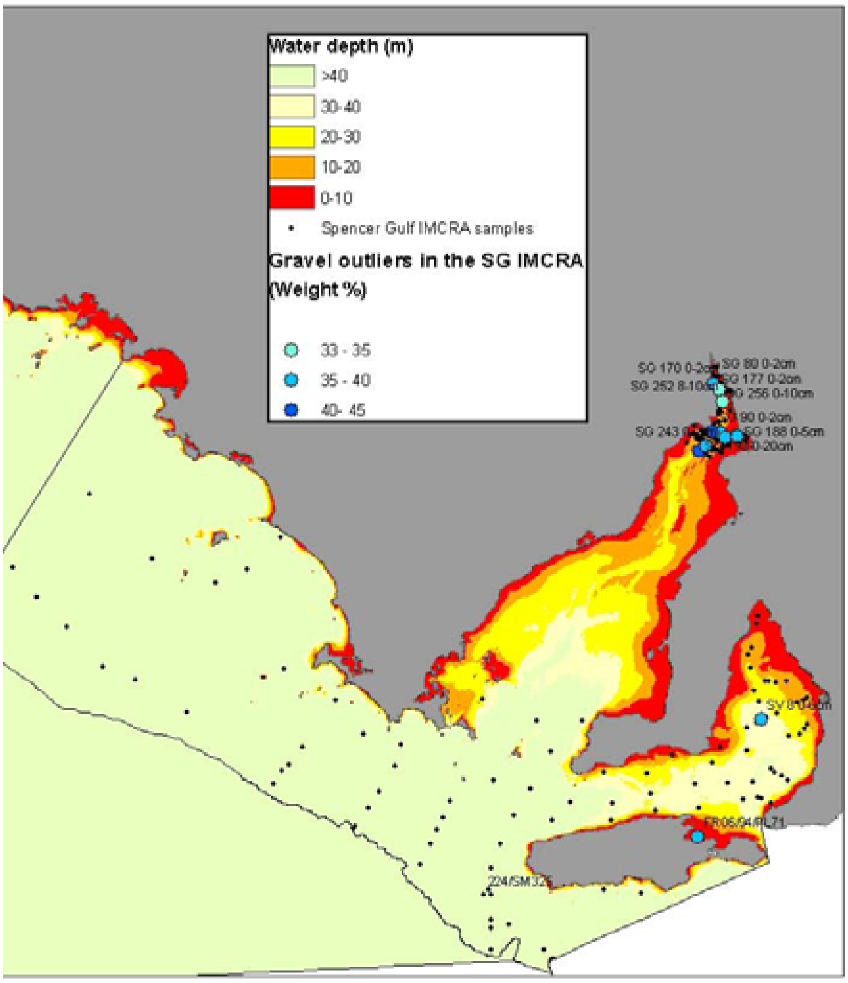


Figure 8.65. Distribution of gravel content outliers for the Spencer Gulf IMCRA Province (Gravel >25 weight %).

Table 8.22. Assays for gravel outliers in the Spencer Gulf IMCRA Province (Gravel >25 weight %)

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
SG 80 0-2cm	15.4	51.3	**33.3**	49.9	56.8	**25.0**	58.6
SG 252 8-10cm	0.6	65.0	**34.4**	Null	53.9	**85.0**	65.0
SG 256 0-10cm	4.4	60.8	**34.8**	57.3	34.2	**90.0**	42.3
SG 188 0-5cm	28.9	34.9	**36.1**	70.6	69.0	**100.0**	80.9
FR06/94/PL71	1.4	61.4	**37.2**	Null	77.0	**55.0**	81.8
SG 278 0-10cm	28.2	34.4	**37.4**	75.8	80.0	**100.0**	78.1
SG 243 0-2cm	2.1	60.3	**37.6**	Null	92.2	**95.0**	94.7
SV 8 0-6cm	13.3	49.0	**37.7**	87.8	94.7	**100.0**	91.3
SG 102 0-2cm	1.8	60.1	**38.1**	Null	70.4	**95.0**	74.1
SG 170 0-2cm	4.1	56.5	**39.5**	Null	31.2	**95.0**	38.5
SG 90 0-2cm	3.5	56.1	**40.4**	Null	90.7	**95.0**	91.0
SG 198 0-20cm	28.1	31.2	**40.7**	74.3	87.8	**100.0**	86.9
SG 177 0-2cm	1.0	52.7	**46.3**	Null	67.0	**95.0**	62.3
224/SM325	0.5	52.5	**46.9**	81.1	84.6	**Null**	91.8

