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# Frontier basins of the west Australian continental margin:

## post-survey report of marine reconnaissance and geological sampling survey GA2476

*James Daniell, Diane C Jorgensen, Tara Anderson, Irina Borissova, Shoiab Burq, Andrew Heap, Michael Hughes, Daniel Mantle, Gabriel Nelson, Scott Nichol, Chris Nicholson, Danielle Payne, Rachel Przeslawski, Lynda Radke, Justy Siwabessy, Craig Smith and Shipboard Party*

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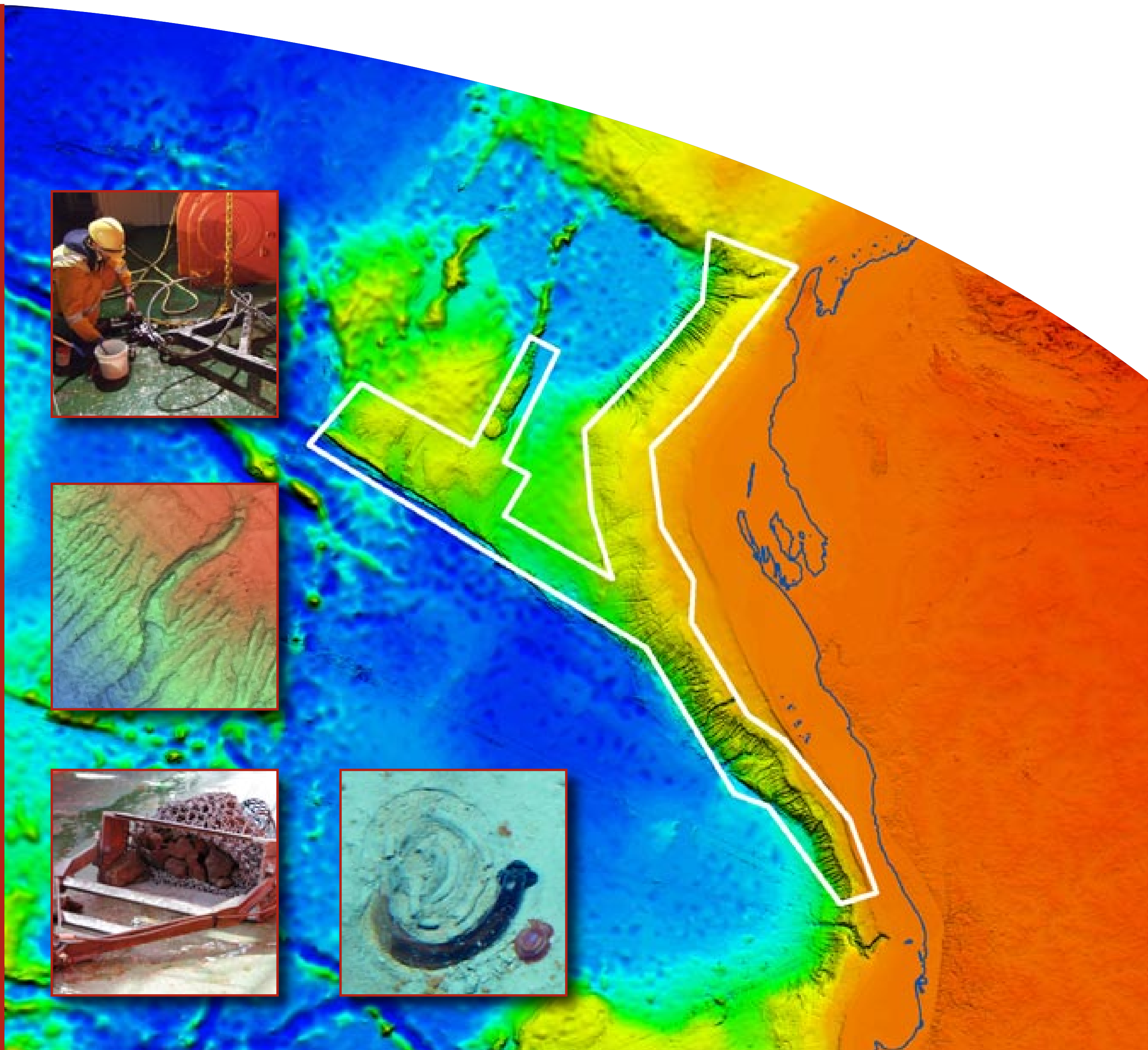

Geoscience Australia Record 2009/38

**Geoscience Australia Survey GA2476**

**Post-survey Report**

# Frontier Basins of the West Australian Continental Margin:

## Post-survey Report of Marine Reconnaissance and Geological Sampling Survey GA2476

***RV SONNE***

**October 2008 – January 2009**

James Daniell, Diane C. Jorgensen, Tara Anderson, Irina Borissova, Shoaib Burq, Andrew D. Heap, Michael Hughes, Daniel Mantle, Gabriel Nelson, Scott Nichol, Chris Nicholson, Danielle Payne, Rachel Przeslawski, Lynda Radke, Justy Siwabessy, Craig Smith and Shipboard Party

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# Executive Summary

This report contains the description and preliminary analysis of datasets acquired during Geoscience Australia marine reconnaissance survey GA2476 to the west Australian continental margin. The survey, completed as part of the Australian Government's Offshore Energy Program, was undertaken between 25 October 2008 and 19 January 2009 using the German research vessel *RV Sonne*. The survey acquired geological, geophysical, oceanographic and biological data over poorly known areas of Australia's western continental margin. Data from the marine reconnaissance survey (GA2476) and the concurrent regional seismic survey (GA0310) will improve knowledge of frontier sedimentary basins and marginal plateaus and allow assessment of their petroleum prospectivity and environmental significance. These data will be used to improve resource management and underpin decisions regarding future acreage release in offshore Western Australia and marine zone management.

Four key areas were targeted: the Zeewyck and Houtman sub-basins (Perth Basin), the Cuvier margin (northwest of the Southern Carnarvon Basin), and the Cuvier Plateau (a sub-feature of the Wallaby Plateau). These areas were mapped using multi-beam sonar, shallow seismic, magnetics and gravity. Over the duration of the survey a total of 229,000 $km^2$ (26,500 line-km) of seabed was mapped with the multi-beam sonar, 25,000 line-km of digital shallow seismic reflection data and 25,000 line-km of gravity and magnetic data.

Sampling sites covering a range of seabed features were identified from the preliminary analysis of the multi-beam bathymetry grids and pre-existing geophysical data (seismic and gravity). A variety of sampling equipment was deployed over the duration of the survey, including ocean floor observation systems (OFOS), deep-sea TV controlled grab (BODO), boxcores, rock dredges, conductivity-temperature-depth profilers (CTD), and epibenthic sleds. Different combinations of equipment were used at each station depending on the morphology of the seabed and objectives of each site. A total of 62 stations were examined throughout the survey, including 16 over the Houtman Sub-basin, 16 over the Zeewyck Sub-basin, 13 in the Cuvier margin, 12 over the Cuvier Plateau and four in the Indian Ocean.

Multi-beam sonar mapping revealed that the west Australian margin is characterised by a large number of variable sized canyons. The Perth (Houtman and Zeewyck sub-basins) and Cuvier margins have many deeply incised canyons, whereas parts of the margin adjacent to the Wallaby Saddle had mostly closely spaced, small canyons and low-angle slumps and scarps. A total of 109 canyons were mapped and a number sampled. The Cuvier Plateau is dominantly a low relief and gently sloping plateau. However, scarps and seamounts on the plateau perimeter have hundreds to thousands of metres of relief and extend along the seafloor for tens to hundreds of kilometres adding a great deal of geomorphic complexity to an area that was previously poorly known. Multi-beam sonar backscatter mosaics indicate that the survey areas were typically characterised by fine pelagic sediments. Areas of high backscatter were restricted to rocky outcrops on volcanic peaks, seamounts, scarps and within canyons. These interpretations were further supported by sediment sampling and underwater video transects.

The geological sampling program was aimed at collecting rock samples to support initial petroleum prospectively assessments of the frontier areas. Fifty-three dredges, 28 grabs, eight boxcores and four benthic sleds were deployed during the survey, which collected hundreds of rock samples in the study areas. The main focus was on dredging of the deeply incised canyons, which provided the best opportunity for sampling basinal successions. Rock samples collected during the survey are being analysed to obtain information on their age, depositional environment and hydrocarbon potential. Initial micropalaeontological analyses of rock samples have shown that most rock samples fall within two broad stratigraphic intervals: early Cretaceous strata (predominately siliciclastic rocks); and middle Paleocene to late Eocene strata (predominately calcareous rocks). The early Cretaceous rocks correspond to the latest stage of basin development preceding the breakup between Greater India and Australia. At least one rock sample from the Cuvier Plateau is likely to be Upper Jurassic, making it the oldest known sedimentary sample from the Cuvier Plateau. As these frontier basins have no previous exploration history, these rocks provide the first insight into their stratigraphy and potentially their petroleum prospectivity. Many dredge samples were taken from the edge of the continental margin, often west of previously mapped basin boundaries. The sedimentary rock obtained from these dredges indicated that the basinal succession

extends further seaward than previously mapped and has the potential to extend areas of the west Australian continental margin suitable for oil exploration.

The Cuvier Plateau is a large marginal plateau recently confirmed as being part of Australia's marine jurisdiction. Little is known about the origin and evolution of this large plateau previously considered to be predominately volcanic; however, analysis of pre-existing seismic data indicates that parts of the feature have a continental origin and could possibly contain sedimentary basins similar in age and origin to the Exmouth Plateau or northern Perth Basin. Previous sampling of the plateau recovered only volcanic rocks. The major achievement of the current sampling program on the Cuvier Plateau was the recovery of several sedimentary rock samples containing micro- and macrofossils. Once analysed and integrated with existing and newly acquired seismic data, these data may prove the sedimentary origin of the previously unresolved seismic sequences and therefore confirm the presence of sedimentary depocentres beneath the plateau.

The benthic ecology component of the survey provided the first observations of deep-water benthic habitats and biota from the west Australian margin. Samples and observations were collected over a broad depth range (641 - 4,827 m) in water depths rarely surveyed within Australia. The most common signs of life were bioturbation marks (tracks, burrows and mounds) which although only present in low levels occurred at almost all sample stations. Deposit-feeding holothurians (sea cucumbers) were the most common taxa observed, with occurrences higher up the slope margins than on the Cuvier Plateau. Biological samples contained extremely low numbers and negligible biomass of marine organisms, however, several important specimens were collected. Several new taxa were identified, and several known taxa were collected from depths greater than previously recorded for Australian waters.

This report is intended to provide a comprehensive overview of the survey activities, equipment used and preliminary results from survey GA2476. Once laboratory analyses are completed and integrated with the other data, detailed analysis and interpretation of these datasets will be published in subsequent GA records addressing different aspects of the geology of the west Australian continental margin.

# 1. Introduction

This record contains a summary of data acquired as part of Geoscience Australia marine reconnaissance survey GA2476 over the western continental margin of Australia. The survey was conducted on three legs between 25 October 2008 and 19 January 2009 using the German research vessel *RV Sonne* operated by RF-Forschungsschiffahrt GmbH (RF): Leg 1 departed Singapore on 20 October 2008 and returned to Fremantle on 20 November; Leg 2 departed Fremantle on 22 November and returned to Fremantle on 18 December; and Leg 3 departed Fremantle on 19 December and returned to Port Headland on 14 January 2009. Geophysical data were also acquired on *RV Sonne's* transit from Port Headland on 16 January 2009 until it exited Australian waters on 19 January 2009. The survey included scientists and technical staff from Geoscience Australia (GA), Geological Survey of Western Australia (GSWA), Australian Institute of Marine Science (AIMS) and 18 students and three staff from the University of the Sea. This marine reconnaissance survey was part of a dual survey programme that Geoscience Australia conducted in the region. The concurrent seismic survey (GA0310) involved the collection of approximately 7,300 kilometres of commercial 2D seismic data during the period 26 November 2008 to 24 February 2009, using CGGVeritas's marine seismic vessel *MV Duke*.

The marine reconnaissance survey GA2476 was designed to increase our understanding of the regional geology, petroleum prospectivity and environmental significance of the west Australian continental margin. In order to assist in this understanding, the survey collected extensive geological, geophysical, biological and oceanographic datasets. The 90-day marine reconnaissance survey focused on the under-explored areas of the west Australian margin – more specifically four areas of interest: the Zeewyck and Houtman sub-basins (Perth Basin, also associated with the Perth margin); the Cuvier margin (associated with the nearby Carnarvon Basin); and the Cuvier Plateau (a sub-feature of the Wallaby Plateau) (Fig. 1.1 and see below). The survey, which took place as three legs between 25 October 2008 and 19 January 2009, successfully mapped and sampled all four areas of interest.

The survey collected 230,000 km$^2$ of multi-beam sonar data, almost 25,000 line kilometres of gravity, magnetic and sub-bottom profiler data and underway oceanographic, meteorological and hydrographic data. Sampling program included 53 dredge hauls, 28 BODO hauls with accompanying camera footage, 17 OFOS camera tracks, eight boxcores, eight CTD profiles with accompanying water samples, four epibenthic sled hauls, 47 surface water samples, two XBTs and one beam trawl haul. A total of 62 stations were occupied throughout the survey, including 16 over the Houtman Sub-basin and 16 over the Zeewyck Sub-basin on the Perth margin, 13 on the Cuvier margin, 13 on the Cuvier Plateau, and four in the Indian Ocean.

This report includes a comprehensive overview of the survey activities and equipment used. The report also contains preliminary results from the survey data. Many of the acquired geophysical datasets, in particular the magnetic and gravity data, are still undergoing processing and as yet are not available for full analysis or interpretation. On the other hand, the analysis and interpretation of acquired physical datasets have undergone different levels of laboratory and/or specialist analysis. Therefore the content varies in its level of detail depending on the extent of the various studies to date. Once laboratory analyses are completed and integrated with other datasets, detailed analysis and interpretation of the physical datasets will be undertaken. Results of this work will be published in subsequent GA records and will address different aspects of the geology of the west Australian margin.

## 1.1. BACKGROUND

The impetus for the survey of remote frontier basins comes from the Commonwealth Government's Offshore Energy Security Program (OESP) that provided A$74 million over five years aimed at stimulating oil/gas/minerals exploration activities. Of this, approximately $18 million was allocated to conduct marine reconnaissance surveys of remote offshore sedimentary basins to gain a better understanding of the seabed and basin architecture and characterise the seabed environments. The marine reconnaissance surveys form part of Geoscience Australia's ongoing collection of fundamental pre-competitive data and information to understand Australia's offshore frontier basins and assist with planning and management of Australia's marine environments.

Information and data collected during the survey program will be used to support the work programs of the Department of Resources, Energy and Tourism and Department of the Environment, Water Heritage and the Arts. Data will be made available to the petroleum exploration industry as pre-competitive

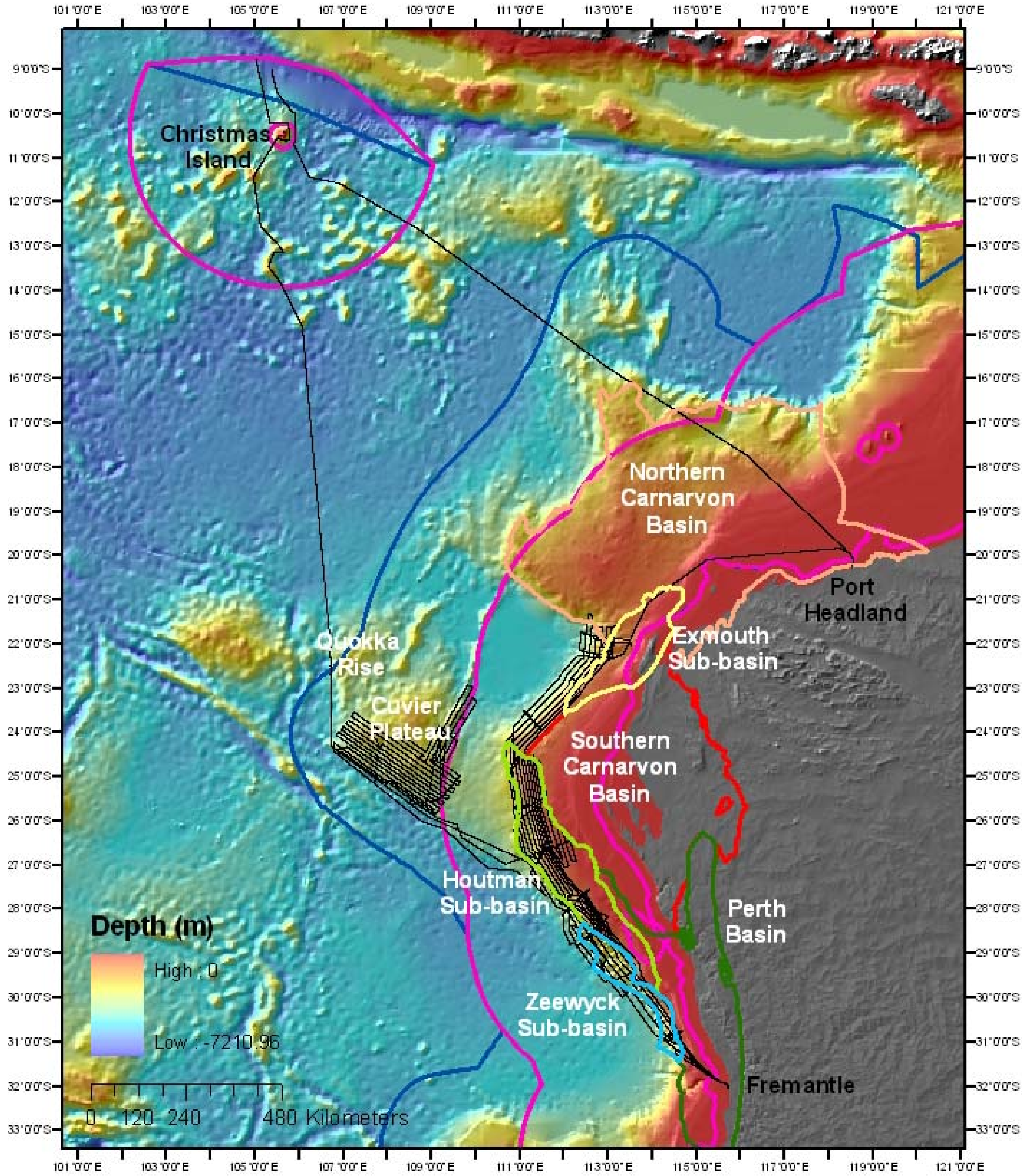



***Figure 1.1.*** *Map of the eastern Indian Ocean and western Australian continental margin along with the route taken by the RV Sonne during survey GA2476 (shown in black). Geophysical data acquisition commenced and concluded within Australian waters, north of Christmas Island. Outlines for the Zeewyck, Houtman, and Exmouth sub-basins are shown in pale blue, pale green and pale yellow, respectively; the Southern Carnarvon, Northern Carnarvon and Perth basins are shown in red, pale beige and dark green, respectively; and the Quokka Rise and Cuvier Plateau are shown by labels. Australia's Exclusive Economic Zone (pink area) and continental shelf (dark blue line) are also shown. Background image is a subset of the Geoscience Australia 250m bathymetry grid of Australia.*

datasets to support Commonwealth Government acreage release. Data will also be provided to the Australian Government to assess environmental significance of the survey areas to assist with the design of a national representative system of marine protected areas.

The western margin of Australia comprises a number of poorly known frontier sedimentary basins. Many of these basins occur in areas adjacent to oil and/or gas producing basins. The main scientific goal of the west Australian margin survey was to collect geological, geophysical, biological and oceanographic data in, or adjacent to, the Zeewyck and Houtman sub-basins (Perth Basin), the Exmouth Sub-basin (Northern Carnarvon Basin) and the Cuvier Plateau to assist in understanding their petroleum prospectivity, geological setting and environmental significance.

### 1.1.1. Zeewyck and Houtman sub-basins (Perth Basin)

Areas of particular interest within the offshore Perth Basin include the Zeewyck and Houtman sub-basins. The term “Perth margin” is used in some parts of this report and refers in general to that part of the continental margin that lies between the Wallaby Saddle in the north and the Naturaliste Trough in the south (Fig. 1.2). The Perth margin is underlain by the Early Permian–Recent Perth Basin, which is a north-south trending, onshore and offshore basin extending about 1,300 km along the southwestern margin of the continent (Fig. 1.2). The offshore part of the Perth Basin includes major depocentres containing Palaeozoic–Mesozoic strata in the Abrolhos and Houtman sub-basins, and Mesozoic strata in the Vlaming and Zeewyck sub-basins (Bradshaw et al., 2003). The onshore Perth Basin is extensively explored, with over 300 wells drilled (Fig. 1.2). Onshore production occurs at five oil fields, two oil and gas fields, and eight gas fields. By comparison, the offshore Perth Basin is under-explored with only 53 wells drilled, with most in the Vlaming Sub-basin, Abrolhos Sub-basin and Beagle Ridge. The most significant offshore discoveries include oil produced from the Cliff Head Field, and three recent discoveries (Frankland—gas; Dunsborough—oil and gas; Perseverance—high $CO_2$ gas). Seismic data coverage in the offshore Perth Basin includes extensive 2D surveys and some recent 3D surveys in the Vlaming, Abrolhos and southern Houtman sub-basins (Fig. 1.2).

Current data coverage in the Houtman Sub-basin varies from sparse regional seismic lines in the north, to extensive seismic coverage and three wells (Charon-1, Houtman-1 and Gun Island-1) in the south (Fig. 1.2). The southern part of the sub-basin is currently being explored as it potentially hosts a commercially viable Jurassic petroleum system (Gorter et al., 2004). Little is known about the exploration potential of the northern part of the sub-basin. Geoscience Australia’s main priority in the Houtman Sub-basin was to understand the geology and exploration potential of its data-poor northern area.