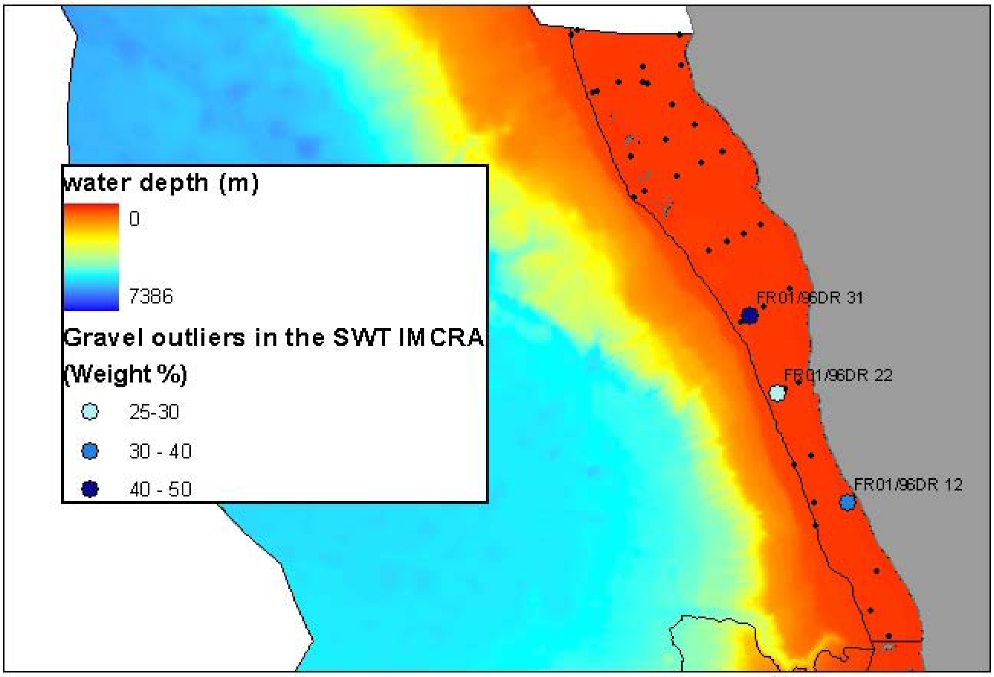


Figure 8.66. Distribution of gravel content outliers for the South West IMCRA Transition (Gravel >25 weight %).

Table 8.23. Assays for gravel outliers in the South West IMCRA Transition (Gravel >25 weight %).

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
FR01/96DR22	0.1	74.2	**25.6**	Null	68.6	**95.0**	73.5
FR01/96DR12	0.2 0.1	63.6 56.5	**36.2** **43.4**	Null Null	93.9 95.0	**100.0** **95.0**	92.5 93.8

All assays are quoted as weight %. Null values indicate no analysis performed due to inadequate sample volume.

8.5.2. South West IMCRA Transition

Three gravel outliers were identified for the South West IMCRA Transition (Figs. 8.15 & 8.66; Table 8.23). Outliers were defined as points with Gravel content >25%. Carbonate content of the gravel fraction of all these samples is >95%, and is made up of skeletal remains of bryozoans, various molluscs, and coralline algae (Collins et al., 1997; James et al., 1999).

8.5.3 South West IMCRA Province

Thirty-one gravel outliers were identified for the South West IMCRA Province (Fig. 8.22; Table 8.24). Outliers were defined as points with Gravel content >40%. These are located on the inner shelf north of Cape Naturaliste and the inner Recherche Shelf near Esperance (Fig. 8.67).

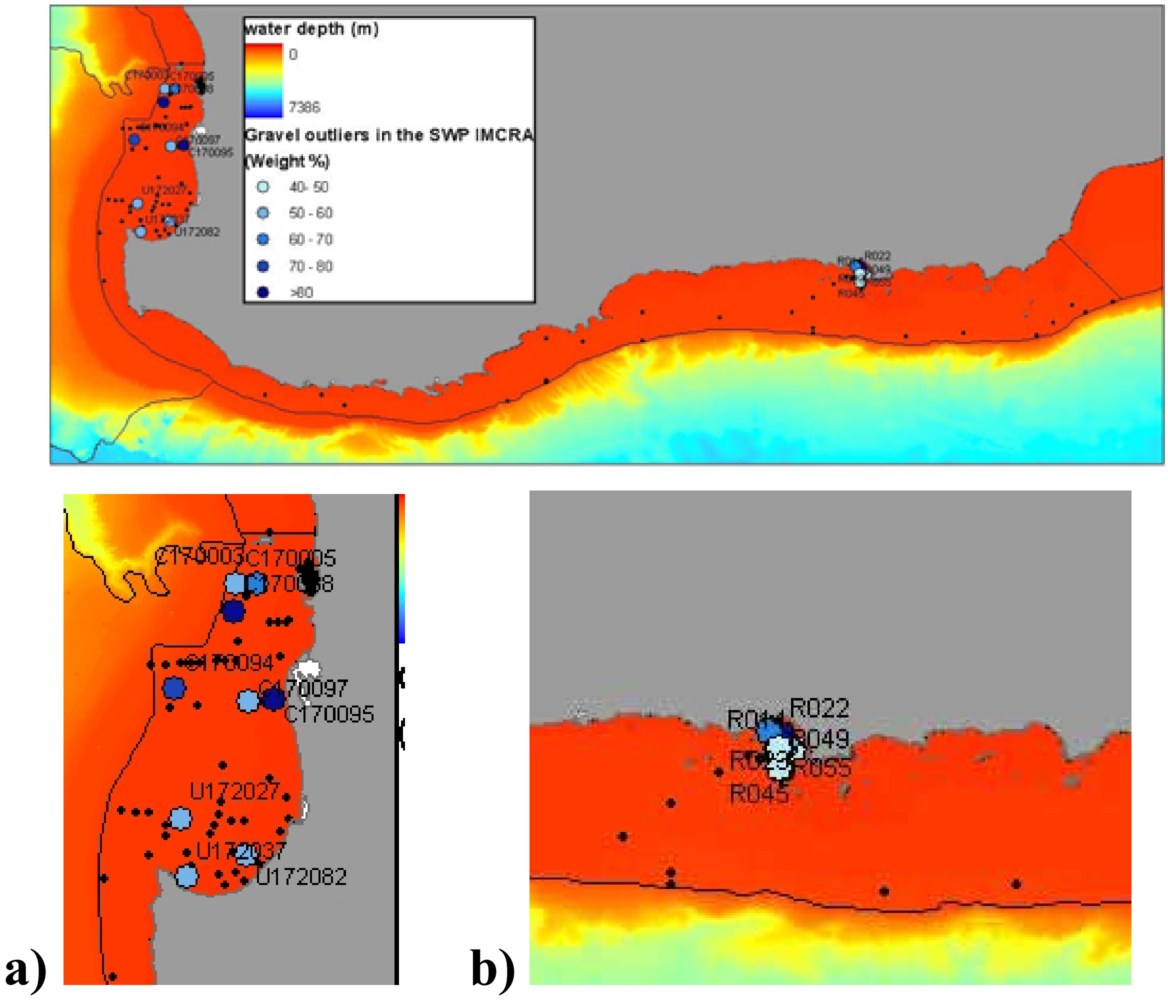


Figure 8.67. Distribution of gravel content outliers for the South West IMCRA Province (Gravel >40 weight %) with detail of a) the western margin north of Cape Naturaliste, and b) the southern margin between Albany and Esperance

Carbonate content of the gravel fraction in these samples varies from 20-100%, although carbonate content of the gravel fraction was not assessed at most sites. Previous work on the Recherche Shelf suggests gravels in this region are dominated by carbonate grains (molluscs, bryozoans, algal material) with minor lithic rock fragments (Cann and Clarke, 1993).

Gravels north of Cape Naturaliste contain both carbonate and non-carbonate components. Non-carbonate material in Cockburn Sound has been identified as mainly terrigenous quartz fragments; carbonate gravels on the inner shelf in this area are dominated by shell fragments (Skene et al., 2005). At other sites non-carbonate gravel is composed of quartz and lithic fragments (Collins, 1988; Carrigy and Fairbridge, 1954).