No wells have been drilled in the Zeewyck Sub-basin, and seismic data coverage is limited to 20 regional dip lines of varying vintage and quality (Fig. 1.2). From the limited data it appears that the sub-basin consists of a series of depocentres containing over four kilometres of Middle Jurassic–Lower Cretaceous syn-rift strata overlain by up to three kilometres of Lower Cretaceous–Cainozoic post-rift strata (Bradshaw et al., 2003). Geoscience Australia’s interest in this frontier area is its potential to contain deep-water to ultra-deepwater structural and stratigraphic plays, and/or depocentres that have formed potential outboard source kitchens for traps in the adjacent Houtman Sub-basin and Turtle Dove Ridge.

### 1.1.2. Cuvier margin

The lower part of the Cuvier margin (1,500-5,000 m) potentially overlies a poorly known frontier sedimentary basin or basins.  The Cuvier margin is part of the continental margin that lies between the Wallaby Saddle and Exmouth Plateau (Fig. 1.3).  The lower part of the continental slope (1,500-5,000 m) lies seaward of the current western boundaries of the Exmouth Sub-basin (Northern Carnarvon Basin) and the Southern Carnarvon Basin (Fig. 1.3).  This part of the continental margin has no previous exploration and is generally considered non-prospective.  All of the data acquisition for the survey occurred outside the currently defined Southern Carnarvon Basin and Exmouth Sub-basin (Northern Carnarvon Basin).  The term “Cuvier margin” is used in this report to refer to the study area that lies in the lower part of the continental slope, outside the boundary for the Northern and Southern Carnarvon basins.  Geoscience Australia’s main objective along this part of the Cuvier margin was to understand the geology and exploration potential of this data-poor area, where potential Palaeozoic and/or Mesozoic depocentres are accessible for dredging (Fig. 1.3).

The Palaeozoic-Recent Northern Carnarvon Basin is a large, mainly offshore basin on the northwest shelf of Australia. The basin is Australia's premier hydrocarbon province where the majority of Australia’s deepwater wells have been drilled (greater than 500 metres water depth). The Northern Carnarvon Basin underlies the Exmouth Plateau, Wombat Plateau (on the northern part of the Exmouth Plateau) and part of the Cuvier margin (Fig. 1.3) and includes the Investigator Sub-basin, Rankin Platform, Exmouth Sub-basin, Barrow Sub-basin, Dampier Sub-basin, Beagle Sub-basin, Enderby Terrace, Peedamullah Shelf and the Lambert Shelf.

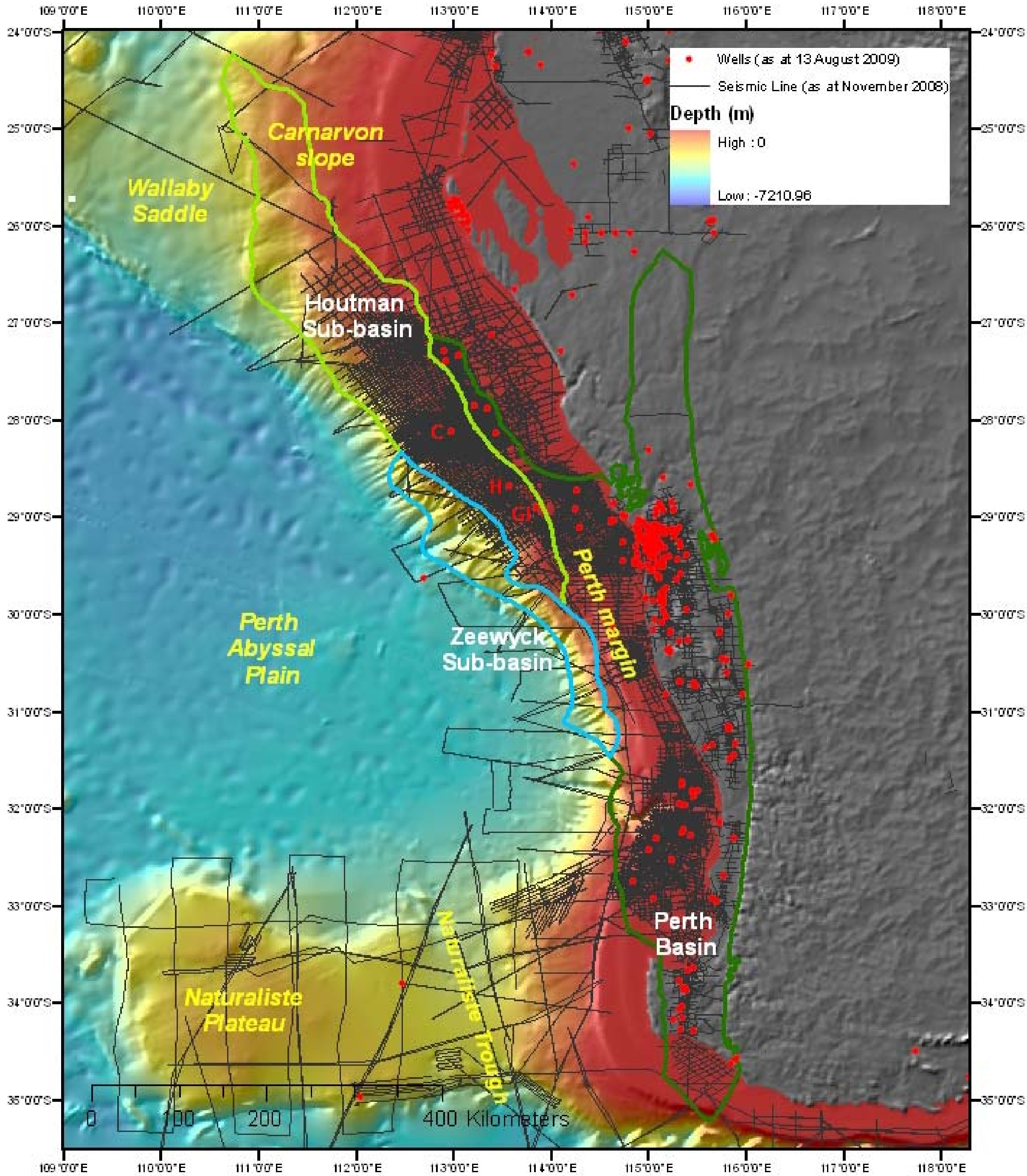



***Figure 1.2.*** *Map of the Perth Basin (dark green) with existing wells and seismic cover. The Zeewyck and Houtman sub-basins are highlighted in pale blue and pale green, respectively. Geoscience Australia seismic data holdings and well locations are shown by thin grey lines and red dots, respectively. Charon-1, Houtman-1 and Gun island-1 wells are labelled C, H and GI, respectively. The physiographic features known as the Wallaby Saddle, Carnarvon slope, Perth margin, Naturaliste Trough, Naturaliste Plateau and Perth Abyssal Plain are labelled also. Background image is a subset of the Geoscience Australia 250m bathymetry grid of Australia.*

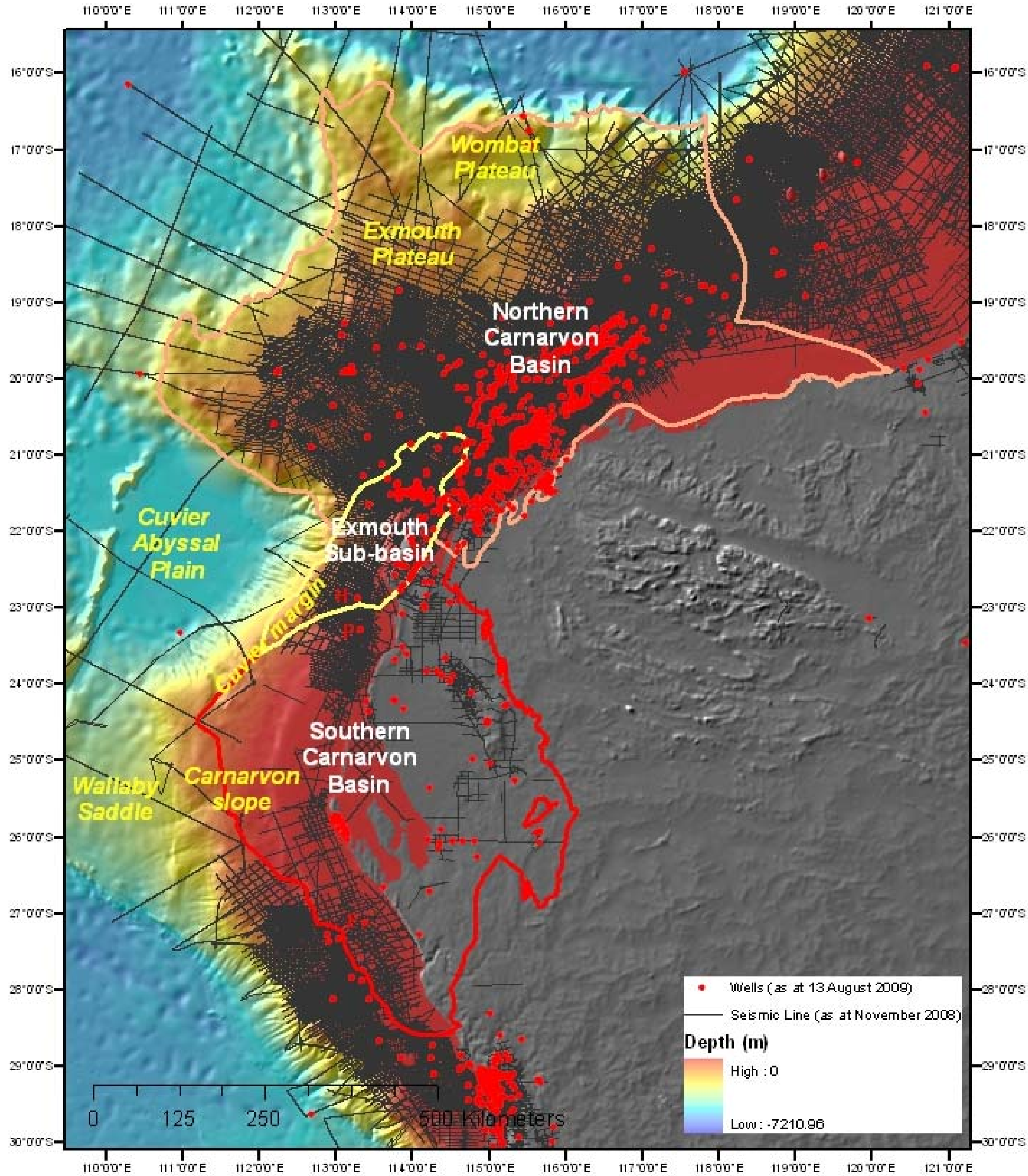



***Figure 1.3.*** *Map of the Northern (pale beige) and Southern Carnarvon (red) basins with existing wells and seismic cover. The Exmouth Sub-basin is highlighted in pale yellow. Geoscience Australia seismic data holdings and well locations are shown by thin grey lines and red dots, respectively. Herdsman-1, Pendock-1 and Edel-1 wells are labelled H, P and E, respectively. The physiographic features known as the Wallaby Saddle, Carnarvon slope, Cuvier margin, Cuvier Abyssal Plain, Exmouth Plateau and Wombat Plateau are labelled also. Background image is a subset of the Geoscience Australia 250m bathymetry grid of Australia.*

The Exmouth Sub-basin contains up to 15,000 m of Triassic to Recent predominantly marine and non-marine siliciclastics. The sub-basin forms part of the Exmouth-Barrow-Dampier intra-cratonic rift system of the Carnarvon Basin. The Exmouth Sub-basin is the most southerly of the northeast-trending Mesozoic sub-basins and is bordered to the northwest by the Kangaroo Syncline (a broad synclinal structure). The bulk of the syn-rift succession accumulated during the Early Jurassic to Early Cretaceous rifting and contains prospective Mesozoic petroleum systems. The main play types include faulted anticlines, tilted fault blocks and stratigraphic pinch-outs, with a regional seal formed by Lower to Upper Cretaceous marine shales and siltstones. Upper Jurassic marine shales form the principal hydrocarbon source.

The Exmouth Sub-basin is an emerging oil province in Australian waters, having yielded in recent years a number of discovered oil and gas fields and a major new oil producing province. The most recent oil discoveries in the northern part of the Exmouth Sub-basin include Stybarrow-1, Ravensworth-1 and Crosby-1. The Pyrenees fields of Crosby, Ravensworth and Stickle were discovered in July 2003 and have estimated recoverable oil reserves of between 80-120 million barrels of oil. First production is expected during the first half of the 2010 calendar year. The estimated economic field life is 25 years. The southern part of the Exmouth Sub-basin lies in deep water (1,000-4,000 metres) and has had little exploration. There is one well (Herdsman-1) in the southern part of the Exmouth Sub-basin and seismic coverage is very sparse.

The Ordovician-Permian Southern Carnarvon Basin incorporates a series of onshore and offshore Palaeozoic depocentres (Fig. 1.3). The offshore part of the basin consists of the Gascoyne Sub-basin, which contains up to five kilometres ?Late Cambrian–Devonian strata and a thin Cretaceous–Cainozoic cover (Iasky et al., 2003). About 20 exploration wells, drilled mostly onshore over Miocene-aged anticlines, had several minor oil and gas shows. Preservation of hydrocarbon accumulations is considered the main exploration risk in this basin (Iasky et al., 2003). In the offshore Southern Carnarvon Basin data coverage is sparse with only two wells (Edel-1 and Pendock-1) drilled and limited seismic coverage (Fig. 1.3).

### 1.1.3. Cuvier Plateau

The Cuvier Plateau is a large marginal plateau (2,100–4,500 m water depth) located about 500 km west of Carnarvon with an areal extent within the 4,500 m isobath of ~70,000 km² (Fig. 1.4). Although the name Wallaby Plateau is widely used in the Australian geoscientific literature (e.g. von Stackelberg et al., 1980; Mihut & Muller 1998; Sayers et al., 2002), on many bathymetric charts and in the Gazetteer of Australia (www.ga.gov.au/place-name/) and the General Bathymetric Chart of the Oceans (GEBCO, www.gebco.net/) the feature is referred to as the Cuvier Plateau. The Cuvier Plateau was initially identified in maps constructed by Heezen and Tharp (1965, 1966; a number of plateaus labelled Wallaby Plateaus) and Falvey & Veevers (1974; eastern plateau labelled Wallaby Plateau). The physiography of the Cuvier Plateau was subsequently described by Veevers et al. (1985; referred to as the Wallaby Plateau), along with a north-western high called the Quokka Rise (Fig. 1.4). To add further confusion, the combined feature of the Cuvier Plateau and Quokka Rise is occasionally referred to in geoscientific literature as the “Wallaby Plateau” (e.g. Symonds & Cameron, 1977; Mihut & Muller, 1998). In this report, the name “Cuvier Plateau” is used to refer to the south-eastern high (Fig. 1.4) and the name “Wallaby Plateau” is used to refer to the composite feature consisting of the Cuvier Plateau and Quokka Rise (Fig. 1.4).

The Wallaby Plateau is separated from the slope to the east (part of which is called the Carnarvon Terrace) by the Wallaby Saddle, which is a wide and deep bathymetric feature about 1,000 metres shallower than the adjoining abyssal areas. The plateau is bounded to the southwest by the Wallaby-Zenith Fracture Zone (Fig. 1.4). Both the Wallaby Plateau and Wallaby Saddle are interpreted as a zone of extensive thick volcanics that were emplaced during the breakup between Australia and Greater India at about 135 Ma (Sayers et al., 2002). Two long narrow ridges, the Sonne and Sonja ridges, trend NNE into the Cuvier Abyssal Plain (Fig. 1.4). The Sonne Ridge has been interpreted as an abandoned spreading ridge formed from about magnetic anomaly M9 (i.e. 129 Ma) to M4-5 time (i.e. 126.5 Ma) (Veevers et al., 1985; Mihut and Muller, 1998) and the Sonja Ridge as a pseudofault resulting from ridge propagation during this episode of spreading (Muller et al., 1998). The nature and origin of the Wallaby Plateau remains speculative; however, its main culmination, the Cuvier Plateau, is believed to have a core of extended continental crust overlain by thick volcanic and volcaniclastic successions formed during the breakup (Symonds et al., 1998; Sayers et al., 2002). Volcanic rocks previously dredged from the Cuvier Plateau are altered transitional tholeiitic basalts with immobile element contents and ratios similar to basalts from the

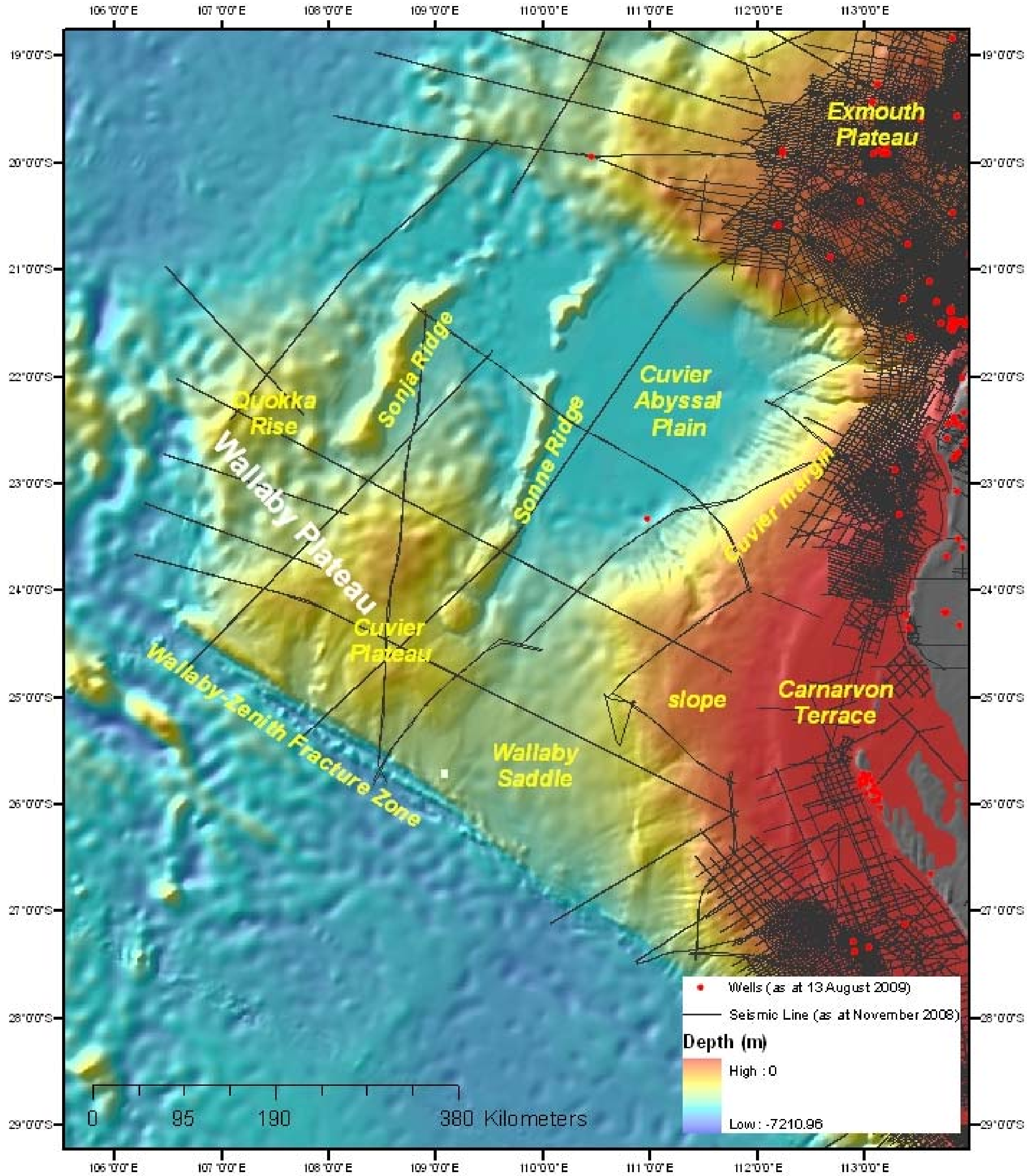



***Figure 1.4.*** *Map of the Cuvier Plateau and Quokka Rise of the Wallaby Plateau composite high with existing wells and seismic cover. Geoscience Australia seismic data holdings and well locations are shown by thin grey lines and red dots, respectively. The physiographic features known as the Cuvier Plateau, Quokka Rise, Sonne Ridge, Sonja Ridge, Wallaby-Zenith Fracture Zone, Wallaby Saddle, Carnarvon slope, Cuvier margin, Cuvier Abyssal Plain and Exmouth Plateau are labelled. Background image is a subset of the Geoscience Australia 250m bathymetry grid of Australia.*

Naturaliste Plateau, eastern Broken Ridge and the Bunbury Basalt of southwestern Australia (Colwell et al., 1994). Analysis of the seismic data collected by Geoscience Australia over the Wallaby Plateau in 1994 showed the presence of stratified sequences which could represent either sedimentary and/or volcaniclastic successions (Sayers et al., 2002). Furthermore, a comparison of seismic profiles over the main part of the Cuvier Plateau and the southern Exmouth Plateau shows visible similarities, possibly suggesting a common origin of these successions (Symonds et al., 1998; Sayers et al., 2002). The sampling program on the Cuvier Plateau was aimed at recovering samples of the pre-breakup sedimentary/volcaniclastic successions, in an attempt to confirm a continental origin of parts of the plateau and the presence of sedimentary basins within this volcanic province. If present, these sedimentary basins may have potential as a future, ultra-deepwater hydrocarbon province analogous to either the Exmouth Plateau or the northern Perth Basin.

## 1.2. GA2476 SURVEY OBJECTIVES

Survey GA2476 represented an opportunity to collect extensive geophysical, geological and biological datasets over poorly known areas of the west Australian continental margin. Although significant exploration has been undertaken in the shallow-water areas of most sedimentary basins in the region, the acquisition of data over the deep-water frontier areas is sparse and remains a core activity of Geoscience Australia through the Commonwealth Government's Offshore Energy Security Program (OESP).