8.5.4 Great Australian Bight IMCRA Transition

Twenty-one gravel outliers were identified for the Great Australian Bight IMCRA Transition, (Fig. 8.31; Table 8.25). Outliers were defined as points with Gravel content >20%. These are located dominantly on the shelf south-east of Eyre (Fig. 8.68). Occasional samples with moderately high gravel content are located in the eastern half of the bioregion.

Table 8.24. Assays for gravel outliers in the South West IMCRA Province (Gravel >40 weight %).

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
R015	0.0	59.2	**40.8**	Null	Null	**Null**	Null
R048	0.1	57.3	**42.6**	Null	Null	**Null**	Null
287/R100	0.7	53.9	**45.4**	Null	Null	**Null**	74.0
R022	1.6	52.3	**46.1**	Null	Null	**Null**	85.2
R045	7.4	46.3	**46.3**	Null	Null	**Null**	Null
R049	0.2	53.2	**46.6**	Null	Null	**Null**	81.1
287/R090	11.6	39.2	**49.1**	Null	Null	**Null**	87.2
287/R089	1.2	49.3	**49.6**	Null	Null	**Null**	91.2
U172082	0.1	48.0	**51.9**	Null	11.3	**20.0**	13.3
287/R076	0.1	46.8	**53.1**	Null	Null	**Null**	85.2
C170005	0.2	45.9	**53.9**	Null	95.8	**95.0**	95.7
287/R108	0.4	43.3	**56.3**	Null	Null	**Null**	87.2
U172037	0.3	42.3	**57.4**	Null	32.1	**90.0**	45.6
287/R083	0.7	41.0	**58.3**	Null	Null	**Null**	81.1
C170097	1.2	40.4	**58.5**	Null	75.7	**55.0**	71.7
U172027	0.3	41.0	**58.7**	Null	70.4	**85.0**	66.9
R014	0.2	38.9	**60.9**	Null	Null	**Null**	Null
R054	0.6	37.8	**61.7**	Null	Null	**Null**	Null
R001	12.6	24.8	**62.6**	Null	Null	**Null**	Null
R055	0.3	35.9	**63.9**	Null	Null	**Null**	Null
287/R075	1.5	33.4	**65.1**	Null	Null	**Null**	89.2
C170003	0.4	33.1	**66.6**	Null	92.2	**80.0**	91.2
R023	5.1	26.9	**68.0**	Null	Null	**Null**	Null
R053	0.5	25.0	**74.5**	Null	Null	**Null**	Null
C170094	0.0	25.5	**74.5**	Null	96.1	**100.0**	95.0
R036	0.8	21.3	**77.9**	Null	Null	**Null**	Null
C170095	0.5	18.8	**80.7**	Null	46.0	**70.0**	58.0
R024	0.5	18.7	**80.8**	Null	Null	**Null**	Null
287/R109	0.7	15.7	**83.6**	Null	Null	**Null**	85.2
C170038	0.5	10.3	**89.2**	Null	82.6	**65.0**	85.9
287/R110	1.8	7.2	**91.0**	Null	Null	**Null**	88.2

Carbonate content of the gravel fraction in these samples varies from 30-100%. Gravel fraction south of Eyre is generally composed of >95% carbonate grains, and is dominated by rhodoliths with minor bivalves, turitellids, oysters and bryozoans (James et al., 2001).

Higher non-carbonate component in the gravel fraction was identified elsewhere in the bioregion. Previous work in the eastern area of the Great Australian Bight by James et al. (2001) identified non-carbonate component of sediments as terrigenous Quartz, Feldspar and crystalline rock fragments. Composition of the carbonate component of gravels varied across the shelf: consisting of varying amounts of bryozoans, intraclasts, molluscs and coralline algae (James et al., 2001).