The principal scientific objectives of survey GA2476 were to:

- map the extent and depth to basement of the main depocentres by integrating seismic interpretation with regional gravity and magnetic data, and high resolution bathymetric data;
- determine the nature of the crust underlying sediment depocentres by modelling calibrated geopotential data collected on both the marine reconnaissance survey (GA2476) and concurrent seismic survey (GA0310);
- determine the age, lithology and geochemical characteristics of rocks from the main sediment depocentres in frontier areas and of the underlying basement;
- characterise the physical properties of the seabed associated with the basin areas; and
- characterise the abiotic and biotic relationships on a variety of ecologically significant features (e.g., submarine canyons, ridges, escarpments and abyssal-plain).

The survey leader's log detailing the day to day survey activity on the *RV Sonne* is contained in Appendix A. A table of survey participants is contained in Appendix B.

## 1.3. SOUTHWEST MARGINS SEISMIC SURVEY (GA0310)

In addition to the *RV Sonne* marine reconnaissance survey (GA2476), Geoscience Australia undertook a regional seismic survey along Australia's western margin during the period 26 November 2008 to 24 February 2009, using CGGVeritas's marine seismic vessel *MV Duke*. This survey was also carried out as part of Geoscience Australia's Offshore Energy Security Program. The aim of the survey was to collect regional scale, industry standard, 2D seismic data over many poorly known sedimentary basins to create a basis for future frontier basin studies. Interpretation of these data will include integration with the bathymetry and sample data acquired during survey GA2476.

The seismic survey acquired 7,317 km of industry-standard 2D reflection seismic data using an eight kilometre solid streamer of 12.5 m groups (106-fold), 4,290 in$^3$ source array capacity and 12 s record lengths. In addition, ship-based gravity and magnetic data were acquired along all seismic lines and transits while ocean-bottom and land-based magnetometers were deployed to better constrain the magnetic field.

The 91-day seismic survey extended from Northwest Cape in the north to Cape Leeuwin in the south and acquired seismic data along 45 lines over the deep-water under-explored areas of the Mentelle Basin, Houtman and Zeewyck sub-basins of the Perth Basin, Southern Carnarvon Basin and Wallaby Plateau (Fig. 1.5). Seismic data acquired over these under-explored areas will be used to improve understanding of its structure and investigate the possible presence of depocentres capable of producing and preserving hydrocarbons.

The industry standard 2D seismic traverses were acquired both on dip and strike lines. The traverses either tied to form industry seismic grids or tied into seismic surveys with existing well ties. This survey design will help to constrain regional stratigraphy during future interpretation of this new dataset.

Together with previously acquired data, Geoscience Australia is using the new seismic to address the following scientific objectives along Australia's western margin:

- assess total sediment thickness of the main depocentres;
- better define the structure and stratigraphy of the frontier basins on the western Australian margin;

- better understand the tectonic evolution of the Western Australian margin; and
- better constrain petroleum system elements, hydrocarbon maturation and potential trapping mechanisms in these basins.

Together with the new swath bathymetry and geological samples acquired during the marine reconnaissance survey (detailed in this record), these data and future interpretations will ultimately assist in understanding the petroleum prospectivity of the region and, thus, will aid the Government in delineating future acreage release areas.

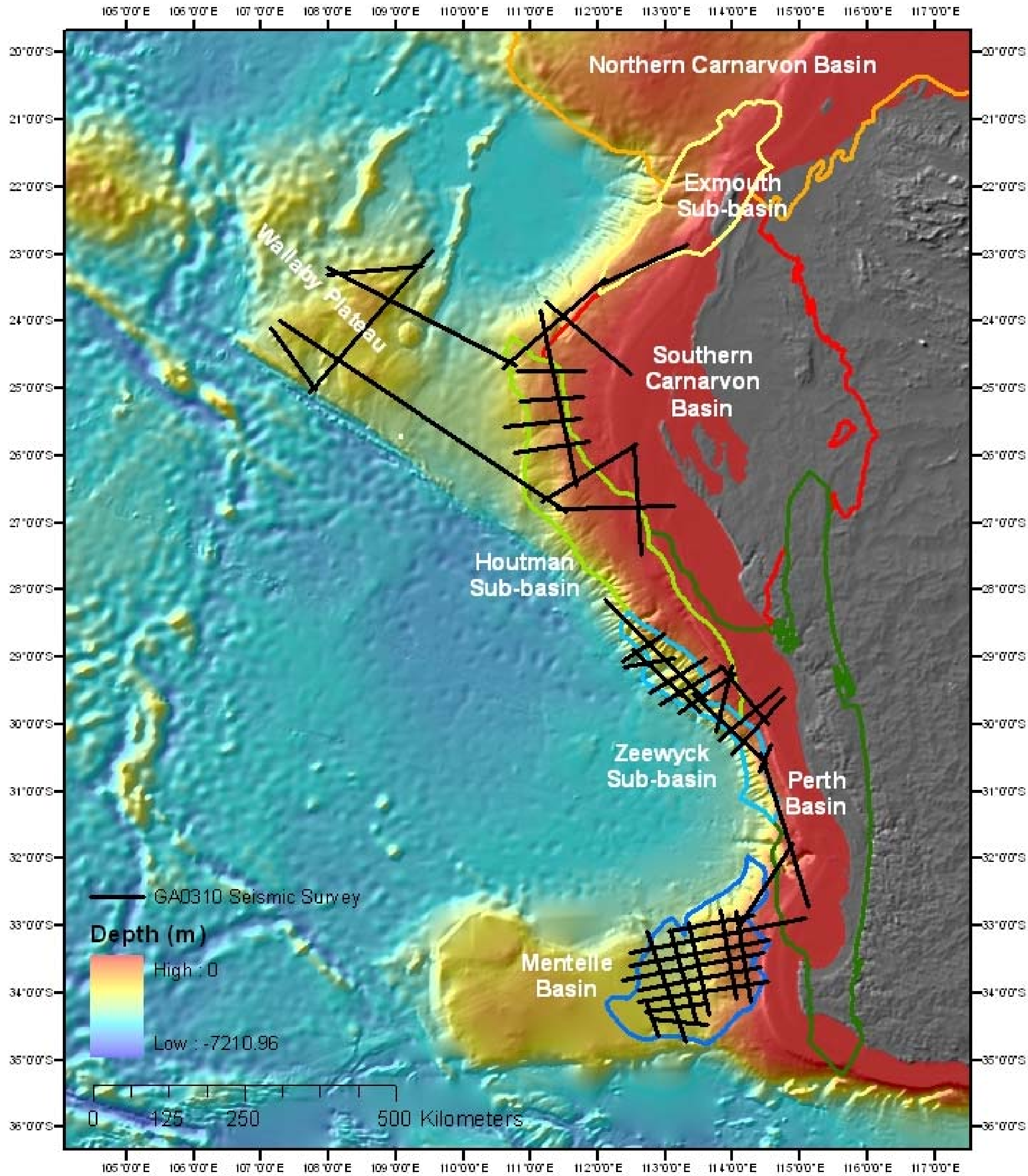



***Figure 1.5.*** *Map of the seismic lines acquired during the Southwest Margin 2D Seismic Survey GA0310 by the MV Duke (shown in black). Outlines for the Zeewyck, Houtman, and Exmouth sub-Basins are shown in pale blue, pale green and pale yellow, respectively; the Southern Carnarvon, Northern Carnarvon, Perth and Mentelle basins are shown in red, pale beige, dark green and dark blue, respectively. Background image is a subset of the Geoscience Australia 250m bathymetry grid of Australia.*

# 2. Geophysics

A comprehensive geophysical survey was conducted to determine the seabed morphology and basement structure within the study areas of the Zeewyck and Houtman sub-basins, the Cuvier margin and the Cuvier Plateau. Each study area was mapped using multi-beam sonar, sub-bottom profiler, magnetometer and gravimeter. The geophysical survey also assisted in identifying priority areas for further detailed investigation and geological sampling. Geophysical data were also acquired within Australian waters on the transits at the start and conclusion of the survey legs from Sunda Strait to the edge of Cuvier Plateau via Christmas Island from 25/10/08 - 28/10/08 and from Port Headland to Indonesia from 16/01/09 - 19/01/09 (Fig. 1.1).

### 2.1. DATA ACQUISITION

#### 2.1.1. Multi-beam Sonar

The RV Sonne has a SIMRAD EM120 12 kHz deep sea multi-beam sonar system onboard. The EM120 has 191 beams with a one degree beam width, and an angular coverage of up to 150°. The low frequency of the multi-beam system made it capable of maintaining an optimal swath width over the deepest parts of the continental margin.

The survey consisted of four study areas within the Zeewyck sub-basin, Houtman sub-basin, Cuvier margin and Cuvier Plateau (Fig. 1.1). Survey lines were orientated, where possible, parallel to bathymetric contours for optimal multi-beam sonar acquisition. Generally, survey lines were laid out in a northwest to southeast direction over the Perth margin (Zeewyck and Houtman sub-basins study areas) and Cuvier Plateau and in a northeast to southwest direction over the Cuvier margin. Ship speeds during the survey were generally between nine and eleven knots but were ultimately dependent on sea state. Higher ship speeds were achieved when travelling with swell direction and currents, which were mainly directed to the northwest throughout the survey.

Sound velocity profiles (SVPs) were obtained to account for changes in the speed of sound in the water column due to changes in temperature and salinity with latitude and other oceanographic features (i.e. Leeuwin Current). The acquired SVP was then used in the multi-beam swath acquisition to determine the depth of the water bottom. SVPs used during the transits to and from the survey areas were generated using the on-board SVP builder utility software, which uses global climatology data to derive a SVP for a given set of coordinates. This method proved so effective at generating accurate SVPs during transits through deep water that conductivity-temperature-depth (CTD) profiler deployments were not a high priority. However, a total of eight CTD and two Expendable Bathythermographs (XBT) casts were undertaken over the study areas. The CTD data were used to generate more accurate SVPs that complimented those generated from the global climatology data. Data from the CTD also allowed calculation of absorption coefficients. The absorption coefficient improves the backscatter measurements by correcting the transducer gains for changes to the speed of sound through the water column as a result of changes in salinity and temperature. A summary of all CTD and XBT data acquisition is located in section three (Sample Acquisition) of this record.

#### 2.1.2. Multi-beam Sonar Backscatter

Backscatter, or acoustic reflectance, was also recorded by the Simrad EM120 multi-beam sonar system. Acoustic reflectance (intensity) was recorded as a voltage and then returned as a value in decibels (dB). Acoustic reflectivity, which is a surrogate for substrate hardness, is normally displayed as a grey scale image. High acoustic reflectivity (i.e., hard seabed type) are generally displayed as light areas and low acoustic reflectivity (i.e., soft seabed type) are generally displayed as dark areas.

#### 2.1.3. Shallow Seismic Reflection

The RV Sonne's hull-mounted ATLAS PARASOUND P70 parametric sub-bottom profiler (www.atlashydro.atlas-elektronik.com) was used during the survey to record the acoustic response of surface and shallow sub-bottom sediments. The parametric system operates in water depths of between ten metres and 10,000 m at primary frequencies of 18-39 kHz to provide secondary frequencies as low as 500 Hz. With a secondary parametric source level of approximately 206 dB, the system is capable of substrate penetration greater than 200 m with resolutions of less than 15 cm depending on surface and sub-bottom characteristics. Raw data was stored as ATLAS Sounding Data (ASD) as well as SEG-Y format for subsequent visualisation and further processing.

#### 2.1.4. Gravity and Magnetics

Gravionic German Geo Services GbR was contracted by Nautilus GmbH, a subsidiary of RF-Forschungsschiffahrt GmbH (RF), on behalf Geoscience Australia to acquire and process gravity and magnetic data. On-board time stamping and positioning of the gravity and magnetic data was provided by a Trimble 4700 GPS (Global Positioning System) receiver linked to a Trimble L1/L2 antenna installed on top of the superstructure deck. Bathymetry data necessary for post-processing were acquired with the Simrad EM120 multi-beam sonar system (section 2.1.1 and 2.2.1). For detailed descriptions of data acquisition, processing and preliminary results, see the report by Gravionic German Geo Services GbR (2009) in Appendix D.

***Gravity***

Gravity data were acquired using a CHEKAN-AM system that consisted of a gravity sensor, a gyro-stabilized platform and a data handling subsystem. The gravity sensor was a two-quartz pendulum and torsion-fibre system designed to counteract horizontal accelerations. It was enclosed within a case that was filled with viscous polymethylsiloxane for damping and temperature stabilization. Further temperature control was provided by four pairs of thermoelectric transducers. Levelling and accelerations was controlled by the gyro-stabilized platform and horizontal accelerometers. Vertical accelerations were eliminated by low pass filtering of the data. Raw gravity data were recorded at 10 Hz and real-time processed gravity data were recorded at a rate of 1 Hz. The CHEKAN-AM system has a measurement range of 10 Gal minimum, a linear measurement drift of about 2 mGal per day, a measurement resolution of 0.01 mGal, and an assumed measurement accuracy at line crossovers of $<1$ mGal.

In order to enable a tie to the Australian Fundamental Gravity Network (AFGN) and the International Gravity Standardization Net (IGSN71), several readings were taken at land stations in Germany, Singapore and Fremantle at the start, during and end of the survey. For the land connection, a LaCoste and Romberg Gravimeter G368 was used. Details of these reference stations are given in the report by Gravionic German Geo Services GbR (2009) in Appendix D.

***Magnetics***

Magnetic data were acquired using a Geometrics G-882 caesium-vapour marine magnetometer. Measurements of the ambient magnetic field strength were made using an internal CM-221 mini-counter that has a sensitivity of $<0.004$ nT/$\sqrt{}$Hz RMS and an absolute accuracy of $<3$ nT. The caesium mini-counter was oriented in the vertical position within the tow-fish apparatus and was towed 267 m behind the RV Sonne. This reduced the error resulting from the instability of the tow fish and the mini-counter's proximity to the steel vessel and ensured the best performance of the caesium mini-counter over the entire survey area. The magnetic data were logged using MagLog, which is a Geometrics software package that combines a data logger and system controller. MagLog uses the position of the vessel from the Trimble 4700 GPS receiver and a proprietary dragging algorithm to calculate the fish position. The software package interpolates the fish position to provide 10 Hz magnetic and position data in real-time.

For the correction of diurnal variations, two permanent geomagnetic reference stations near Perth and Exmouth were used, as well as four additional temporary magnetometer reference stations installed by Geoscience Australia at Geraldton, Carnarvon, Meekatharra and to the south of Perth near Busselton.

### 2.2. DATA PROCESSING AND ANALYSIS

#### 2.2.1. Multi-beam Sonar

The multi-beam sonar data were processed using Caris HIPS/SIPS version 6.1 software. Initially, a vessel configuration file was created to record the co-ordinate offsets of the motion sensor, the DGPS antenna and patch test results. The raw swath sonar data, in "raw.all" format, for each line was then imported into the project and the vessel information assigned to the data. The motion sensor, DGPS antenna and heading data were then cleaned using a filter that averaged adjacent data to remove outliers.

The multi-beam sonar data were cleaned by applying several filters that removed spikes within the bathymetry data using user-defined threshold values. A visual inspection of the data for each line was then undertaken where artefacts and noisy data not removed by the filtering process were removed manually using Swath and Subset Editor modules of the Caris HIPS/SIPS software. Due to the good quality of data acquired, post-processing of the raw data was kept to a minimum. A weighted grid of the processed data was then created for each survey area.

Preliminary bathymetry grids for each survey area were produced at 100 m resolution. The coordinate system for the bathymetry grid was WGS84 (datum) UTM-49S (projection). The gridded data for each survey area were exported as a XYZ ASCII file and a georeferenced image (GeoTiffs) for import into ArcGIS software. The final processed multi-beam data were exported as Generic Sensor Format (GSF), which is a multi-beam data format that can be read by non-Caris users.

### 2.2.2. Multi-beam Sonar Backscatter

Geoscience Australia and the Centre for Marine Science and Technology (CMST) at Curtin University of Technology have co-developed a multi-beam backscatter software toolbox for processing multi-beam backscatter data acquired using SIMRAD EM series and Reson SeaBat series sonars that includes the SIMRAD EM120 multi-beam sonar system installed on the RV Sonne. The multi-beam backscatter software toolbox version v8.11.02.1 was used for processing the multi-beam backscatter data acquired during the survey. The software toolbox includes an algorithm to calculate the backscatter coefficient corrected for transmission loss and isonification areas, and is based on the equation given in Talukdar et al. (1995). With these measurements, the corresponding incidence angle and coordinates on the seafloor (i.e. X, Y and depth (Z)) are calculated. The full processing algorithm was developed in the computer software program Matlab®. It contains the following steps:

1. conversion from the SIMRAD "raw.ALL" data format into Matlab data format;
2. calculation of the absolute seafloor coordinate position (X, Y, Z) and the incidence angle (θ) for each beam and each ping;
3. removal of the system transmission loss;
4. calculation of the surface backscattering strength, which involves correction for transmission loss and area; and
5. removal of the angular dependence.

The SIMRAD multi-beam sonar system incorporates a scattering model that makes best use of the limited dynamic range of the electronics used (Hammerstad, 2000). The scattering model includes corrections for Lambert's Law and the scattering area. In addition, the SIMRAD multi-beam sonar system uses different expressions in three different angular domains of the incidence angle, the first domain relates to the normal incidence angle ($\theta = 0°$); the second domain pertains to the incidence angle (defined by $0° < \theta < \theta_{crossover}$); and the third domain involves the oblique incidence angle ($\theta > \theta_{crossover}$, where $\theta_{crossover}$ is the crossover angle that is between 5° and 30° as selected by the operator).

The surface scattering coefficient can be determined by correcting the backscatter intensity for the actual transmission loss and normalising the values for the area under investigation. The transmission loss is the energy lost due to spherical spreading of acoustic energy and acoustic absorption in the water column. Spherical spreading loss is a function of range (R ) and for two-way travel is equal to $40\log_{10}R$ (measured in decibel (dB)). Absorption loss is also a function of range and the acoustic absorption coefficient (a), so for two-way travel this is 2aR (measured in dB). The area that controls the peak backscatter intensity is called the insonified area. The more accurate insonified area is calculated as:

$$A = \varphi R^2\left\{\cos(\theta)\tan\left[\cos^{-1}\left(\frac{\cos(\theta)}{1+\frac{cT_w}{2R}}\right)\right] - \sin(\theta)\right\} \quad (2.1)$$

A technique for removing the angular dependence developed by the CMST was applied to the data (cf. Gavrilov et al., 2005a). Removing the local mean angular trend also filters out large-scale variations due to change, either sharp or gradual, in the seabed properties along the swath line. To recover this useful information and obtain absolute values of backscatter strength, the angularly equalised backscatter strength within the sampling window is increased by adding the window-mean backscatter level at a specified reference angle - in this case a moderate angle of 25° was used.

The algorithm is as follows:

$$BScor(X,Y,\theta) = BS(X,Y,\theta) - \overline{BS}(X,Y,\theta) + \overline{BS}(X,Y,25°) \qquad (2.2)$$

Where BS(X,Y,θ) is all the backscatter data within the sampling window (X,Y) at angle θ, $\overline{\text{BS}}$ (X,Y,θ) is the mean backscatter strength within the sampling window (X,Y) at angle θ, and $\overline{\text{BS}}$ (X,Y,25°) is the mean backscatter strength measured within the sampling window at the reference angle of 25°.

Following the procedure described in Siwabessy et al. (2006), and Gavrilov and Parnum (in press), the probability distribution function (PDF) and the probability of false alarm (PFA) were derived from normalised backscatter values using a linear scale across a homogenous area. The PFA (PFA=1-CDF, where CDF is a cumulative distribution function) plot is very useful to visually emphasise the tail portion of the distributions, which is of particular importance for multi-modal or heavier tail distribution. The backscatter values were then normalised to the maximum backscatter value of the area and a gamma distribution model fitted to the resulting distribution. This approach is based on the work of Middleton (1999) who demonstrated theoretically that the statistical distribution of the average backscatter intensity for a Gaussian scattering process should follow a gamma distribution. A nonparametric Kolmogorov-Smirnoff (KS) statistic test was used to assess the goodness-of-fit between the theoretical and experimental distributions of the data collected in the study areas using respective cumulative distribution functions (CDFs). This defines the maximum absolute difference ($D_{KS}$) between the theoretical and experimental CDFs. The $p$-value of $D_{KS}$ indicates the probability of observing an absolute difference greater than $D_{KS}$ under the null hypothesis ($H_o$).

### 2.2.3. Shallow Seismic Reflection

The ATLAS sub-bottom profiler used ATLAS HYDROMAP CONTROL and ATLAS PARASTORE software to enable the processing and display of data acquired in real-time. Preliminary interpretation of the data was recorded as a log of echo types using a combination of classification schemes documented in Damuth (1980), Chouch et al., (1997) and Whitmore and Belton (1997) (Table 2.1). The log documented changes in the acoustic character of the data and the associated echo types.

### 2.2.4. Gravity and Magnetics

Gravionic German Geo Services GbR (Gravionic) were contracted to process the gravity and magnetic data. Detailed descriptions of the Gravionic approach to data processing are available in the accompanying report (Appendix D). Processed data will be supplied to Geoscience Australia and, once combined with existing data from the Southwest Margins Seismic Survey (GA-0310), will be used in regional hydrocarbon prospectivity studies of the southwest Australian margin. The raw and processed data will be available from GA's Data Repository at cost of transfer.

***Gravity Data***

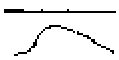
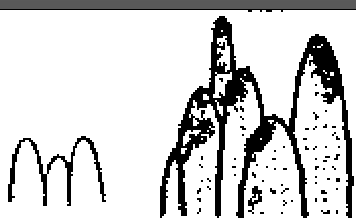
The measured gravity data will be tied to the Australian Fundamental Gravity Network (AFGN) and the International Gravity Standardization Net (IGSN71). Gravionic will apply a number of corrections and reductions to the gravity data to remove the influence of earth tides, instrumental drift, gravity variations with latitude (latitude correction), Eötvös effect (Eötvös correction), elevation effect (free-air correction) and topography/bathymetry (Bouguer correction). These corrections are described in more detail in Gravionic's post-survey report (Appendix D).