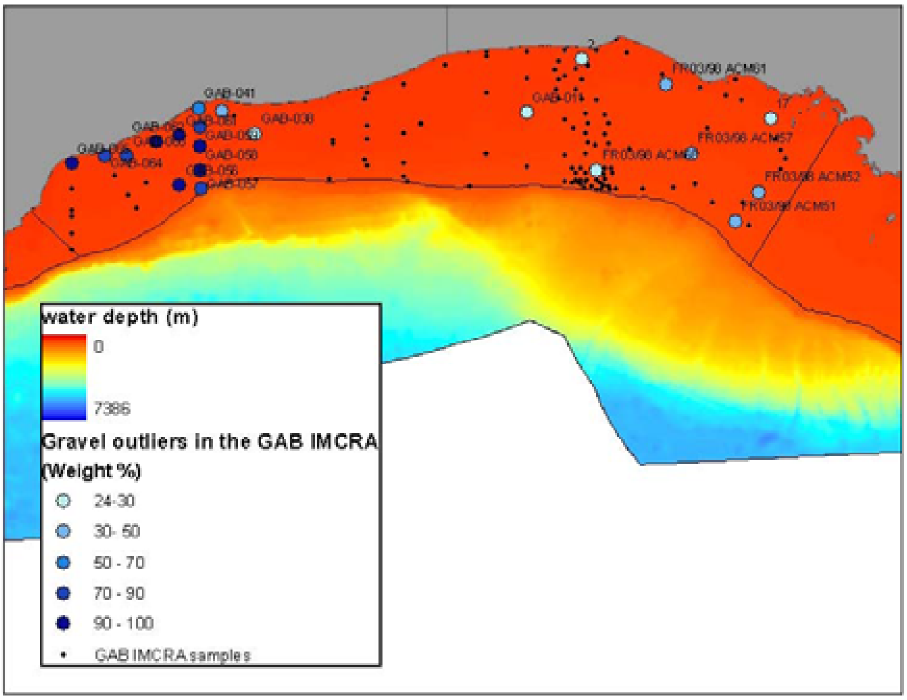


Figure 8.68. Distribution of gravel content outliers for the Great Australian Bight IMCRA Transition (Gravel >20 weight %).

Table 8.25. Assays for gravel outliers in the Great Australian Bight IMCRA Transition (Gravel >20 weight %).

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
GAB-011	0.1	75.6	**24.3**	Null	94.1	**95.0**	93.8
2	2.1	71.9	**25.9**	Null	94.3	**100.0**	91.9
FR03/98 ACM68	0.2	73.8	**26.0**	Null	96.8	**95.0**	96.7
17	0.7	71.5	**27.8**	Null	97.3	**95.0**	94.1
GAB-038	0.1	71.2	**28.7**	Null	89.7	**75.0**	89.2
FR03/98 ACM57	0.4	68.5	**31.2**	Null	96.6	**95.0**	94.8
FR03/98 ACM61	0.1	63.0	**36.9**	Null	63.2	**30.0**	61.8
GAB-040	1.9	59.6	**38.4**	Null	62.8	**100.0**	65.6
FR03/98 ACM52	0.1	59.5	**40.4**	Null	84.9	**35.0**	65.3
FR03/98 ACM51	5.7	51.4	**43.0**	89.7	93.5	**100.0**	93.4
GAB-041	0.6	32.0	**67.4**	Null	83.7	**95.0**	88.6
GAB-060	24.0	0.0	**76.1**	Null	83.2	**100.0**	79.0
GAB-057	15.1	0.0	**84.9**	Null	92.8	**100.0**	92.1
GAB-064	13.7	0.0	**86.4**	Null	91.9	**95.0**	90.4
GAB-063	12.3	0.0	**87.7**	Null	91.4	**100.0**	90.0
GAB-059	6.2	0.0	**93.8**	Null	92.4	**95.0**	92.2
GAB-056	5.0	0.0	**95.0**	Null	92.7	**100.0**	92.3
GAB-058	4.3	0.0	**95.7**	Null	92.4	**95.0**	92.1
GAB-065	3.0	0.0	**97.0**	Null	92.4	**95.0**	90.7
GAB-061	0.9	0.0	**99.1**	Null	93.0	**100.0**	94.8
GAB-062	0.0	0.0	**100.0**	Null	86.8	**95.0**	93.6