***Magnetic Data***

The raw magnetic data will be corrected for diurnal variations using the permanent and temporary magnetic reference stations in the vicinity of the survey area. Final processing will be carried out by Gravionic after they receive the magnetic reference station data from Geoscience Australia. An appropriate International

Geomagnetic Reference Field will be removed from the diurnally-corrected data to give magnetic anomalies.

**Table 2.1.** The sub-bottom profiler classification scheme used on survey GA2476. The classification scheme is outlined in Damuth (1975, 1980) and Whitmore and Belton (1997) and their echo character examples are presented here.

| Echo Type 1: | Distinct | |
|---|---|---|
| Type IA: | Sharp, continuous echo with no sub-bottom reflectors.<br>Diagrammatic line drawings: |  |
| Type IB: | Sharp, continuous echo with continuous parallel sub-bottom reflectors.<br>Diagrammatic line drawings: |  |
| Type IC: | Sharp, continuous echo with non-conformable sub-bottom reflectors.<br>Diagrammatic line drawings: |  |
| Echo Type 2: | Indistinct or Prolonged | |
| Type IIA: | Semi-prolonged echo with discontinuous parallel sub-bottom reflectors.<br>Diagrammatic line drawings: |  |
| Type IIB: | Prolonged to very prolonged "fuzzy" echoes with no sub-bottom reflectors.<br>Diagrammatic line drawings: |  |
| Type IIBa: | Irregular sharp echo (IA) overlying a prolonged (IIB) echo with no sub-bottom reflectors and separated by an acoustically transparent zone.<br>Diagrammatic line drawings: |  |
| Echo Type 3: | Hyperbolic or Parabolic | |
| Type IIIA: | Large (>100 m relief), irregular, overlapping prolonged hyperbolic echoes. Typically with large variations in vertex elevation.<br>Diagrammatic line drawings: |  |
| Type IIIB: | Regular, single hyperbolic echoes with varying vertex elevations and conformable sub-bottom reflectors.<br>Diagrammatic line drawings: |  |

| | | |
|---|---|---|
| Type IIIC: | Smaller (<100 m relief), regular to irregular, overlapping, semi-prolonged to prolonged hyperbolas with varying vertex elevation. Diagrammatic line drawings: |  |
| Type IIID: | Small, regular, overlapping hyperbolas, with vertices tangential to the sea floor. Diagrammatic line drawings: |  |
| Type IIIE: | Regular, overlapping hyperbolas, with vertices tangent to a parallel, sub-bottom reflectors. Diagrammatic line drawings: |  |
| Type IIIF: | Irregular, single hyperbolae with non-conformable sub-bottom reflectors (migrating drifts). Diagrammatic line drawings: |  |
| Echo Type 4: | Hybrid or Combined | |
| For example Type IA/IIIC and IB/IIIC: | Short (<1 km) flat sections of either IIA or IIB echo type between large irregularly spaced hyperbolic IIIC echo types. Diagrammatic line drawings: |  |

## 2.3. RESULTS

### 2.3.1 Multi-beam Sonar

A total of 26,475 line kilometres of swath data were acquired during 86 days of surveying. 20,906 line kilometres of swath data were within the study areas and the remaining line kilometres were acquired during ship transits to and from the study areas (Fig. 2.1, Table 2.2). The GA2476 survey added 229,226 km$^2$ of multi-beam data in water depths ranging from 6,345 m to 15 m to a region that was previously data poor (Table 2.2). Line spacing of the swath tracks ranged from 16 kilometres to five kilometres. The line spacing of the swath tracks was designed to provide maximum overall coverage over the survey areas in water depths typically ranging from 1,000 – 4,000 m and often in excess of 5,000 m, particularly on the edge of the Perth and Cuvier margins and along the edge of the Cuvier Plateau study area. The performance of the multi-beam sonar system during the survey as reflected by data quality and swath coverage was generally very good. The low reflectivity of the surficial ooze throughout the survey areas reduced the expected swath coverage, and resulted in a swath width on the order of four to five times the water depth. The reduced swath coverage necessitated occasional revisions to the survey plan and resulted in some gaps in multi-beam coverage between some lines. Summary statistics of the multi-beam sonar data are provided in Appendix C.

Weather conditions during the survey were generally good. The sea state ranged from slight to moderate, with regular swells of between one to three metres. Average wind speeds were between five to ten metres/second (or 18-36 km/hr) and winds were mostly from the south and south-southwest (see section 9.3.3 of this record). Data quality was greatly affected by the sea state. In sea states greater than three (of the World Meteorological Organisation sea state code), significant levels of cavitation (formation of vapour bubbles) occurred and resulted in interference between the sonar transducer and the received signal. Generally noise levels in the data were more noticeable when heading into prevailing seas (i.e. heading southwards into southerly winds).

Features revealed by the geophysical survey include: canyons, slumps, volcanic cones and seamounts. A comprehensive description of the geomorphology is contained in section five (Geomorphology). The total data acquired for the survey amounts to ten Gigabytes of raw multi-beam swath data.

**Table 2.2.** Summary statistics of multi-beam sonar data collected by survey leg and survey area.

| | Multi-beam area (km$^2$) | Multi-beam line-km | | Multi-beam area (km$^2$) | Multi-beam line-km |
|---|---|---|---|---|---|
| ***Survey Leg*** | | | ***Study Areas*** | | |
| Leg 1 | 75,708 | 7,595 | Zeewyck Sub-basin | 35,865 | 5,467 |
| Leg 2 | 55,045 | 8,092 | Houtman Sub-basin | 34,465 | 5,803 |
| Leg 3 | 78,113 | 8,863 | Cuvier margin | 32,683 | 3,155 |
| Transit from Port Headland | 21,290 | 1,925 | Cuvier Plateau | 63,428 | 6,481 |
| | | | Transits | 62,785 | 5,596 |
| **Total Survey** | **229,226** | **26,475** | **Total Survey** | **229,226** | **26,475** |

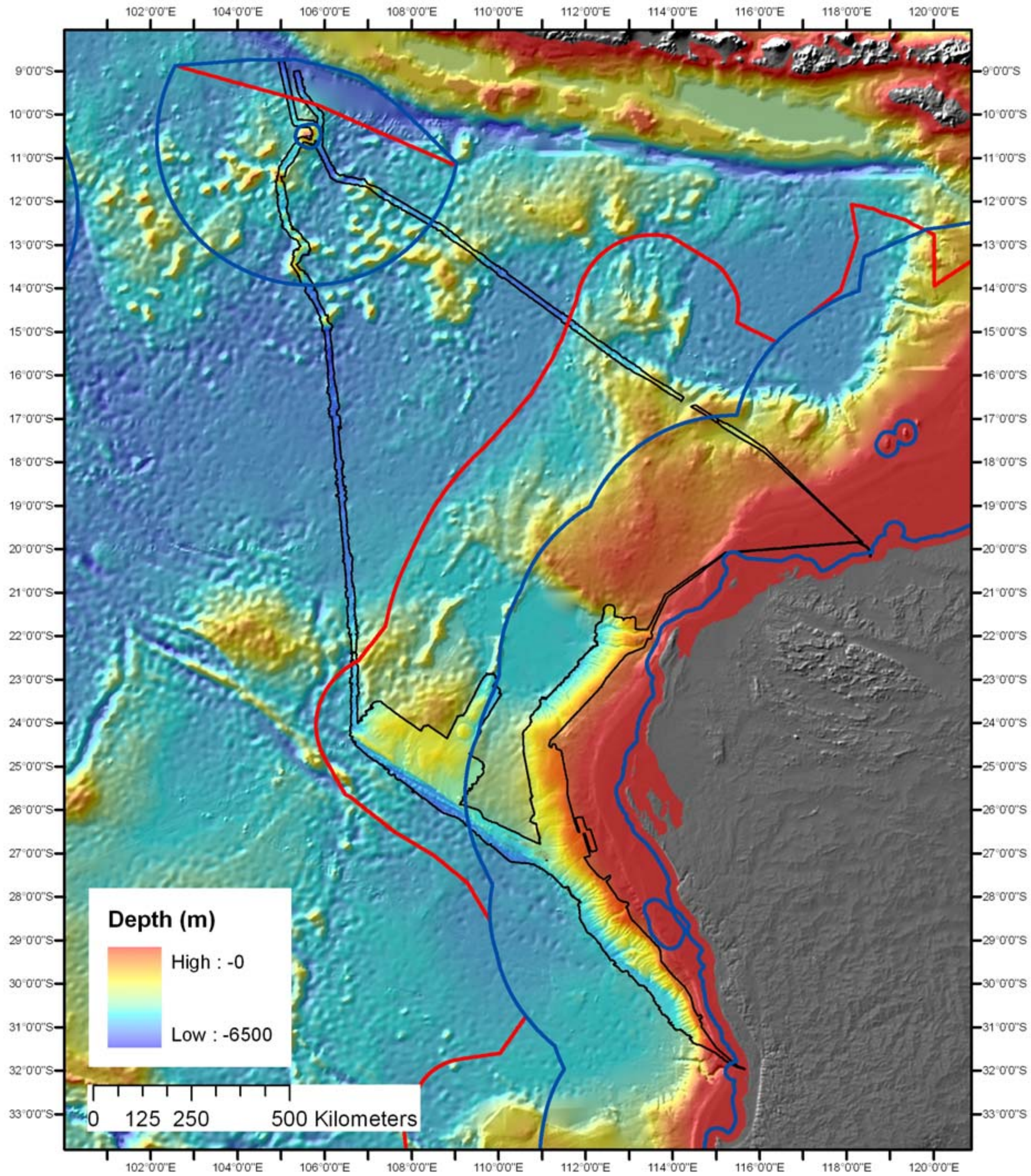



***Figure 2.1.*** *Coverage of multi-beam bat hymetry data acquired during survey GA 2476. Outline of the areas of acquired multi-beam bathymetry data is shown in black. Note the transits to and from the study areas via Christmas Island.*

### 2.3.2. Multi-beam Sonar Backscatter

The multi-beam backscatter image was processed and arranged using the multi-beam backscatter software toolbox version v8.11.02.1 co-developed by Geoscience Australia and CMST from Curtin University. Results from the survey areas are shown in Fig. 2.2. In general, the quality of the backscatter data is reasonably good. However, there are instances in which the quality drops and is due mainly to bad weather and/or very soft sediment (e.g. ooze). High backscatter strength (or high acoustic reflectivity) is shown in red in Fig. 2.2 and occurs dominantly around canyons in the Zeewyck and south Houtman sub-basins. High backscatter strengths are associated with harder, more reflective substrates, such as outcrops of rock. Low backscatter strength (or low acoustic reflectivity) is shown in blue in Fig. 2.2 and occurs dominantly where soft sediment, such as mud and ooze, accumulates – for example the top of the plateau in the Cuvier Plateau (Fig. 2.2).

Various geomorphic features are observed in the study areas and are in general are also visualised in the backscatter image. The grid of backscatter strengths from the west Australian margin study areas can be quantised into low and high backscatter strengths (see Fig. 2.3). The study areas are largely associated with low backscatter strengths related to various soft sediments, mainly ooze (e.g. Cuvier Plateau in Fig. 2.2). The presence of canyons is generally associated with high backscatter strengths (e.g. Cape Range Canyon in Fig. 2.2). A histogram of backscatter strengths from the study areas (Fig. 2.3) suggests two peaks at -36.5 dB and -25.5 dB that are associated with low and high backscatter strengths respectively.

Backscatter strengths from a cross-section along the Cuvier Plateau study area (located in Fig. 2.2) were extracted to produce the histogram shown in Fig. 2.4. The histogram shows two peaks at -39.5 dB and -23.5 dB that correspond to low acoustic reflective facies (such as mud on the plateau and valley of the study area) and higher acoustic reflective facies (such as outcropping rocks along the ridge, escarpment and terraces within the study area), respectively. The backscatter strengths extracted over an area of homogeneous seabed from the plateau of the Cuvier Plateau study area produce the PDF and PFA histograms shown in Fig. 2.5. Both gamma and log-normal distribution models fit the empirical distribution derived from the plateau (Fig. 2.5) according to the KS statistic test ($p$-value>0.05) and indicates an acoustically homogeneous seabed. The gamma distribution model (red line in Fig. 2.5) suggests a peak occurring at -38.84 dB.

A histogram of the backscatter strengths from the Cuvier margin study area (Fig. 2.6), was produced from a cross-section through the margin (located in Fig. 2.2). A skewed, backscatter-strength histogram with a peak at -34.5 dB characterises the Cuvier margin study area. Moderate to low backscatter strengths dominate the Cuvier margin study area, which are different from and higher than the low backscatter strengths found from the plateau surface of the Cuvier Plateau study area.

Backscatter strengths from a cross-section along the Houtman Sub-basin study area, which is associated with the Perth margin and Carnarvon slope, (located in Fig. 2.2) were extracted to produce the histogram shown in Fig. 2.7. The Houtman sub-basin part of the Perth margin and Carnarvon slope (see section 4 Geomorphology) is more diverse in acoustic characters than the Cuvier margin and the Cuvier Plateau study areas. The histogram suggests two peaks at -36.5 dB and -32.5 dB and a minor peak at -21.5 dB that correspond to low acoustic reflective facies (such as mud), moderate acoustic reflective facies and higher acoustic reflective facies (such as outcropping rocks in canyons and volcanic cones), respectively.

A histogram of the backscatter strengths from the Zeewyck Sub-basin study, which is associated with the Perth margin (Fig. 2.8), was produced from a cross-section through the study area (located in Fig. 2.2). The histogram shows two peaks at -36.5 dB and -23.5 dB, that correspond to the lower acoustic reflective facies (such as mud) and higher acoustic reflective facies (such as outcropping rock in canyons), respectively. Like the part of the Perth margin study area associated with the Houtman Sub-basin, the Zeewyck Sub-basin area is diverse and complex in its acoustic characteristics (Fig. 2.2). The two sub-basin areas are mostly characterised by canyons with outcrops of rock producing zones of high backscatter strength.

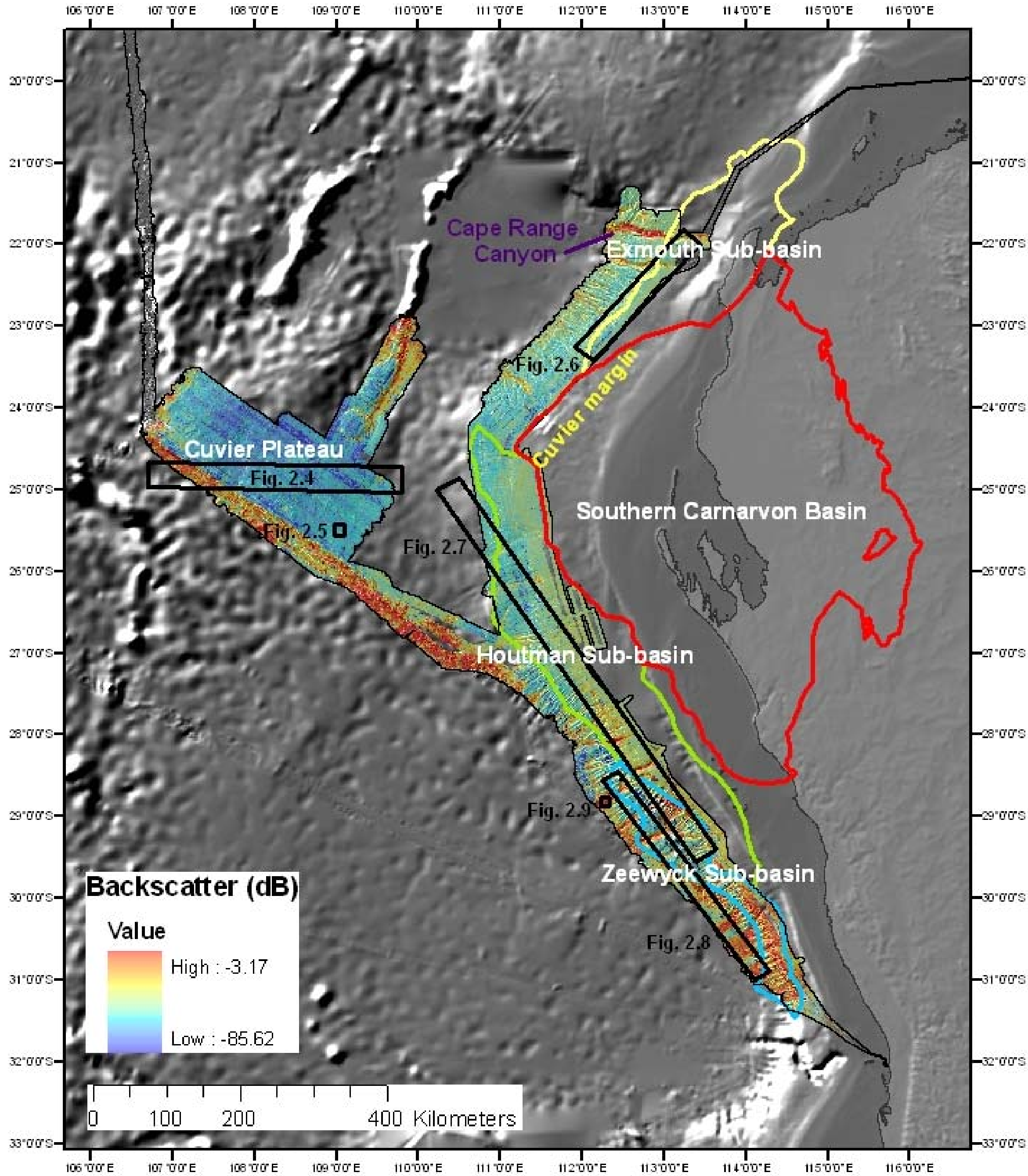



***Figure 2.2.*** *Coverage of multi-beam backscatter data acquired during survey GA2476. High backscatter strength is displayed in red and low backscatter strength is displayed in blue. Thick black boxes indicate areas used to generate backscatter histograms seen in Figures 2.4-2.9 that show local 'high' and 'low' backscatter responses.*

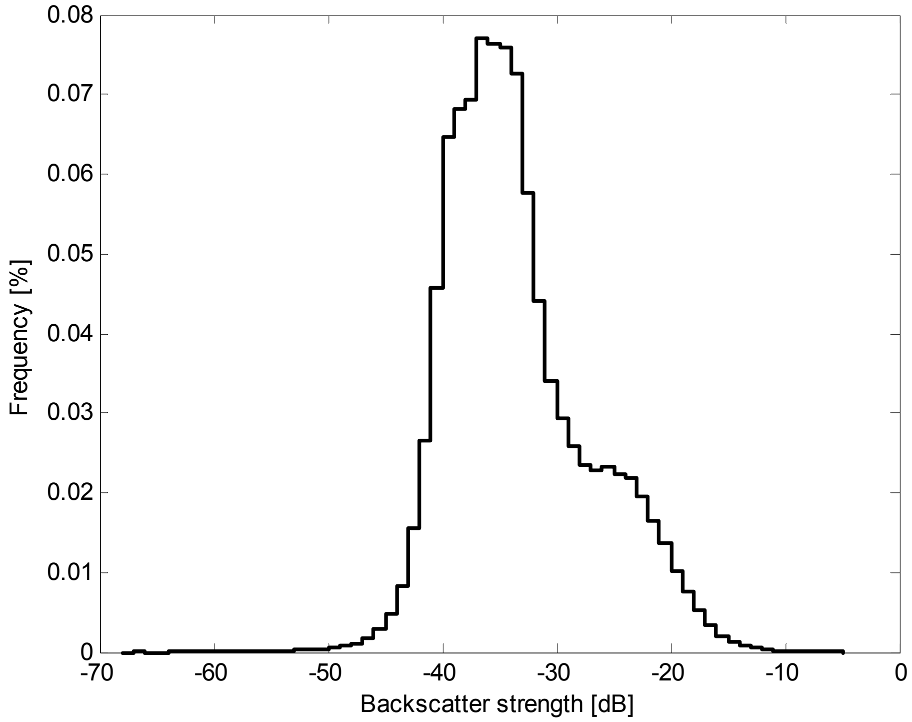



***Figure 2.3.*** *A histogram of the backscatter strengths from the region shown in Fig. 2.2. Peaks occurring at -36.5 dB and -25.5 dB.*

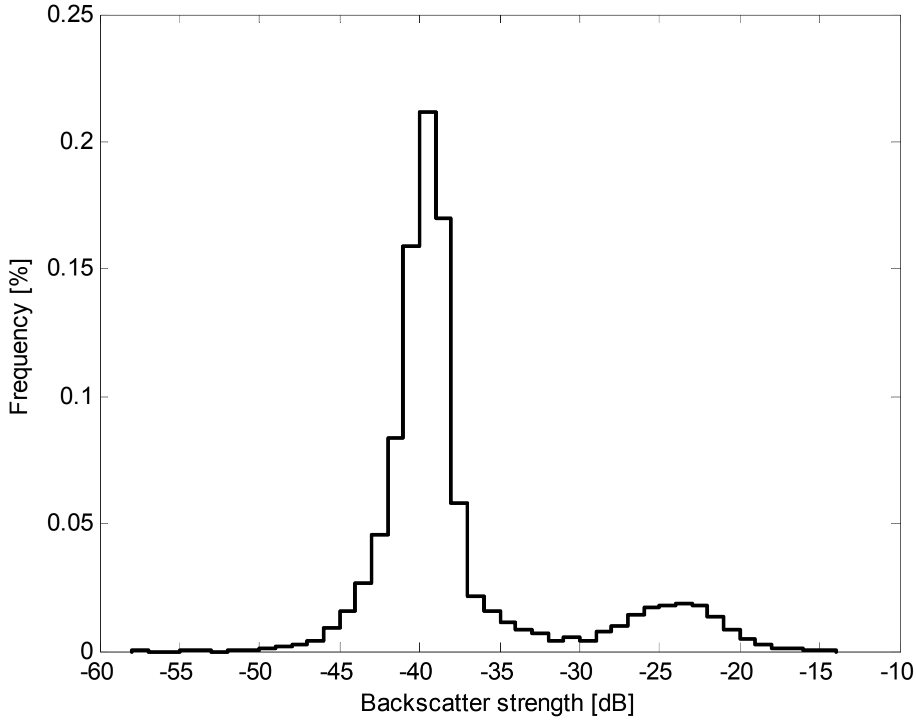



***Figure 2.4.*** *A histogram of the backscatter strengths diagonally across the Cuvier Plateau study area. Peaks occurring at -39.5 dB and -23.5 dB.*

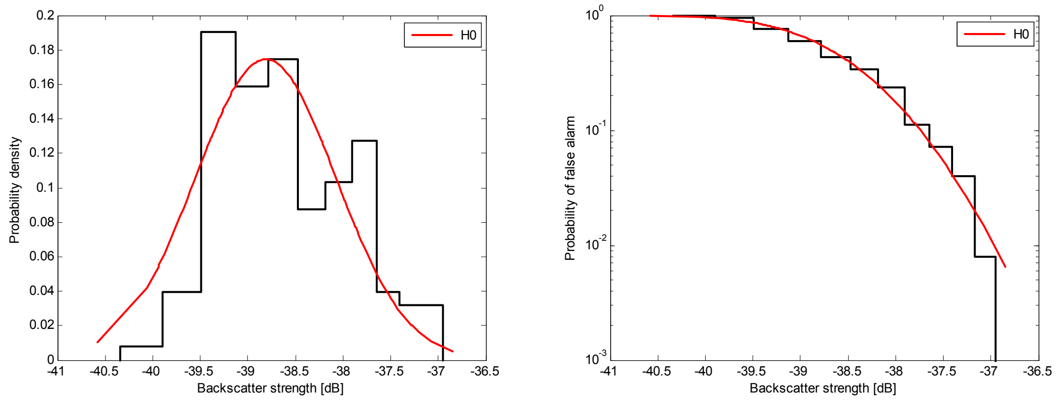



***Figure 2.5.*** *Histograms/Plots of the Probability distribution function (PDF) and probability false alarm (PFA) that have the lowest backsc atter strengths over a r elatively homogenous area on the plateau of the Cuvier Plateau study area (see Fig. 2.2). The lowest backscatter strengths are due to ooze sediments on the plateau. The theoretical gamma distribution model (red line, labelled HO) peaks at -38.84 dB.*

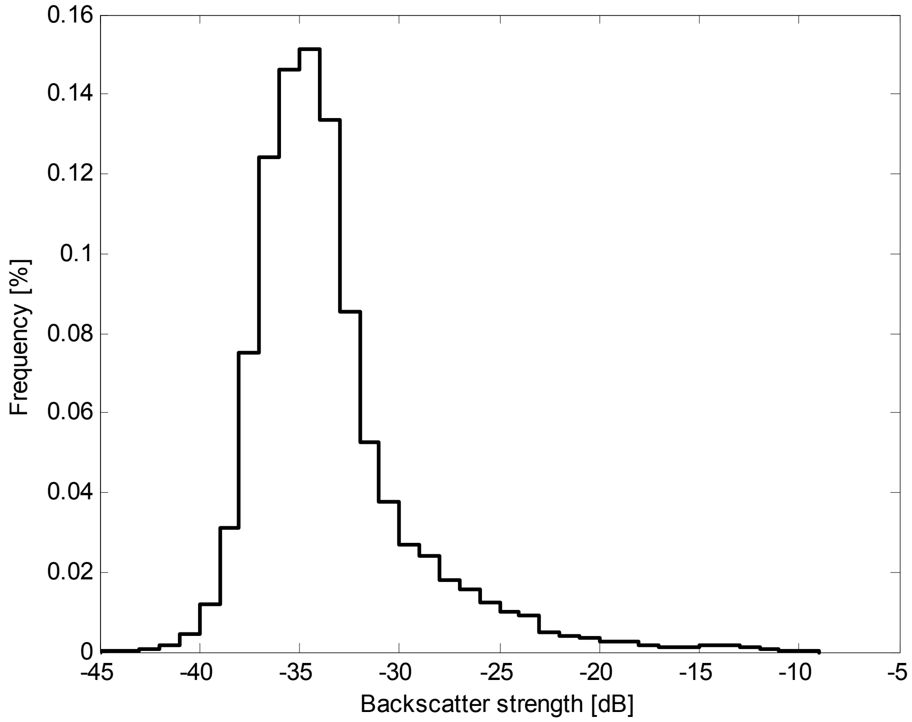



***Figure 2.6.*** *A histogram of the backscatter strengths from the Cuvier margin study area. A peak occurs at -34.5 dB.*

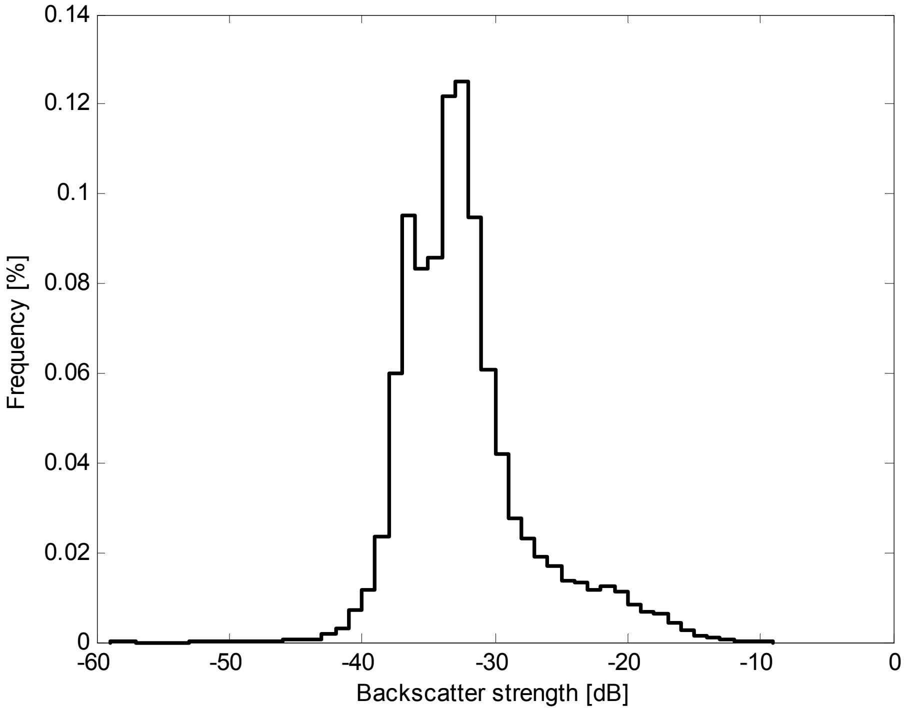



***Figure 2.7.*** *A h istogram of th e backscatter streng ths from th e Houtman-Sub-basin st udy area, associated with the Perth margin and Carnarvon slope. Two peaks occur at -36.5 dB and -32.5 dB and a minor peak occurs at -21.5 dB.*

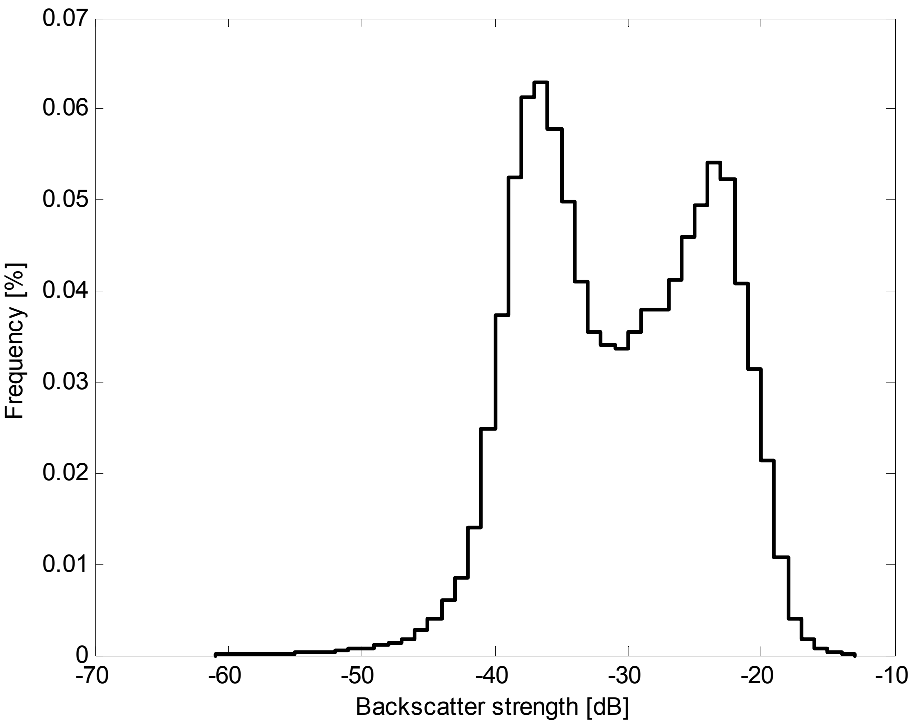



***Figure 2.8.*** *A histogram of the backscatter strengths from the Zeewyck Sub-basin study area associated with the Perth margin. Two peaks occur at -36.5 dB and -23.5 dB.*

PDF and PFA plots derived from high backscatter strengths taken from a homogeneous area of acoustic character in the Houtman Canyon located in the Zeewyck Sub-basin (located in Fig. 2.2), together with theoretical models, are shown in Fig. 2.9. The theoretical models fit the empirical distribution (Fig. 2.9) according to the KS statistic test (*p*-value>0.05) and indicates an acoustically homogeneous seabed. The theoretical gamma distribution model (red line in Fig. 2.9) infers a peak at -18.9 dB. The PFA plot indicates the presence of a slight heavier tail distribution.

In conclusion, the thick, soft ooze on the Cuvier Plateau study area and the hard outcropping rock (volcanic and other) in the Zeewyck and south Houtman sub-basin study areas associated with the Perth margin and Carnarvon slope (see 4 Geomorphology) represent the two extremes associated with the lowest and highest backscatter strengths through the survey areas, respectively. These two extremes control the acoustic returns received by the SIMRAD EM120 multi-beam sonar system. The soft and compressible character of the ooze results in a very low acoustic impedance contrast and the lowest backscatter strength. In contrast, the hard, solid, rigid and uncompressible character of the outcropping rock results in a high acoustic impedance contrast and the highest backscatter strength.

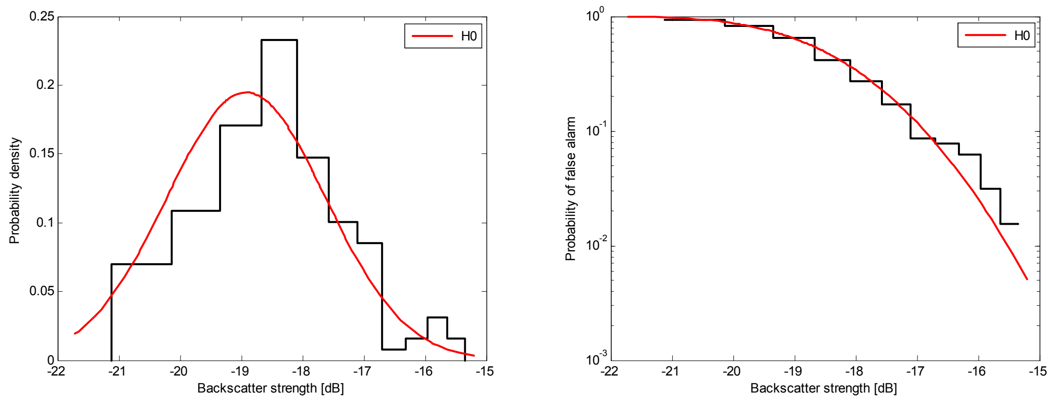


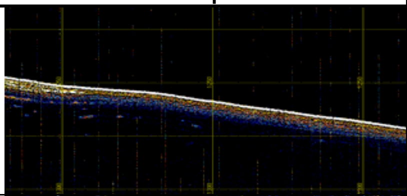
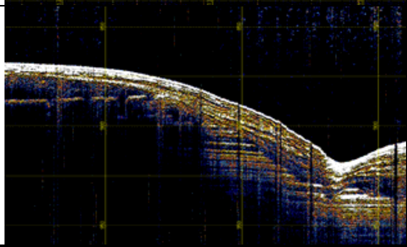
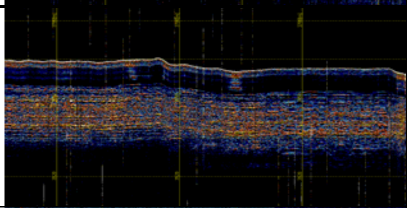
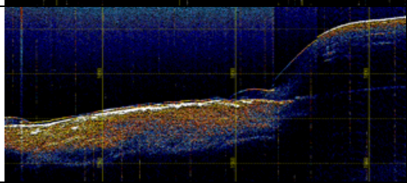
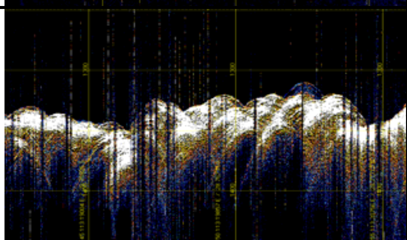
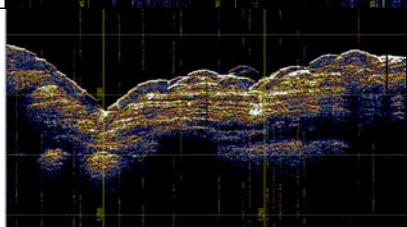
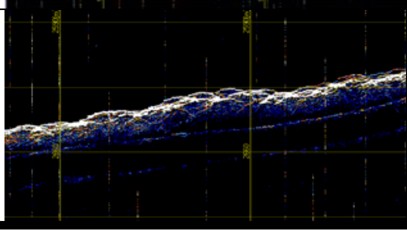

***Figure 2.9.*** *Plots/Histograms of the Probability distribution function (PDF) and probability false alarm (PFA) data over a relatively homogenous area in the Houtman Canyon located in the Zeewyck Sub-basin (see Fig. 2.2). The data has higher backscatter strength due to exposed rocks in the Houtman Canyon. Theoretical gamma distribution model (red line, labelled HO) peaks at -18.9 dB.*

### 2.3.3. Shallow Seismic Reflection

A total of almost 25,000 line kilometres of digital sub-bottom profiler data were acquired during the survey (Fig. 1.1). Over the course of the survey, rough seas combined with variable seabed morphologies and water depths of up to 6,000 m led to variable data quality. Sub-bottom penetration was dependant on sediment character, water depth, ocean floor morphology and ranged from zero metres to ~100 meters below the sea floor. Due to deep water and the large number of closely spaced canyons over much of the survey area, sub-bottom penetration and quality of the reflection data were generally poor. The best data with maximum penetration of up to 100 m was recorded in the relatively shallow, flat areas on the shelf and mid-slope. In these areas, reflection images can be interpreted to differentiate volcanic and sedimentary structures and in some cases, to classify sedimentary features. The orientation of the ship tracks across the continental slope (to maximise swath bathymetry data acquisition), also contributed to the poor data quality.

Seven acoustic echo-types were observed throughout the survey area and are summarised in Table 2.3. Representative examples of the observed echograms were also captured as screenshots that can be seen in Table 2.3. While spatial distribution of acoustic facies has not yet been analysed, some basic observations can be made. Distinct (type 1) echograms are dominant on the shelf and upper-slope areas where canyon incision is minimal. Indistinct, prolonged, hyperbolic or parabolic echo types are dominant in canyoned and rugged areas along the mid- and lower-slopes.

**Table 2.3.** Descriptions and representative examples of the seven echo-types observed throughout the west Australian margin study area. Echotypes are as classified by Damuth (1974; 1980) and Whitmore and Belton (1997) and outlined in Table 2.1.

| Class | Type | Example | Description | Location |
|---|---|---|---|---|
| Distinct echoes | IA |  | Sharp, continuous echo with no sub-bottom reflectors. | Slope (non-incised) in northern Houtman Sub-basin (Carnarvon Slope)<br><br>LAT -24.68173<br>LON 111.29333 |
| | IC |  | Sharp, continuous echo with non-conformable sub-bottom reflectors. | Slope (incised) in southern Houtman Sub-basin (Perth Slope – *30km NE of Houtman Canyon*)<br><br>LAT -28.11922<br>LON 112.73517 |
| Indistinct or Prolonged | IIA |  | Semi-prolonged echo with discontinuous parallel sub-bottom reflectors. | Slope (saddle) on the eastern edge of the Cuvier Plateau<br><br>LAT -25.5019<br>LON 109.19867 |
| | IIB |  | Prolonged to very prolonged "fuzzy" echoes with no sub-bottom reflectors. | Slope (slumped) in central Houtman Sub-basin (Carnarvon Slope)<br><br>LAT -26.02375<br>LON 111.36843 |
| Hybrid or Combined | IIIB |  | Regular, single hyperbolic echoes with varying vertex elevations and conformable sub-bottom reflectors. | Slope (incised) in southern Houtman Sub-basin (Perth Slope)<br><br>LAT -28.78700<br>LON 113.21520 |
| | IIIC |  | Smaller (<100 m relief), regular to irregular, overlapping, semi-prolonged to prolonged hyperbolas with varying vertex elevation. | Slope (incised) in southern Houtman Sub-basin (Perth Slope)<br><br>LAT -29.00573<br>LON 113.50012 |
| | IIID |  | Small, regular, overlapping hyperbolas, with vertices tangential to the sea floor. | Slope in the central Cuvier Plateau<br><br>LAT -24.71633<br>LON 108.70797 |

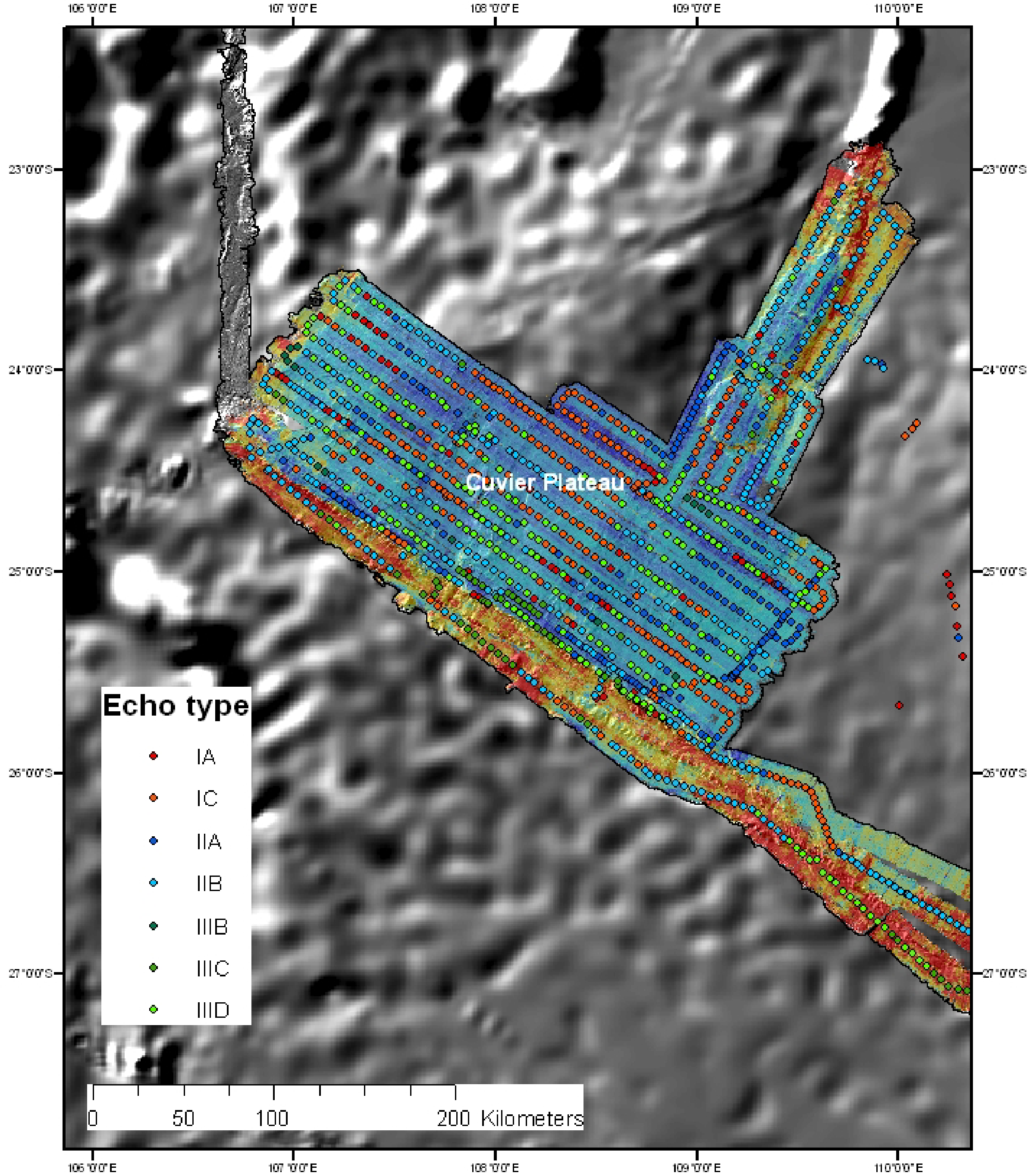



***Figure 2.10.*** *An echo-character map of the Cuvier Plateau study area showing the acoustic facies identified on-board during the survey overlying the multi-beam backscatter data.*

An initial assessment of acoustic facies identified a link between echo types (or echograms) and multi-beam backscatter data acquired with the SIMRAD EM120 multi-beam sonar system over the Cuvier Plateau study area (Fig. 2.10). Distinct echo types (type I) tend to correspond with low acoustic reflectivity in the multi-beam backscatter data, whereas indistinct and prolonged (type II) or hyperbolic (type III) echo types tend to correspond with higher acoustic reflectivity in the multi-beam backscatter data, particularly over the Wallaby Saddle. Detailed analysis of the sub-bottom profiler data collected from the survey areas is yet to be undertaken by Geoscience Australia.