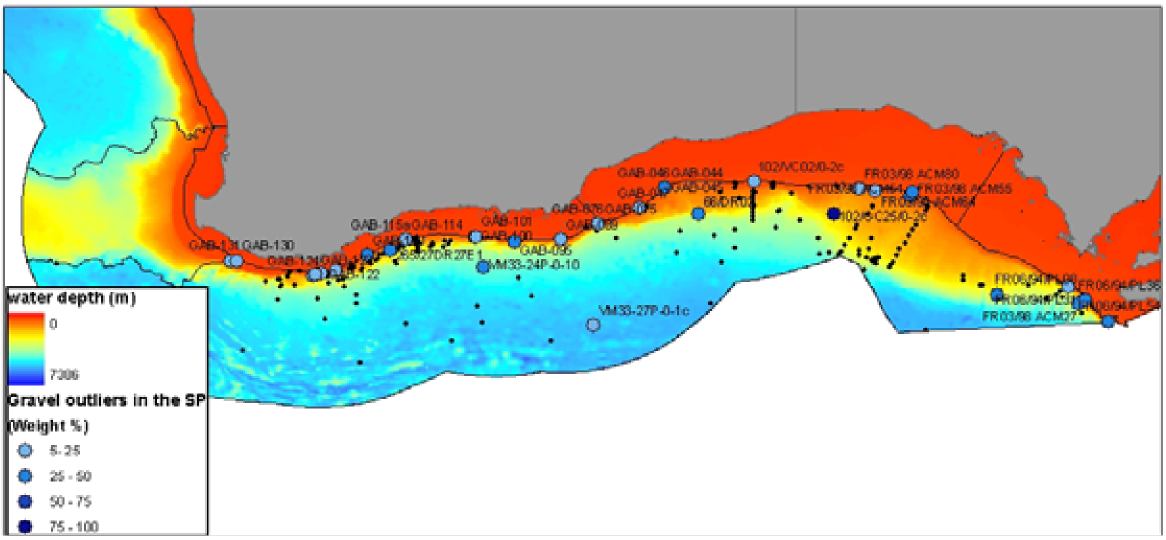


Figure 8.69. Distribution of gravel content outliers for the Southern Province (Gravel >5 weight %).

8.5.5. Southern Province

Thirty-five gravel outliers were identified for the Southern Province (Fig. 8.39; Table 8.26). Outliers were defined as points with Gravel content >5%. These are located on the upper slope, and occasionally occur on the lower slope and AP/DOF (Fig. 8.69).

Carbonate content of the gravel fraction in these samples varies from 5-100%. Gravels on the upper slope tend to be dominated by carbonate grains. In the east of the bioregion, carbonate gravels are dominated by bryozoans, with minor rhodoliths, molluscs and coralline algae (James et al., 2001).

Significant non-carbonate component is observed occasionally in gravels on the upper slope in the middle of the Bight. Carbonate gravels in this area consists mainly of bryozoans (James et al., 2001).

Large non-carbonate component in the gravel fraction is observed in samples from deep water areas. James et al. (2001) and Davies et al. (1989) describe coarser carbonate components of these sediments as skeletal fragments, particularly bryozoans.

8.5.6 South West Transition & Central Western Province

Five gravel outliers were identified for the South West Transition (Table 8.27), and 15 for the Central Western Province (Table 8.28). Outliers were defined as points with Gravel content >10% (Figs. 8.50 & 8.58). These samples are located on the upper slope near the shelf break (Fig. 8.70).

Carbonate content of the gravel fraction in these samples is consistently >95%. Based on their proximity to the shelf break, gravels are likely to be material sourced from the adjacent shelf (see South West IMCRA Province and South West IMCRA Transition non-carbonate and carbonate gravel components).

Table 8.26. Assay results for gravel outliers in the Southern Province (Gravel >5 weight %)