### 2.3.4. Gravity and Magnetics

More than 24,000 line-km of gravity and magnetic data were acquired during survey GA2476. Geoscience Australia currently holds all raw gravity and magnetic survey data. At the time of this report's publication, the final processed datasets were not fully processed and therefore not presented herein. After the fully processed data are received from Gravionic, they will be integrated with existing data and data from the Southwest Margins Seismic Survey (GA310) to produce composite gravity and magnetic images. The combined datasets will then be available from GA's Data Repository at cost of transfer.

## 2.4. SUMMARY

An area of about 230,000 $km^2$ of the west Australian margin was successfully mapped by multi-beam sonar, as well as along transits within Australian waters. Numerous seafloor features revealed by the backscatter- and swath-mapping include canyons, slumps, volcanic peaks and seamounts. The newly acquired bathymetric data proved critical in identifying successful dredge, grab, camera and boxcore targets – in particular, enabled selection of the steepest canyon slopes and identification of accessible rock outcrops. Accurate maps of the seafloor will prove to be a useful dataset to evaluate the possible risks of trap and seal breach over the Zeewyck and southern Houtman sub-basins and assist in further understanding of the sedimentary processes and the distributions of benthic habitats throughout the region.

A total of almost 25,000 line kilometres of gravity, magnetic and sub-bottom profiler data were acquired during the survey. Sub-bottom penetration and overall quality of the sub-bottom profiler data was variable but generally poor due to rough seas combined with variable seabed morphologies (i.e. a large number of closely spaced canyons over much of the Zeewyck Sub-basin) and water depths of up to 6,000 m. At the time of this report, the magnetic and gravity data acquired during the survey are being processed by Gravionic. The processed magnetic and gravity data will be subsequently integrated with existing data to produce composite gravity and magnetic images that will be available from GA's Data Repository at cost of transfer.

# 3. Sample Acquisition

Bathymetry grids from the multi-beam sonar survey were used to identify areas of the seabed suitable for further detailed investigation and geological sampling. The sampling program was designed to acquire lithological, sedimentological and biological specimens over a variety of geomorphic features and rock outcrops. The nomenclature used by Geoscience Australia to catalogue the marine samples is as follows: the survey identifier is listed first in the sequence followed by a forward slash, the station number, a code to indicate the sample type (see Table 3.1, e.g. DR=dredge, GC=gravity core), and its corresponding number in the sequence of sample types (Table 3.2). A typical sample designation for Survey GA2476 would be GA2476/005GR001, where:

• Survey Identifier = GA2476;
• Station Number = 005;
• Sample Type Code = Sediment Grab (GR);
• Sample Type Number = 001;

A total of 62 stations were occupied during the survey (Fig. 3.1, Table 3.2, 3.5-13). Different combinations of sampling devices were used at each station depending on the objectives for that location.

**Table 3.1.** Table of sample types and corresponding abbreviations used for sample identification.

| CODE | SAMPLE TYPE |
|---|---|
| GR | Sediment Grab |
| GC | Gravity Core |
| BC | Box Core |
| DR | Pipe Dredge |
| DR | Chain Bag Dredge |
| BS | Benthic Sled/ Benthic Dredge |
| BT | Beam Trawl |
| CAM | Under water camera |
| CM | Current Meter |
| CTD | Conductivity Temperature Depth |
| XBT | Expendable Bathythermograph |
| WS | Water sample |

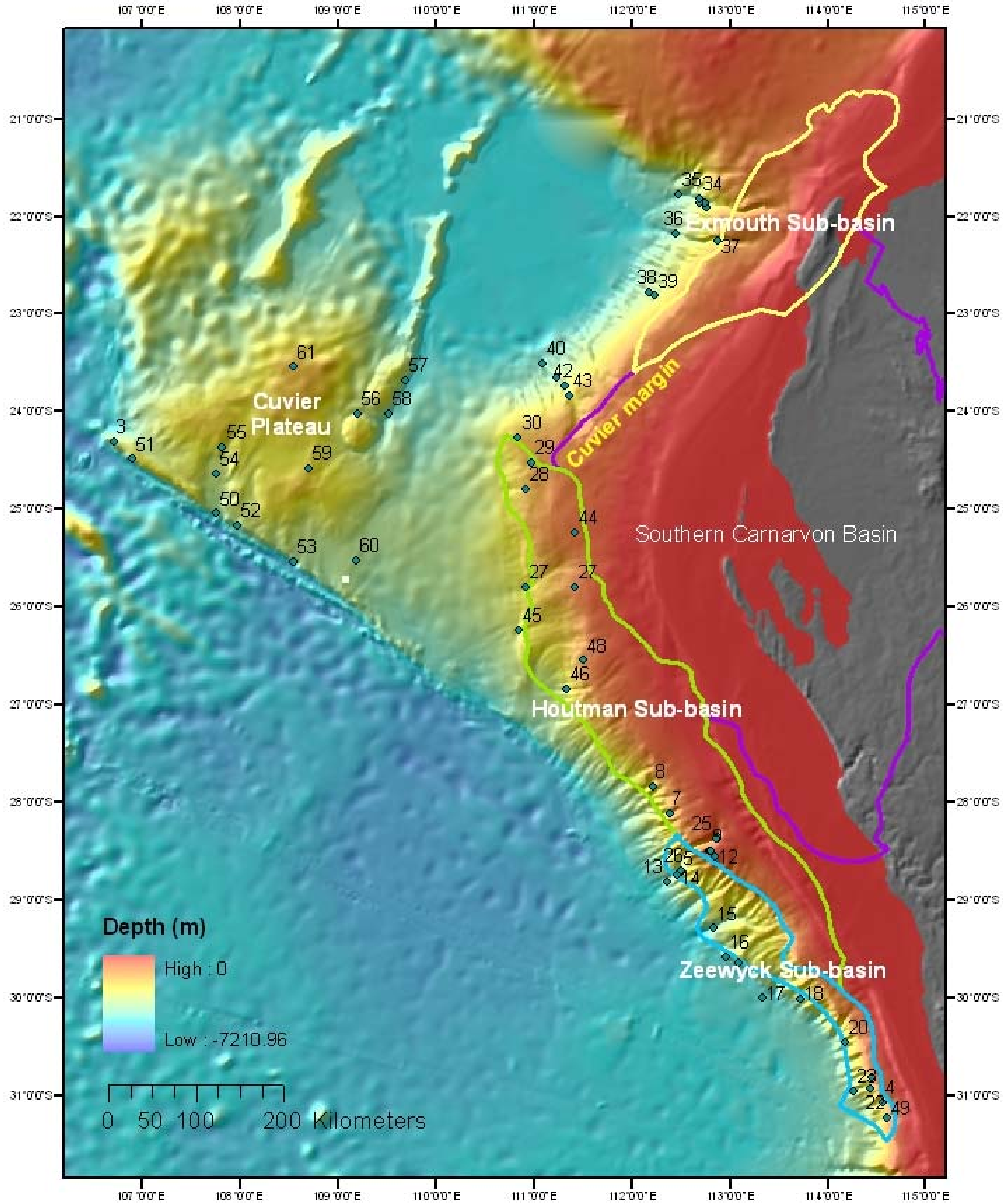



***Figure 3.1.*** *Location of sampling stations occupied during survey GA2476. Note: a number of sampling devices were deployed at most stations hence locations are approximate.*

**Table 3.2.** Summary of physical samples collected on survey GA2476. Symbols: ^ - video but no grab sample acquired; * - no pipe dredges attached (i.e. no sediment sub-samples were acquired); $^{X}$ - seabed characterisation was not successfully collected (see section 8 Benthic Ecology).

| STATION | LEG | LOCALITY | OFOS CAMERA (CAM) | BOX-CORE (BC) | BODO TVGRAB (GR) | DREDGE (DR) | BEAM TRAWL (BT) | BENTHIC SLED (BS) | XBT | CTD | WATER SAMPLES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 001 | 1 | Indian Ocean | | | | | | | | 001 | 001 |
| 002 | 1 | Indian Ocean | | | | | | | 001 | | |
| 003 | 1 | Indian Ocean | | | | | | | | 002 | 002 |
| 004 | 1 | Indian Ocean | | | | | | | | 003 | 003 |
| 005 | 1 | Zeewyck Sub-basin, Houtman Canyon | 001 | | | | | | | | |
| 006 | 1 | Houtman Sub-basin, Houtman Canyon | 002 | 001 002 | | 001 002 | 001 | | | | |
| 007 | 1 | Houtman Sub-basin | | | | 003 004 005 006 | | | | | |
| 008 | 1 | Houtman Sub-basin | | | | 007 008* | | | | | |
| 009 | 1 | Houtman Sub-basin, Peak feature | 003 | | 001 | 009* | | | | | |
| 010 | 1 | Houtman Sub-basin, Peak feature | | | 002 ^ | | | | | | |
| 011 | 1 | Houtman Sub-basin, Peak feature | | | 003 | | | | | | |
| 012 | 1 | Houtman Sub-basin, Peak feature | | | | 010* | | | | | |
| 013 | 1 | Indian Ocean | | | | | | | 002 | 004 | 004 |
| 014 | 1 | Zeewyck Sub-basin, Houtman Canyon | | | | 011 012 | | | | | |
| 015 | 1 | Zeewyck Sub-basin, Geraldton Canyon | | | | 013 014 015* | | | | | |
| 016 | 1 | Zeewyck Sub-Basin | | | | 016 017 018 | | | | | |
| 017 | 1 | Abyssal Plain, outer Zeewyck Sub-basin | | | 004 | | | | | | |
| 018 | 1 | Zeewyck Sub-Basin | | | 005 006 | 019 | | | | | |
| 019 | 1 | Zeewyck Sub-Basin | | | | | | | | | |
| 020 | 1 | Zeewyck Sub-Basin | | | 007^ 008 | 020 | | | | | |
| 021 | 1 | Zeewyck Sub-Basin | | | 009 | 021 | | | | | |
| 022 | 1 | Zeewyck Sub-Basin | | 003 | 010^ | 022 023 024 | | | | | |
| 023 | 1 | Zeewyck Sub-Basin | | 004 | 011 | | | | | | |
| 024 | 2 | Zeewyck Sub-Basin | | | | 025 | | | | | |
| 025 | 2 | Houtman Sub-Basin, Houtman Canyon | | | | 026 | | | | | |
| 026 | 2 | Zeewyck Sub-Basin | | | | 027 | | | | | |
| 027 | 2 | Houtman Sub-basin | | | 012$^{X}$ | | | 001 | | | |
| 028 | 2 | Houtman Sub-basin | | | 013$^{X}$ | | | 002 | | | |
| 029 | 2 | Houtman Sub-basin | | | 014 | | | 003 | | | |
| 030 | 2 | Houtman Sub-basin | | | | | | | | 005 | 005 |
| 031 | 2 | Cuvier margin, Cape Range Canyon | | | 015^ | 028 | | | | | |

| STA-TION | LEG | LOCALITY | OFOS CAMERA (CAM) | BOX-CORE (BC) | BODO TVGRAB (GR) | DREDGE (DR) | BEAM TRAWL (BT) | BENTHIC SLED (BS) | XBT | CTD | WATER SAM-PLES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 032 | 2 | Cuvier margin, Cape Range Canyon | | | 016 | 029 | | | | | |
| 033 | 2 | Cuvier margin, Cape Range Canyon | | | 017 | 030 | | | | | |
| 034 | 2 | Cuvier margin, Cape Range Canyon | | | 018 | 031 | | | | | |
| 035 | 2 | Cuvier margin | | | | | | | | 006 | 006 |
| 036 | 2 | Cuvier margin, Cloates Canyon | | | 019 | 032 | | | | | |
| 037 | 2 | Cuvier margin, Cloates Canyon | | | 020 | 033 | | | | | |
| 038 | 2 | Cuvier margin | | | 021 | 034 | | | | | |
| 039 | 2 | Cuvier margin | | | 022 | 035 | | | | | |
| 040 | 2 | Cuvier margin | | | 023 | | | | | | |
| 041 | 2 | Cuvier margin | | | 024 | | | | | | |
| 042 | 2 | Cuvier margin, Carnarvon Canyon | 004 | | | 036 | | | | | |
| 043 | 2 | Cuvier margin, Carnarvon Canyon | 005 | | | 037 | | | | | |
| 044 | 2 | Houtman Sub-basin, Peak feature | 006 | | | 038 | | | | | |
| 045 | 2 | Houtman Sub-basin | 007 | | | 039 | | | | | |
| 046 | 2 | Houtman Sub-basin | | | 025^X | 040 | | | | | |
| 047 | 2 | Houtman Sub-basin | 008 | | | 041 | | | | | |
| 048 | 2 | Houtman Sub-basin | 009 | 005 | | | | | | | |
| 049 | 3 | Zeewyck Sub-Basin | | | 026 | 042 | | | | | |
| 050 | 3 | Cuvier Plateau | 010 | | | 043 | | | | | |
| 051 | 3 | Cuvier Plateau | 011 | | | 044 045 | | | | | |
| 052 | 3 | Cuvier Plateau | | | | 046 | | | | | |
| 053 | 3 | Cuvier Plateau | | | | 047 | | | | | |
| 054 | 3 | Cuvier Plateau | 012 | 006 | | | | | | | |
| 055 | 3 | Cuvier Plateau | | | 027 | 048 | | 004 | | | |
| 056 | 3 | Cuvier Plateau, Seamount | | | 028 | 049 050 | | | | | |
| 057 | 3 | Cuvier Plateau | 013 | | | 051 | | | | | |
| 058 | 3 | Cuvier Plateau | 014 | | | 052 | | | | | |
| 059 | 3 | Cuvier Plateau | 015 | 007 | | | | | | 007 | 007 |
| 060 | 3 | Cuvier Plateau | 016 | 008 | | | | | | 008 | 008 |
| 061 | 3 | Cuvier Plateau | | | | 053 | | | | | |
| 062 | 3 | Saddle, Cuvier Plateau | 017 | | | | | | | | |

## 3.1. TOWED-VIDEO AND STILL IMAGES

The Sonne has two pieces of equipment for acquiring video and still images of the seabed - the Ocean Floor Observation System (OFOS) and the deep-sea TV controlled grab (called BODO). Both OFOS and BODO were used to characterise the physical properties of the seabed, any observable biota and trace fossils. Positioning for both the OFOS and BODO was provided by an IXSEA Posidonia long range USBL tracking system with an accuracy of <5 m. Typically, a camera run (either BODO or OFOS) was completed at each station to characterise the physical properties and biota. In many instances BODO or OFOS was used before dredges to acquire video footage down slope. This allowed for the assessment of site suitability before commencing a dredge. BODO was generally used in preference to OFOS due to its ability to acquire a grab sample and thus reduce the number of operations undertaken at each station. OFOS was used instead of BODO over the period 12 to 15 December due to a failure of the hydraulic motor controlling the grab mechanism.

### 3.1.1. Ocean Floor Observation System (OFOS)

The OFOS is a video-sled that transmits digital signals from the seafloor via conducting cable to the ship's laboratory (Fig. 3.2a). It acquires colour and high resolution back and white video footage and stereo photographs. The OFOS was mounted with 3 down-facing cameras: a colour video camera (Deep Sea Power and Light Micro Seacam 2002), a black-and-white video camera (Deep Sea Power and Light SSC-5000) and a still camera (Panasonic Lumix DMC-LX2), along with their associated strobe lights and a three-point laser system (Deep Sea Power and Light Micro-Sea-Laser). The black-and-white and colour video feeds were transferred in real-time via fibre optic cable to monitors on the ship (Fig. 3.2b) and the footage was recorded using a dual DVD recorder system. Still photographs of the seabed were taken automatically every 15 seconds. A Conductivity-Temperature-Depth profiler (CTD) sensor is also attached to the OFOS system to acquire temperature, pressure, salinity, density and sound velocity profiles. The OFOS was deployed from the starboard winch (Fig. 3.2a) and towed at a speed of 0.5 to 1 knot and 1 to 2 m above the seafloor. The height of the towed-camera system above the seabed was controlled manually by the winch operator using the ship-board winch while watching one of two surface video monitors (Fig. 3.2b). A weight on a rope is used to gauge the distance between OFOS and the seabed (Fig. 3.2c). Images and video data were recorded directly to hard drive and later archived to DVD. The OFOS was deployed at 16 stations and between 0.5 - 2 hrs of footage was acquired per station (Table 3.3).

### 3.1.2. Deep-sea TV controlled grab (BODO)

The deep-sea TV controlled grab (commonly referred to as BODO) is designed to take large-volume samples from the seafloor, including sediments, biota and/or hard substrate (Fig. 3.2d). A video camera mounted between the jaws of the grab allows the operator to search for objects of interest on the seafloor with the jaws open. After lowering the grab to the seafloor the jaws are closed by a hydraulic motor. A surface area between the jaws of about 1.8 $m^2$ can be sampled. The BODO was mounted with 2 down-facing cameras: a colour video camera (Deep Sea Power and Light CCD Multi-Sea-Cam 2050) and a black-and-white video camera (Kongsberg CCD OE 1390/1391), along with their associated strobe lights. BODO does not acquire still images. BODO was deployed from the starboard winch and towed at a speed of 0.5 to 1 knot at 1 to 2 m above the seafloor. Similar to the OFOS, the height of the towed-camera system above the seabed was controlled manually using the ship-board winch while watching one of two surface video monitors with weight on a rope used to gauge depth (Figs 3.2c and 3.2d). Similar to the OFOS, video footage from the BODO was transferred in real-time via fibre optic cable to monitors on the ship and footage was recorded using the dual DVD recorder system. This footage was archived to DVD. At the end of each video transect a grab sample was acquired where possible and winched up to the starboard deck for processing (Fig. 3.2b, see 3.2.2). BODO was deployed at 28 stations and acquired video footage of between 0.5 - 2 hrs per station (Table 3.4).

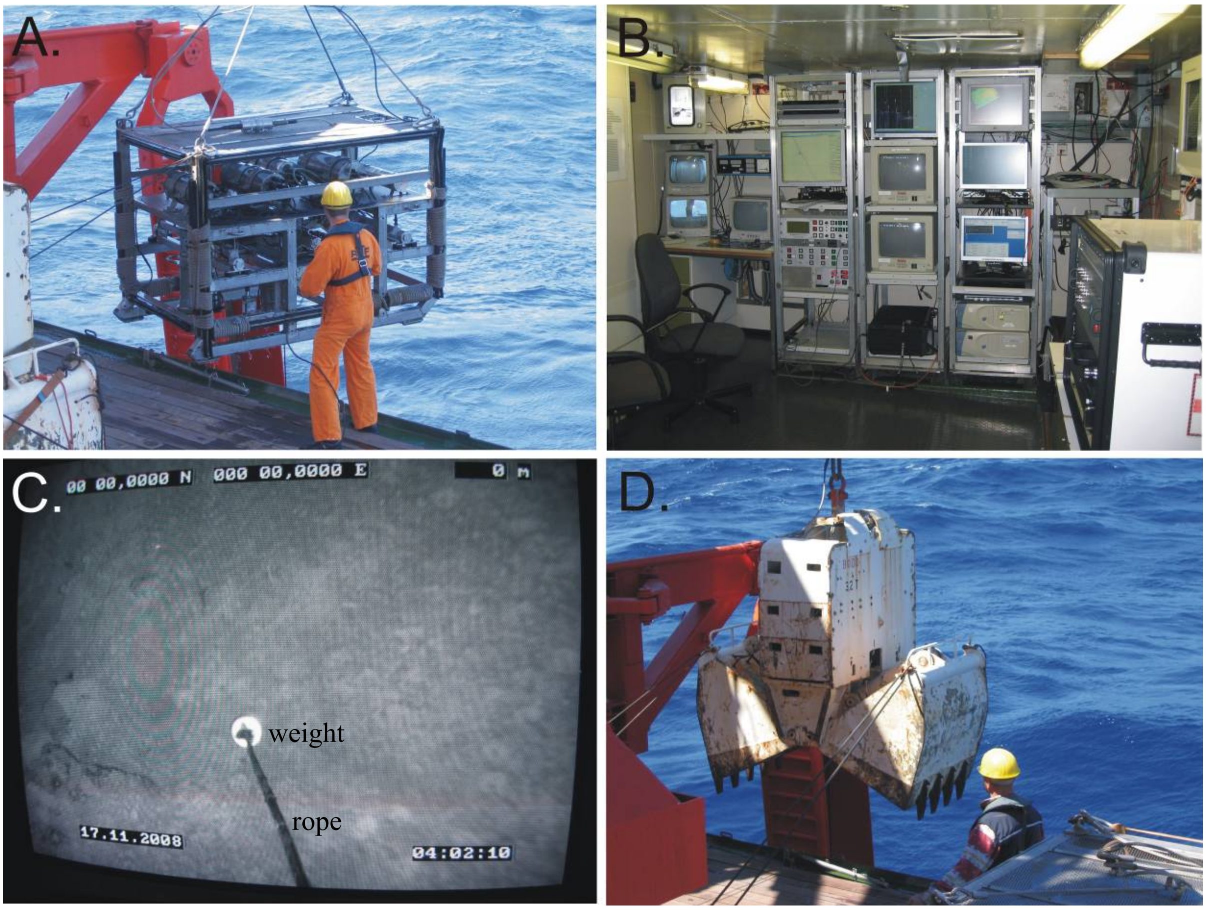



*__Figure 3.2.__ Photos of equipment used for the video and still image acquisition: a) deployment of the OFOS off the starboard side of the ship; b) the OFOS and BODO control room; c) the real-time, high-resolution video footage as viewed in control room and the weight on a rope used to gauge the distance to the seabed; d) deployment of the BODO and the opening of the BODO jaws.*

**Table 3.3.** Sample acquisition information for the Ocean Floor Observation System (OFOS) towed-video (CAM) including start and end locations and water depths, video duration and the recovery of seabed characterisations.