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
GAB-101	0.3	93.6	**6.1**	Null	94.4	**100.0**	93.3
GAB-131	0.5	92.5	**7.0**	Null	93.7	**100.0**	93.5
GAB-089	0.4	91.4	**8.2**	Null	95.6	**50.0**	93.7
GAB-075	1.6	89.9	**8.4**	Null	92.4	**95.0**	91.1
102/VC02/0-2c	13.5	77.9	**8.7**	Null	94.5	**100.0**	90.8
GAB-122	0.1	90.7	**9.1**	Null	93.7	**95.0**	93.0
296/43GR44A	3.1	87.7	**9.3**	Null	94.6	**100.0**	92.0
GAB-115a	3.3	86.0	**10.7**	Null	84.7	**100.0**	83.9
FR03/98 ACM64	2.9	86.2	**10.8**	Null	96.1	**100.0**	95.0
FR03/98 ACM80	0.1	88.9	**11.0**	Null	98.0	**100.0**	97.4
VM33-27P-0-1c	53.3	34.3	**12.4**	45.4	-999.0	**20.0**	45.4
GAB-100	4.7	82.9	**12.4**	Null	91.8	**100.0**	90.5
GAB-046	0.9	86.7	**12.4**	Null	92.5	**95.0**	90.9
FR06/94/PL31	43.8	43.7	**12.5**	90.1	94.2	**100.0**	90.1
GAB-045	1.6	84.8	**13.6**	Null	92.2	**95.0**	90.3
GAB-123	0.2	85.1	**14.7**	Null	94.2	**95.0**	94.4
GAB-124	0.6	84.5	**14.9**	Null	92.9	**100.0**	92.2
296/41GR42A	0.1	84.1	**15.8**	Null	94.0	**100.0**	95.3
GAB-130	0.1	83.1	**16.8**	Null	95.2	**95.0**	94.7
GAB-114	0.8	81.9	**17.2**	Null	93.7	**95.0**	92.0
GAB-047	2.4	74.6	**23.1**	Null	84.3	**95.0**	82.1
FR06/94/PL54	5.5	69.1	**25.4**	Null	96.1	**100.0**	94.0
FR03/98 ACM27	0.5	73.6	**25.9**	Null	95.2	**100.0**	94.5
GAB-120	0.9	71.2	**27.9**	Null	91.0	**100.0**	89.9
FR03/98 ACM54	3.4	68.6	**28.0**	Null	95.4	**100.0**	94.1
FR06/94/PL36	1.0	70.1	**28.9**	Null	95.0	**100.0**	95.4
FR06/94/PL08	6.4	60.4	**33.2**	Null	96.6	**100.0**	94.9
VM33-24P-0-10	50.7	15.8	**33.5**	Null	Null	**60.0**	69.2
FR03/98 ACM55	1.5	64.1	**34.4**	Null	95.4	**100.0**	95.1
GAB-044	2.0	63.6	**34.5**	Null	92.5	**95.0**	91.0
265/27DR27E1	30.4	34.4	**35.2**	64.4	18.0	**5.0**	33.2
GAB-076	1.5	59.2	**39.3**	Null	91.6	**100.0**	90.0
GAB-095	2.6	57.1	**40.2**	Null	85.7	**100.0**	83.2
66/DR02	23.1	30.3	**46.6**	71.3	63.7	**5.0**	55.9
102/GC25/0-2c	1.9	9.6	**88.5**	Null	Null	**5.0**	1.5