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Video Duration (hr:min: sec) | No. Stills | Seabed characterisation Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 005 | GA2476/005CAM001 | Houtman Canyon, Zeewyck Sub-basin | -28.71553 | 112.49922 | 3,387 | -28.69559 | 112.49934 | 3,720 | 3:7:34 | 409 | Y |
| 006 | GA2476/006CAM002 | Houtman Canyon, Houtman Sub-basin | -28.36372 | 112.88068 | 906 | -28.34687 | 112.86782 | 1,866 | 2:27:57 | 591 | Y |
| 009 | GA2476/009CAM003 | Peak feature, Houtman Sub-basin | -28.49537 | 112.80174 | 1,009 | -28.4984 | 112.79841 | 831 | 0:39:0 | 70 | Y |
| 042 | GA2476/042CAM004 | Carnarvon Canyon, Cuvier margin | -23.73289 | 111.31112 | 3,663 | -23.73207 | 111.30427 | 3,984 | 1:2:0 | 0 | Y |
| 043 | GA2476/043CAM005 | Carnarvon Canyon, Cuvier margin | -23.83332 | 111.36107 | 2,855 | -23.83157 | 111.35374 | 3,120 | 2:0:0 | 235 | Y |
| 044 | GA2476/044CAM006 | Peak feature, Houtman Sub-basin | -25.23217 | 111.41478 | 990 | -25.23562 | 111.4193 | 1,130 | 0:46:0 | 176 | Y |
| 045 | GA2476/045CAM007 | Houtman Sub-basin | -26.2319 | 110.85005 | 3,107 | -26.23572 | 110.8473 | 3,251 | 1:23:0 | 332 | Y |
| 047 | GA2476/047CAM008 | Houtman Sub-basin | -26.84388 | 111.41442 | 2,591 | -26.84923 | 111.41808 | 2,867 | 1:2:0 | 163 | Y |
| 048 | GA2476/048CAM009 | Houtman Sub-basin | -26.5437 | 111.50253 | 1,158 | -26.54605 | 111.49194 | 1,600 | 1:0:0 | 164 | Y |
| 050 | GA2476/050CAM010 | Cuvier Plateau | -25.0315 | 107.7636 | 4,080 | -25.0395 | 107.75721 | 4,302 | 1:24:0 | 260 | Y |
| 051 | GA2476/051CAM011 | Cuvier Plateau | -24.4798 | 106.89845 | 3,021 | -24.48583 | 106.89294 | 3,783 | | | Y |
| 054 | GA2476/054CAM012 | Cuvier Plateau | -24.63142 | 107.75414 | 3,442 | -24.637 | 107.75713 | 3,431 | 0:55:0 | 188 | Y |
| 057 | GA2476/057CAM013 | Cuvier Plateau | -23.67297 | 109.67894 | 3,868 | -23.67157 | 109.68633 | 4,224 | 1:2:0 | 232 | Y |
| 058 | GA2476/058CAM014 | Cuvier Plateau | -24.01554 | 109.50895 | 4,221 | -24.01994 | 109.51587 | 4,563 | | | Y |
| 059 | GA2476/059CAM015 | Cuvier Plateau | -24.57982 | 108.69585 | 2,581 | -24.57213 | 108.69445 | 2,624 | 0:58:0 | 176 | Y |
| 060 | GA2476/060CAM016 | Cuvier Plateau | -25.52575 | 109.18283 | 3,827 | -25.52197 | 109.18171 | 3,818 | 0:55:0 | 179 | Y |
| 062 | GA2476/062CAM017 | Saddle, Cuvier Plateau | -26.61368 | 110.05239 | 4,577 | -26.60808 | 110.04963 | 4,581 | 1:2:55 | 0 | Y |

**Table 3.4.** Sample acquisition information for the BODO video-grab (GR) including start and end locations and water depths, video duration and the recovery of physical samples and seabed characterisations. No physical sample was taken on 010GR002, 020GR007, 022GR010, 031GR015 or 046GR025 due to equipment malfunction. The physical sample acquisition for the BODO was acquired at the end latitude, longitude and water depth.

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Geochemistry Sample Y/N | Biology Sample Y/N | Video Duration (hr:min:sec) | Seabed Characti-sation Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 009 | GA2476/009GR001 | Peak feature, Houtman Sub-basin | -28.49685 | 112.80091 | 901 | -28.49625 | 112.80116 | 952 | N | Y | Y | Y | 0:20:0 | Y |
| 010 | GA2476/010GR002 | Peak feature, Houtman Sub-basin | -28.49567 | 112.80171 | 993 | -28.49567 | 112.8013 | 994 | N | N | N | N | 0:53:0 | Y |
| 011 | GA2476/011GR003 | Peak feature, Houtman Sub-basin | -28.55354 | 112.83796 | 878 | -28.5537 | 112.83776 | 889 | Y | Y | Y | Y | 0:12:0 | Y |
| 017 | GA2476/017GR004 | Abyssal Plain, outer Zeewyck Sub-basin | -29.99395 | 113.32596 | 4,801 | -29.9951 | 113.32679 | 4,799 | N | Y | Y | Y | 0:32:0 | Y |
| 018 | GA2476/018GR005 | Zeewyck Sub-basin | -30.01834 | 113.71835 | 3,241 | -30.0169 | 113.71712 | 3,317 | Y | Y | Y | Y | 0:40:0 | Y |
| 018 | GA2476/018GR006 | Zeewyck Sub-basin | -30.01646 | 113.71673 | 3,195 | -30.01208 | 113.71233 | 3,660 | Y | Y | Y | Y | 1:29:0 | Y |
| 020 | GA2476/020GR007 | Zeewyck Sub-basin | -30.45588 | 114.17936 | 3,525 | -30.4554 | 114.17842 | 3,615 | N | N | N | N | 0:31:0 | Y |
| 020 | GA2476/020GR008 | Zeewyck Sub-basin | -30.45425 | 114.17749 | 3,661 | -30.4543 | 114.17699 | 3,664 | N | Y | Y | Y | 1:6:0 | Y |
| 021 | GA2476/021GR009 | Zeewyck Sub-basin | -30.8176 | 114.4486 | 1,597 | -30.8088 | 114.44006 | 2,353 | Y | Y | Y | Y | 1:44:0 | Y |
| 022 | GA2476/022GR010 | Zeewyck Sub-basin | -30.94299 | 114.44211 | 2,281 | -30.9361 | 114.43562 | 2,667 | N | N | N | N | 1:48:0 | Y |
| 023 | GA2476/023GR011 | Zeewyck Sub-basin | -30.9619 | 114.26087 | 3,841 | -30.958 | 114.25638 | 4,176 | N | Y | Y | Y | 1:14:0 | Y |
| 027 | GA2476/027GR012 | Houtman Sub-basin | -25.78791 | 110.93648 | 2,854 | -25.79421 | 110.92015 | 2,983 | N | Y | Y | Y | 1:30:0 | N |
| 028 | GA2476/028GR013 | Houtman Sub-basin | -24.78364 | 110.90549 | 2,170 | -24.7924 | 110.90711 | 2,191 | N | Y | Y | Y | 1:30:0 | N |
| 029 | GA2476/029GR014 | Houtman Sub-basin | -24.51307 | 110.97604 | 1,872 | -24.52491 | 110.97523 | 1,958 | Y | Y | Y | Y | 1:30:0 | Y |
| 031 | GA2476/031GR015 | Cape Range Canyon, Cuvier margin | -21.91045 | 112.76224 | 3,416 | -21.90625 | 112.76338 | 3,661 | N | N | N | N | 1:4:0 | Y |
| 032 | GA2476/032GR016 | Cape Range Canyon, Cuvier margin | -21.85995 | 112.75275 | 3,823 | -21.85977 | 112.74759 | 3,856 | Y | Y | Y | Y | 1:4:0 | Y |
| 033 | GA2476/033GR017 | Cape Range Canyon, Cuvier margin | -21.86778 | 112.68757 | 4,023 | -21.86078 | 112.68806 | 4,221 | Y | Y | Y | Y | 1:34:0 | Y |
| 034 | GA2476/034GR018 | Cape Range Canyon, Cuvier margin | -21.81307 | 112.69041 | 3,815 | -21.81679 | 112.69105 | 4,037 | Y | Y | Y | Y | 1:5:0 | Y |

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sedi-ment Sam-ple Y/N | Geo-chemist-ry Sample Y/N | Biology Sample Y/N | Video Duration (hr:min: sec) | Seabed Characti-sation Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 036 | GA2476/036GR019 | Cloates Canyon, Cuvier margin | -22.17003 | 112.444517 | 4,271 | -22.17547 | 112.441517 | 4,692 | Y | Y | Y | Y | 0:50:0 | Y |
| 037 | GA2476/037GR020 | Cloates Canyon, Cuvier margin | -22.25012 | 112.87176 | 2,114 | -22.24627 | 112.87212 | 2,690 | Y | Y | Y | Y | 0:56:0 | Y |
| 038 | GA2476/038GR021 | Cuvier margin | -22.772 | 112.1784 | 3,790 | -22.77378 | 112.17386 | 3,976 | Y | Y | Y | Y | 1:30:0 | Y |
| 039 | GA2476/039GR022 | Cuvier margin | -22.81005 | 112.2346 | 3,256 | -22.81606 | 112.22674 | 3,522 | Y | Y | Y | Y | 1:6:0 | Y |
| 040 | GA2476/040GR023 | Cuvier margin | -23.50843 | 111.07999 | 4,691 | -23.50258 | 111.08345 | 4,829 | N | Y | Y | Y | 0:55:0 | Y |
| 041 | GA2476/041GR024 | Cuvier margin | -23.64258 | 111.23327 | 3,732 | -23.65067 | 111.23198 | 3,981 | N | Y | Y | Y | 1:22:0 | Y |
| 046 | GA2476/046GR025 | Houtman Sub-basin | -26.83053 | 111.33468 | 2,972 | -26.83758 | 111.334098 | 3,230 | N | N | N | N | 1:1:0 | N |
| 049 | GA2476/049GR026 | Zeewyck Sub-basin | -31.23515 | 114.6088 | 1,899 | -31.2327 | 114.60506 | 2,304 | N | N | Y | Y | 1:2:0 | Y |
| 055 | GA2476/055GR027 | Cuvier Plateau | -24.36163 | 107.80717 | 2,924 | -24.36532 | 107.81981 | 3,157 | N | Y | Y | Y | 1:35:0 | Y |
| 056 | GA2476/056GR028 | Seamount, Cuvier Plateau | -24.02643 | 109.19897 | 3,050 | -24.01867 | 109.19873 | 3,492 | Y | Y | Y | Y | 1:6:0 | Y |

### 3.2. ROCK, SEDIMENT AND BENTHIC BIOTA SAMPLING

Rock samples, surface sediments and benthic biota were collected using a rock dredge, BODO video grab, boxcore and epibenthic sled (Figs 3.3-3.8). Station locations were primarily dredge sites targeted using pre-existing seismic lines and multi-beam sonar mapping. A range of geomorphic features were selected for sampling such as canyons, seamounts, volcanic cones, etc. Details of samples and sub-samples were entered into Geoscience Australia's Marine Samples database (MARS; http://www.ga.gov.au/oracle/mars).

#### 3.2.1. Rock Dredge

The aim of the geological sampling program was to acquire a variety of rock types (also called lithologies) and ages in order to establish a lithostratigraphic and chronostratigraphic framework for the depocentres in each survey area. Dredge sites were selected mainly to recover rocks from the pre-breakup succession in order to determine the age of synrift deposition and to identify potential source rocks in the northern Perth and southern Carnarvon basins, as well as on the Cuvier Plateau. To ensure the sampling of a complete stratigraphic section, a number of dredges were also planned for the post-breakup succession.

In the Zeewyck and northern Houtman sub-basins (Perth Basin), potential dredging targets were identified by evaluating pre-exiting seismic lines and swath bathymetry. In areas where bathymetric and seismic coverage were poor, such as the Cuvier margin and the Cuvier Plateau, dredge targets were identified during the survey using the newly acquired bathymetry, sub-bottom profiler records and camera tows. In general, submarine canyons provided the best opportunity for sampling the pre-breakup sedimentary strata as they were deeply incised and had steep slopes. Other steep slopes where the basin succession was exposed were identified close to the base of the continental slope. In addition, some dredge targets were selected on small conical seafloor features in an attempt to identify whether they were volcanic, carbonate reef or diapiric in origin.

Dredge sites were targeted using slope maps generated from multibeam bathymetry data. Bathymetry data exported from the Caris HIPS/SIPS software was imported into ArcGIS. In ArcGIS, maps of seabed gradients were produced to identify slopes of 30-35° or greater that had the greatest potential for exposed strata and were thus favourable for dredging. From the GIS analysis, a dredge track was chosen and in many cases an OFOS camera was deployed downslope, along the track, to confirm the presence of a suitable rocky outcrop. Dredging was conducted upslope to take advantage of outcropping rock. This approach was used to ensure the highest possible success rate was achieved by the geological dredging.

The rock dredge comprised a 0.5 x 1 m rectangular-shaped metal collar to which a 1 x 1 m chain bag was attached and two pipe dredges (steel cylinders) were then secured to the chain bag (Fig. 3.3a). Standard practise was to attach one coarse-meshed pipe and one close-ended pipe to the chain bag. The dredge frame was linked to the main wire by a 12 tonne shear-pin to prevent excessive strain being imparted to the wire in the event the dredge was caught on the seafloor. The dredge, when full, was capable of recovering approximately 200 kg of rocks and semi-consolidated sediments per deployment. The dredge was deployed off the aft A-frame of the RV Sonne. It was lowered to the starting point of the proposed dredge track and wire was payed out along the seafloor for the length of the track plus an additional several hundred metres. The ship then remained near the end of the dredge track while the hydraulic winch pulled the dredge along the proposed track and up onto deck.

Rocks, surface sediments and benthic biota were variously recovered at 53 stations using the rock dredge technique (Table 3.5). Initially, all biological material collected from a dredge were carefully removed. To examine pipe-dredge sediments for benthic organism, a single eight centremetre diameter PVC pipe was pushed into the sediment to a depth of 20 cm. The PVC sub-sample was then removed and its contents gently elutriated and passed through a 500 µm sieve. Sediment samples from pipe dredges were double bagged, labelled (including an aluminium tag), stored in a refrigerated container, and metadata entered into Geoscience Australia's Marine Samples database (MARS) (www.ga.gov.au/oracle/mars).

The contents of the chain bag were emptied onto the aft deck for sorting and the contents of the pipes emptied into buckets. After screening for biological samples was complete, recovered rocks were washed and sorted into different lithologies. Representative samples of each rock lithology were described and catalogued in the ship's laboratory. Selected rock samples were also sawn to allow closer examination. After sorting, description and labelling, all rock samples were stored in the ship's fridge. In addition to the nomenclature used for other geological samples, a lithologic type within a dredge was assigned a letter with further individual sub-samples designated a numerical suffix. A typical rock sample designation for Survey GA2476 would be GA2476/005DR001A1, where:

• Survey Identifier = GA2476;
• Station Number = 005;
• Sample Type Code = dredge (DR);
• Sample Type Number = 001;
• Lithologic Type = A; and
• Individual Subsample Number = 1

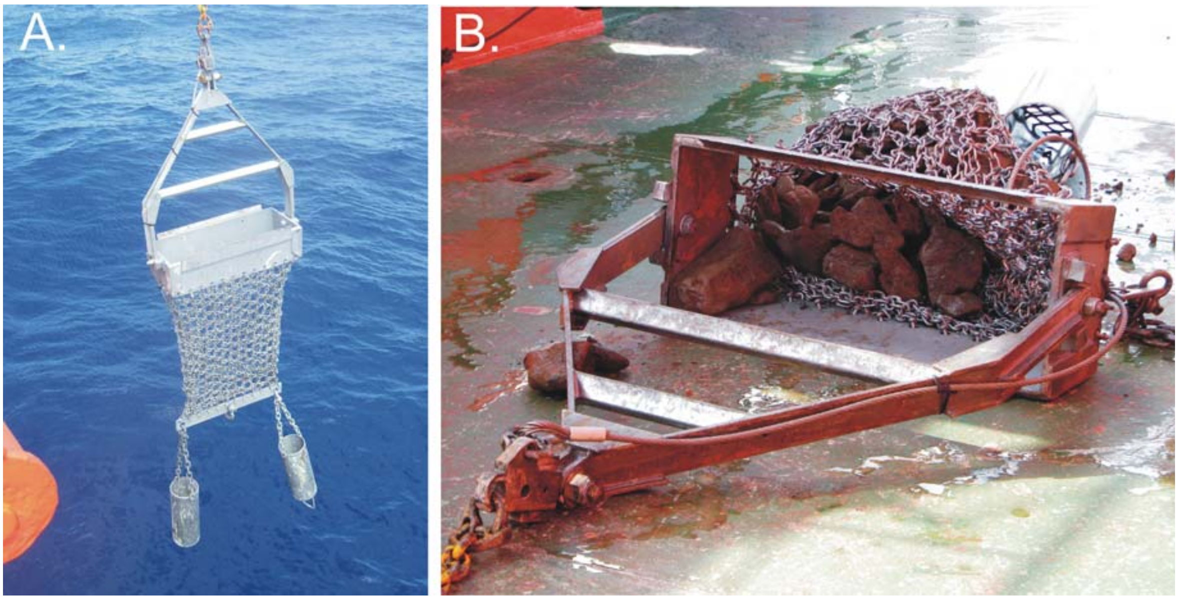



***Figure 3.3.*** *Photos of dredge deployment and recovery: a) dredge collar, chain bang, and pipes; b) a successful dredge recovery on the aft deck.*

**Table 3.5.** Sample acquisition information for the rock dredge (DR) including start and end locations and water depths and the recovery success of physical samples.

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 006 | GA2476/006DR001 | Houtman Canyon, Houtman Sub-basin | -28.35545 | 112.8723667 | 1,910 | -28.3618 | 112.868 | 1,700 | Y | N | Y |
| 006 | GA2476/006DR002 | Houtman Canyon, Houtman Sub-basin | -28.35433333 | 112.87205 | 1,847 | -28.3596 | 112.8721 | 1,752 | Y | Y | Y |
| 007 | GA476/007DR003 | Houtman Sub-basin | -28.11001667 | 112.38695 | 2,688 | -28.1187 | 112.4004 | 2,513 | N | Y | Y |
| 007 | GA2476/007DR004 | Houtman Sub-basin | -28.11501667 | 112.3992167 | 2,588 | -28.1187 | 112.4012 | 2,515 | Y | Y | Y |
| 007 | GA2476/007DR005 | Houtman Sub-basin | -28.10633333 | 112.41635 | 2,526 | -28.1134 | 112.4165 | 2,341 | Y | Y | Y |
| 007 | GA2476/007DR006 | Houtman Sub-basin | -28.10101667 | 112.4324 | 2,409 | -28.108 | 112.4336 | 2,159 | Y | Y | Y |
| 008 | GA2476/008DR007 | Houtman Sub-basin | -27.83558333 | 112.21455 | 2,600 | -27.8415 | 112.215 | 2,363 | Y | Y | Y |
| 008 | GA2476/008DR008 | Houtman Sub-basin | -27.83556667 | 112.2147 | 2,600 | -27.841 | 112.215 | 2,379 | Y | N | Y |
| 009 | GA2476/009DR009 | Peak feature, Houtman Sub-basin | -28.49911667 | 112.7902333 | 1,247 | -28.4982 | 112.7944 | 1,123 | Y | N | Y |
| 012 | GA2476/012DR010 | Peak feature, Houtman Sub-basin | -28.55028333 | 112.8387333 | 1,059 | -28.5539 | 112.8369 | 918 | Y | N | Y |
| 014 | GA2476/014DR011 | Houtman Canyon, Zeewyck Sub-basin | -28.74025 | 112.4529167 | 4,103 | -28.745 | 112.4568 | 3,877 | Y | Y | Y |
| 014 | GA2476/014DR012 | Houtman Canyon, Zeewyck Sub-basin | -28.72734017 | 112.4539868 | 4,307 | -28.7318 | 112.4602 | 4,000 | Y | Y | Y |
| 015 | GA2476/015DR013 | Geraldton Canyon, Zeewyck Sub-basin | -29.29178333 | 112.8350333 | 4,587 | -29.2967 | 112.8382 | 4,304 | Y | Y | Y |
| 015 | GA2476/015DR014 | Geraldton Canyon, Zeewyck Sub-basin | -29.28905 | 112.8626667 | 4,574 | -29.2966 | 112.8691 | 4,087 | Y | Y | Y |
| 015 | GA2476/015DR015 | Geraldton Canyon, Zeewvck Sub-basin | -29.29103333 | 112.8514833 | 4,577 | -29.2977 | 112.8535 | 4,284 | Y | Y | Y |
| 016 | GA2476/016DR016 | Zeewyck Sub-basin | -29.58345 | 112.96325 | 4,770 | -29.5808 | 112.9713 | 4,574 | Y | Y | Y |
| 016 | GA2476/016DR017 | Zeewyck Sub-basin | -29.56436667 | 112.9305667 | 4,600 | -29.5606 | 112.9411 | 4,418 | Y | Y | Y |
| 016 | GA2476/016DR018 | Zeewyck Sub-basin | -29.59583333 | 112.9981667 | 4,350 | -29.5967 | 113.0032 | 4,250 | N | Y | Y |
| 018 | GA2476/018DR019 | Zeewyck Sub-basin | -30.0147 | 113.7147 | 3,512 | -30.018 | 113.7188 | 3,286 | Y | Y | Y |
| 020 | GA2476/020DR020 | Zeewyck Sub-basin | -30.45476667 | 114.1771167 | 3,685 | -30.4588 | 114.1822 | 3,390 | Y | Y | Y |