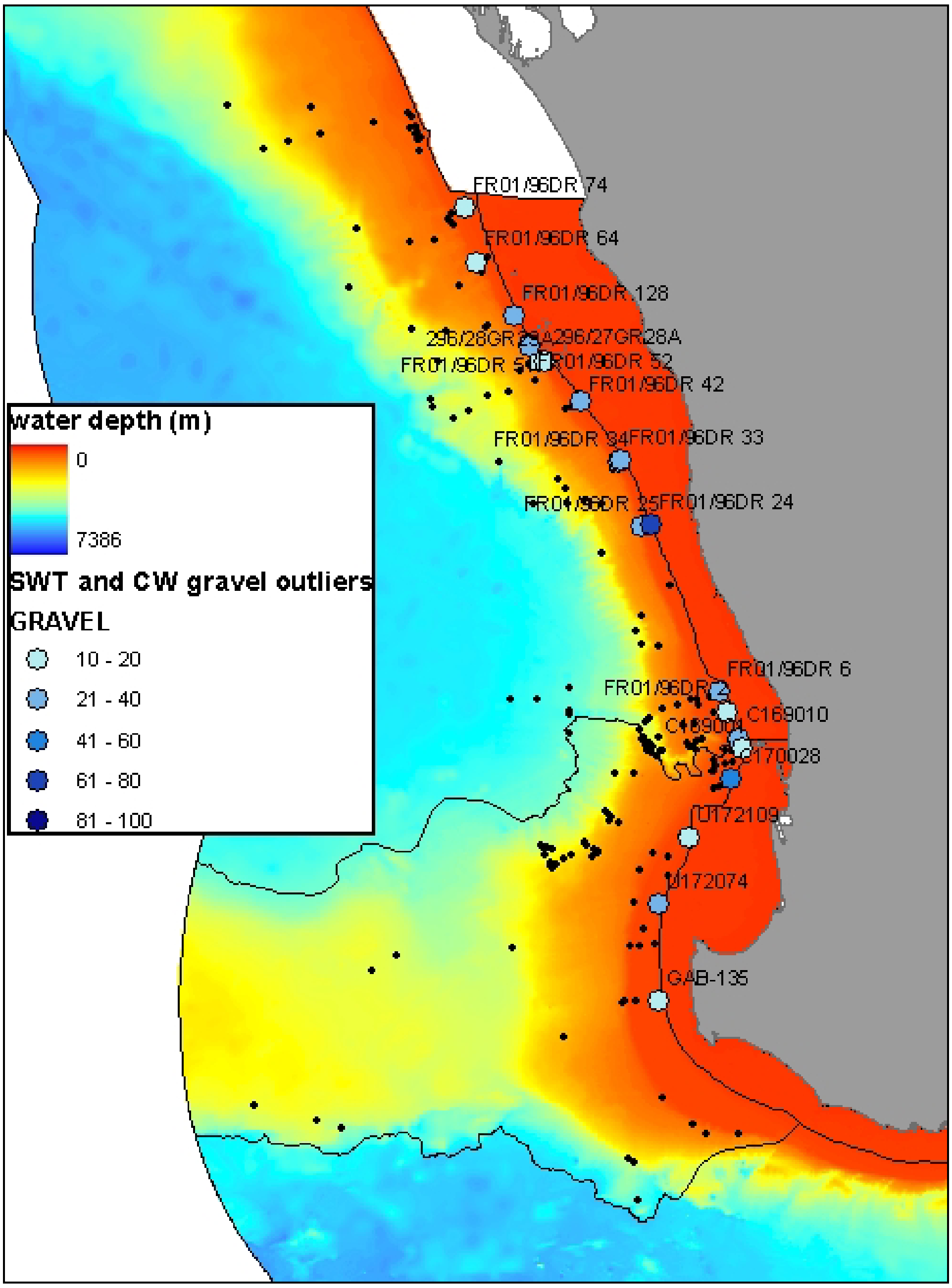


Figure 8.70. Distribution of gravel content outliers for the Central Western Province and South West Transition (Gravel >10 weight %).

Table 8.27. Assay results for gravel outliers in the South West Transition (Gravel >10 weight %).

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
U172109	1.3	87.7	**11.0**	Null	92.5	**95.0**	90.3
C169001	0.1	87.5	**12.5**	Null	92.2	**100.0**	90.5
GAB-135	0.2	86.0	**13.8**	Null	94.3	**95.0**	94.7
U172074	0.8	75.9	**23.3**	Null	94.3	**100.0**	92.3
C170028	0.8	53.1	**46.1**	Null	94.6	**100.0**	94.7

Table 8.28. Assay results for gravel outliers in the Central Western Province (Gravel >10 weight %)

Sample ID	Mud	Sand	**Gravel**	$CaCO_3$ (Mud)	$CaCO_3$ (Sand)	**$CaCO_3$ (Gravel)**	$CaCO_3$ (Bulk)
FR01/96DR64	0.5	87.2	**12.2**	Null	93.0	**100.0**	93.1
296/27GR28A	0.3	87.6	**12.2**	Null	97.1	**100.0**	95.2
296/28GR29A	2.4	85.1	**12.5**	Null	94.0	**100.0**	93.0
FR01/96DR51	0.1	83.5	**16.4**	Null	96.3	**100.0**	95.5
FR01/96DR2	0.2	83.2	**16.5**	Null	95.0	**95.0**	93.6
FR01/96DR74	2.0	80.9	**17.1**	Null	89.8	**100.0**	90.4
FR01/96DR52	0.2	79.3	**20.5**	Null	95.9	**100.0**	95.7
FR01/96DR25	0.4	75.8	**23.8**	Null	94.8	**100.0**	93.6
FR01/96DR33	0.9	74.7	**24.4**	Null	95.4	**95.0**	94.0
FR01/96DR34	0.9	73.9	**25.3**	Null	94.4	**100.0**	92.5
FR01/96DR6	0.1	74.1	**25.9**	Null	96.9	**95.0**	95.6
FR01/96DR128	0.6	66.9	**32.4**	Null	95.2	**95.0**	93.8
FR01/96DR42	0.6	66.5	**32.9**	Null	95.8	**95.0**	94.4
C169010	0.7	61.1	**38.2**	Null	92.2	**95.0**	91.8
FR01/96DR24	0.2	34.6	**65.2**	Null	95.4	**95.0**	94.0