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 021 | GA2476/021DR021 | Zeewyck Sub-basin | -30.80993333 | 114.441 | 2,248 | -30.8164 | 114.4466 | 1,623 | Y | Y | Y |
| 022 | GA2476/022DR022 | Zeewyck Sub-basin | -30.93495 | 114.43495 | 2,808 | -30.9412 | 114.44 | 2,303 | Y | Y | Y |
| 022 | GA2476/022DR023 | Zeewyck Sub-basin | -30.9361 | 114.4365167 | 2,686 | -30.9474 | 114.4393 | 2,372 | Y | Y | Y |
| 022 | GA2476/022DR024 | Zeewyck Sub-basin | -30.93598333 | 114.42955 | 2,822 | -30.9396 | 114.4342 | 2,584 | Y | Y | Y |
| 024 | GA2476/024DR025 | Zeewyck Sub-basin | -29.643 | 113.08605 | 4,000 | -29.6407 | 113.0937 | 3,650 | Y | Y | Y |
| 025 | GA2476/025DR026 | Houtman Canyon, Houtman Sub-basin | -28.3685 | 112.85395 | 2,057 | -28.3733 | 112.8581 | 1,745 | Y | Y | Y |
| 026 | GA2476/026DR027 | Zeewyck Sub-basin | -28.6963 | 112.4950333 | 3,933 | -28.703 | 112.5014 | 3,578 | Y | Y | Y |
| 031 | GA2476/031DR028 | Cape Range Canyon, Cuvier margin | -21.90758333 | 112.7625667 | 3,710 | -21.9125 | 112.7614 | 3,326 | Y | N | Y |
| 032 | GA2476/032DR029 | Cape Range Canyon, Cuvier margin | -21.86096667 | 112.7489167 | 4,230 | -21.8607 | 112.7506 | 3,986 | Y | N | Y |
| 033 | GA2476/033DR030 | Cape Range Canyon, Cuvier margin | -21.86241667 | 112.6875833 | 4,291 | -21.8696 | 112.6872 | 3,834 | Y | Y | Y |
| 034 | GA2476/034DR031 | Cape Range Canyon, Cuvier margin | -21.81675 | 112.6907167 | 4,029 | -21.8134 | 112.6938 | 3,776 | Y | Y | Y |
| 036 | GA2476/036DR032 | Cloates Canyon, Cuvier margin | -22.17506667 | 112.44275 | 4,660 | -22.1712 | 112.4439 | 4,347 | Y | Y | Y |
| 037 | GA2476/037DR033 | Cloates Canyon, Cuvier margin | -22.24653333 | 112.87125 | 2,732 | -22.2505 | 112.8716 | 2,123 | Y | Y | Y |
| 038 | GA2476/038DR034 | Cuvier margin | -22.77646667 | 112.1732 | 3,955 | -22.7724 | 112.1792 | 3,790 | Y | Y | Y |
| 039 | GA2476/039DR035 | Cuvier margin | -22.81255 | 112.2229167 | 3,520 | -22.8087 | 112.2304 | 3,249 | Y | Y | Y |
| 042 | GA2476/042DR036 | Carnarvon Canyon, Cuvier margin | -23.73348333 | 111.3036333 | 4,036 | -23.7363 | 111.3104 | 3,684 | Y | Y | Y |
| 043 | GA2476/043DR037 | Carnarvon Canyon, Cuvier margin | -23.8313 | 111.3548333 | 3,199 | -23.8319 | 111.3592 | 2,897 | Y | Y | Y |
| 044 | GA2476/044DR038 | Peak feature, Houtman Sub-basin | -25.23528333 | 111.4175 | 1,145 | -25.228 | 111.4163 | 1,119 | Y | Y | Y |
| 045 | GA2476/045DR039 | Houtman Sub-basin | -26.236 | 110.8460167 | 3,285 | -26.234 | 110.8505 | 3,137 | Y | Y | Y |
| 046 | GA2476/046DR040 | Houtman Sub-basin | -26.83801667 | 111.329 | 3,262 | -26.8319 | 111.3389 | 2,979 | Y | Y | Y |
| 047 | GA2476/047DR041 | Houtman Sub-basin | -26.85016667 | 111.4186 | 2,936 | -26.8434 | 111.4182 | 2,566 | Y | Y | Y |

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 049 | GA2476/049DR042 | Zeewyck Sub-basin | -31.2319 | 114.6014333 | 2,434 | -31.2453 | 114.6158 | 2,053 | Y | N | Y |
| 050 | GA2476/050DR043 | Cuvier Plateau | -25.04106667 | 107.7565 | 4,162 | -25.0349 | 107.761 | 4,083 | Y | Y | Y |
| 051 | GA2476/051DR044 | Cuvier Plateau | -24.48545 | 106.89385 | 3,762 | -24.4803 | 106.8989 | 3,395 | Y | N | Y |
| 051 | GA2476/051DR045 | Cuvier Plateau | -24.48611667 | 106.8936167 | 3,778 | -24.4816 | 106.898 | 3,466 | Y | Y | Y |
| 052 | GA2476/052DR046 | Cuvier Plateau | -25.1638 | 107.9689167 | 4,264 | -25.1606 | 107.9722 | 3,996 | Y | Y | Y |
| 053 | GA2476/053DR047 | Cuvier Plateau | -25.53283333 | 108.5391333 | 4,438 | -25.5276 | 108.5452 | 4,049 | Y | Y | Y |
| 055 | GA2476/055DR048 | Cuvier Plateau | -24.36725 | 107.8228333 | 3,163 | -24.3634 | 107.8126 | 3,015 | Y | N | Y |
| 056 | GA2476/056DR049 | Seamount, Cuvier Plateau | -24.01886667 | 109.19885 | 3,502 | -24.0256 | 109.1992 | 3,189 | Y | Y | Y |
| 056 | GA2476/056DR050 | Seamount, Cuvier Plateau | -24.01938333 | 109.1989 | 3,503 | -24.0268 | 109.198 | 3,177 | Y | N | Y |
| 057 | GA2476/057DR051 | Cuvier Plateau | -23.67205 | 109.6871167 | 4,304 | -23.6745 | 109.6808 | 4,021 | Y | Y | Y |
| 058 | GA2476/058DR052 | Cuvier Plateau | -24.02113333 | 109.5162333 | 4,650 | -24.0167 | 109.5087 | 4,246 | Y | Y | Y |
| 061 | GA2476/061DR053 | Cuvier Plateau | -25.54153333 | 108.53405 | 5,159 | -25.5373 | 108.5411 | 4,678 | Y | Y | Y |

### 3.2.2. Boxcore

Seabed sediment and biota were recovered at eight stations using a boxcorer deployed from the Sonne's starboard winch (Tables 3.2 and 3.6). The boxcorer was an Oktopus standard boxcore that comprised a 0.5 x 0.5 m box fitted to the deployment mechanism (Fig. 3.4). The box penetrates the seabed when triggered by the firing mechanism as the frame hits the seabed. Upon retrieval, the spade swings down under the box to encase the sample for transport to the surface.

Organisms may be associated with different sediment layers. For example, some organisms are associated with the supernatant (i.e. water directly above the sediments) (Vereshchaka, 1995), while the majority of infaunal specimens are found in the upper 2-5 cm of benthic sediments (Hines and Comtois, 1985; Blake, 1994), and only a few generally larger and more robust organisms are found in sediment-depths greater than 5 cm (Hines and Comtois, 1985). To sample the biology, boxcore samples were stratified into three vertical components: supernatant (water above sediment), surface layer sediments (≤ 5 cm sediment depth) and bottom layer sediments (> 5 cm sediment depth) and processed separately (Fig. 3.5).

**Table 3.6.** Sample acquisition information for the boxcore (BC) including location, water depth, penetration depth and the recovery success of physical samples.

| Station | Sample ID | Locality | Latitude | Longitude | Water Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N | Geo-chemistry Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|
| 006 | GA2476/ 006BC001 | Houtman Canyon, Houtman Sub-basin | -28.3503 | 112.8701 | 1,982 | Y | Y | Y | Y |
| 006 | GA2476/ 006BC002 | Houtman Canyon, Houtman Sub-basin | -28.3641 | 112.8805 | 1,200 | N | Y | Y | Y |
| 022 | GA2476/ 022BC003 | Zeewyck Sub-basin | -30.9442 | 114.4501 | 2,355 | N | Y | Y | Y |
| 023 | GA2476/ 023BC004 | Zeewyck Sub-basin | -30.9613 | 114.2605 | 3,794 | N | Y | Y | Y |
| 048 | GA2476/ 048BC005 | Houtman Sub-basin | -26.5439 | 111.5021 | 1,525 | N | Y | Y | Y |
| 054 | GA2476/ 054BC006 | Cuvier Plateau | -24.6358 | 107.7553 | 3,467 | N | Y | Y | Y |
| 059 | GA2476/ 059BC007 | Cuvier Plateau | -24.5733 | 108.6956 | 2,608 | N | Y | Y | Y |
| 060 | GA2476/ 060BC008 | Cuvier Plateau | -25.5198 | 109.1815 | 3,828 | N | Y | Y | Y |

NB: ½ of the 0.50 $m^3$ boxcore (i.e. 0.25 m x 0.50 m x depth); ¼ of the 0.50 $m^3$ boxcore (i.e. 0.25 m x 0.25 m x depth); All = vertical sections combined; Top = surface sediments (≤0.05 m sediment depth); Btm = bottom sediments (>0.05 m sediment depth); (No btm) = no bottom sediments were retrieved (i.e., penetration depth was ≤0.05 m).

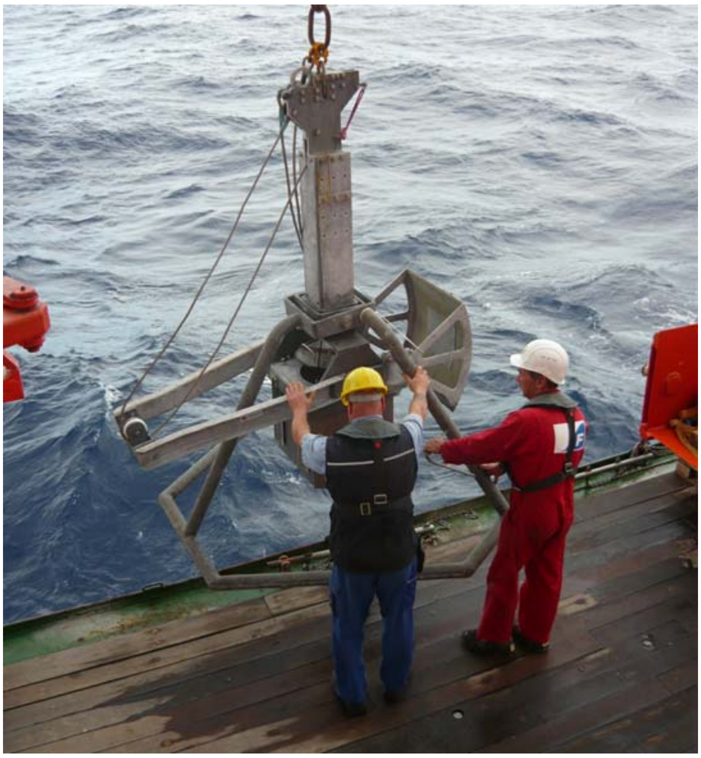


***Figure 3.4.*** *Deployment of the boxcore.*

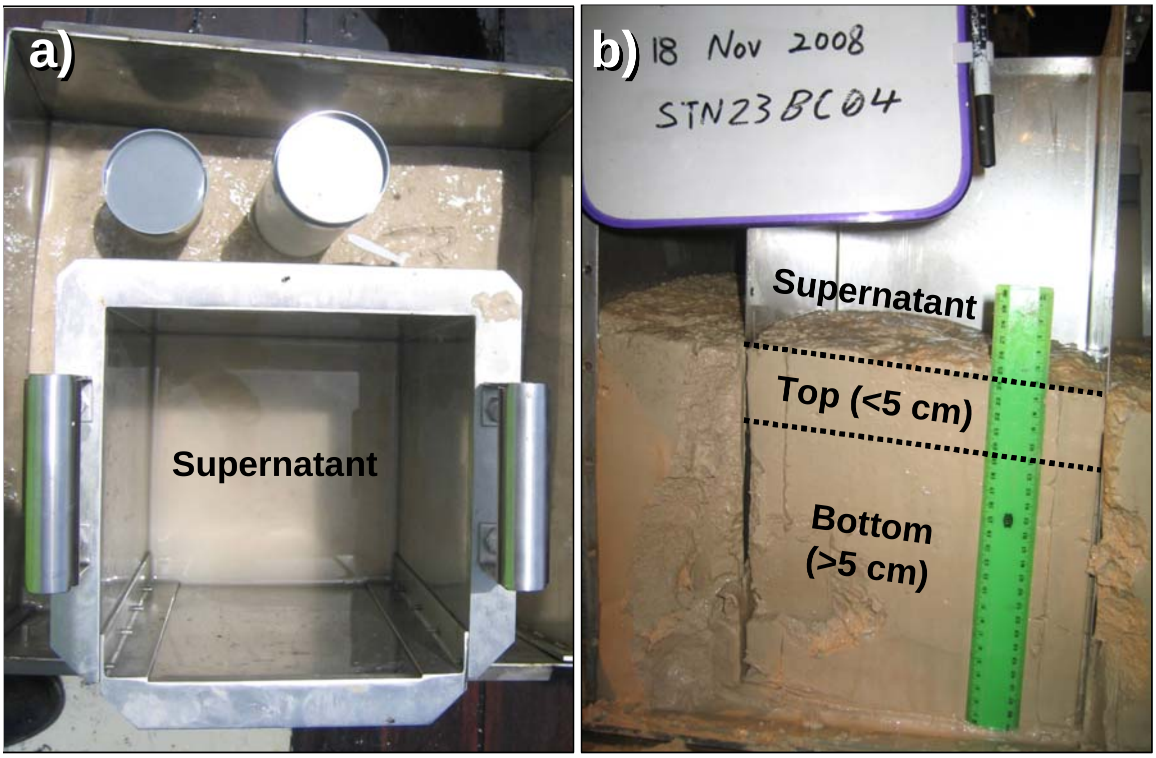



***Figure 3.5.*** *On-deck photographs of a box core sample (023BC04) and the biological sub-corer used to sample infauna. a) top-down view of the boxcore showing the supernatant (water above sediment) contained within the water-tight sub-corer; b) side-view of the boxcore showing the vertical profile of the sediments collected within the sub-corer, and the position of the 3 stratified layers (supernatant, top 5 cm sediment layer, and >5cm bottom sediments) that were sampled.*

For each boxcore, a 25 x 25 cm water-tight square biological sub-corer was carefully pushed down into the sediment (Fig. 3.5a). Supernatant was then siphoned through a 500 µm sieve to collect animals in the water immediately above the sediment. The face-plate of the boxcore was then carefully removed to enable the <5 cm surface and >5 cm bottom sediments to be separated using a 25 x 25 cm blade. The top 5 cm was placed in its entirety into a container for elutriating. As large amounts of bottom sediment were collected compared to the top layer, a three litre sub-sample of bottom sediments (>5 cm) was collected. Once removed, each vertical section was separately elutriated, passed through a 500 µm sieve, transferred to a barcode-labelled container and preserved in 70% ethanol, with the exception of macro-organisms which were removed, photographed and stored in preservatives as listed in Appendix I. For three boxcores (054BC06, 059BC07, 060BC08), sieves with finer mesh were used to quantify smaller-bodied animals: 100 µm sieve for supernatant and a 300 µm sieve for the top sediment layer.

Surface and shallow (<0.20 mbsf) sub-surface sediments were sub-sampled for chlorins, chemistry (acid-extractable metals, nutrients and XRF), porosity, bulk density, grain size and %carbonate. In addition, cores were also taken for incubation experiments and sediment profiles.

Sediment samples from boxcores to undergo textural analysis at Geoscience Australia, were double bagged, labelled (including an aluminium tag), stored in a refrigerated container, and metadata entered into Geoscience Australia's Marine Samples database (MARS) (www.ga.gov.au/oracle/mars). Additional sediment samples were also acquired for bulk chemistry (acid-extractable metals, nutrients and XRF) and similarly stored.

Samples of wet sediment for porosity and bulk density analysis were collected from each boxcores by pushing a syringe into the undisturbed sediment surface to a depth of 0.02 m. The sediments were then ejected into pre-weighed 20 ml plastic vials and frozen for transport to Geoscience Australia.

For each boxcore, one sediment core designated for incubation was collected. The sediment core (and overlying water) were collected by hand-pushing 84 mm diameter PVC tubes into the top of the boxcore sample. Once in the sediment, the core liners were sealed at the bottom with plastic plugs fitted with o-rings and the top of each core barrel were sealed using gas-tight lids, which were fitted on the underside with magnetic stirrers.

After sample acquisition for geochemistry, sedimentology and benthic ecology was complete, the contents of the boxcorer were emptied into a container and checked for rocks. Recovered rocks were washed and sorted into different lithologies and processed as outlined for rocks recovered by the dredge technique described in 3.2.1.

### 3.2.3. Deep-sea TV Controlled Grab (BODO)

Seabed sediments, rocks and/or biota were recovered at 26 stations (Tables 3.2 and 3.4) using the Sonne's BODO video grab (Fig. 3.6a). Once on the deck, the top panels of the BODO were opened and the contents visually inspected. To sample the biology, sediments in the BODO were sub-sampled identically to the boxcore method, with the exception of the collection of supernatant animals which was only successfully collected twice on Leg 1 due to the inability to trap water within the BODO. The top five centimetres of sediment from a 25 x 25 cm area was removed and placed in its entirety into a container for elutriating. A three litre sediment sample was then collected from the bottom sediments (>5 cm) from the same 25 x25 cm area. Once removed, each vertical section was separately elutriated, passed through a 500 um sieve. Each BODO was also sampled for chlorins, chemistry (acid-extractable metals, nutrients and XRF) and grain size and %carbonate using the same methods as the boxcore. Sediment cores were not taken from the BODO due to the disturbed nature of the retrieved sediment except at site 020GR008 where a sediment core was extracted for a core incubation experiment.

After the sub-samples were acquired, the contents of the grab were emptied onto the starboard deck and checked for rocks. Recovered rocks were washed and sorted into different lithologies and processed using the same method outlined for rocks recovered by the dredge technique described in 3.2.1.

Sediment recovery from the BODO was generally substantial. The surface area between the BODO's jaws is about 1.8 $m^2$ leading to a recovery of up to > 0.5 $m^3$. Whilst the volume recovered by BODO was not typically 100%, the generally soft and sticky substrate allowed for good penetration into the seabed and allowed grab samples of more than adequate volumes for laboratory analysis. A failure (and subsequent repair) of the hydraulic motor controlling the BODO's grab mechanism prevented the acquisition of BODO grab samples at Station 46 on Leg 2 of the survey.

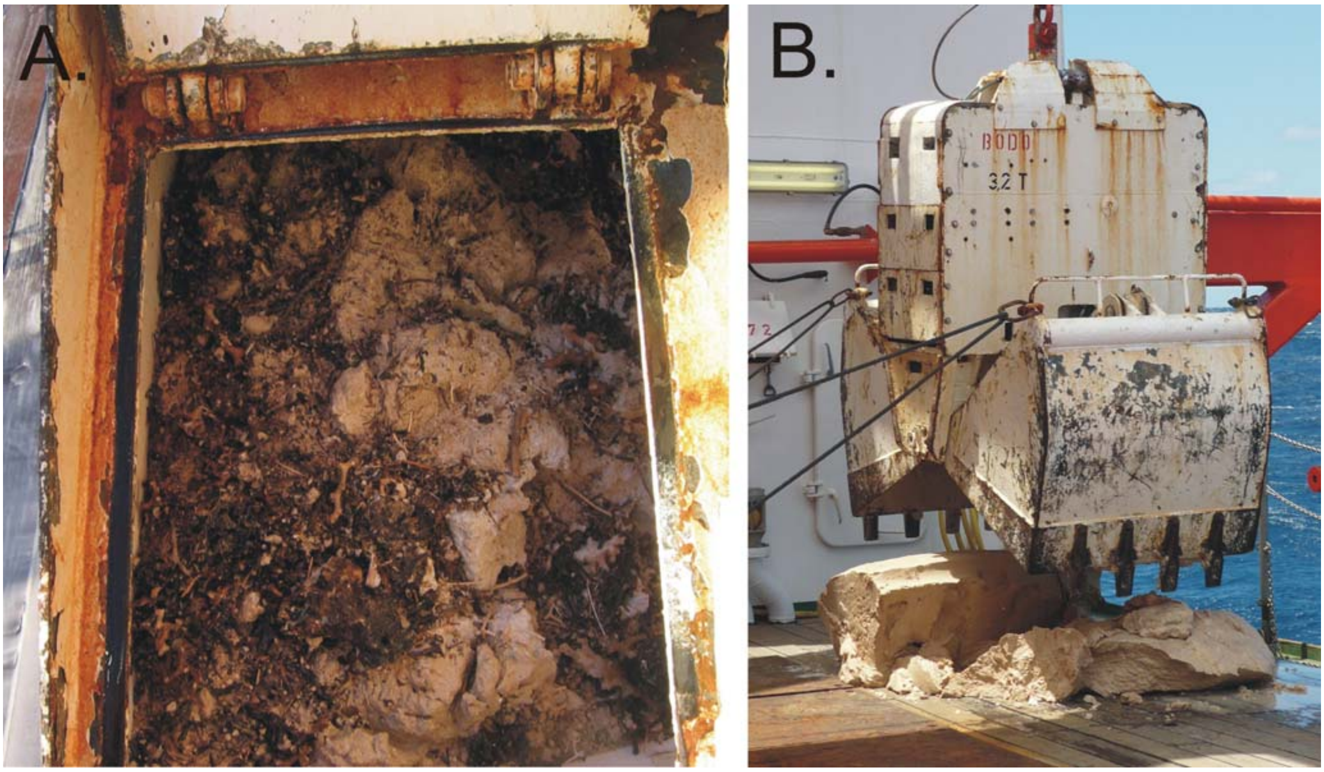



***Figure 3.6.*** *Photos of sediment and biota recovered from the BODO (a) and a BODO sediment sample released to be searched for rock samples (b).*

### 3.2.4. Epibenthic Sled

An epibenthic sled was used at four stations to collect samples of epibenthic biota (Tables 3.2 and 3.7). The sled comprised a plastic net inside a 0.5 x 1 m x 1.5 m metal frame that was towed behind the ship (Fig. 3.7). Two pipe dredges (similar to those attached to the rock dredge) were also attached to the base of the net to collect surface sediments, rock and biota that were not caught in the net. Initially, all biological material collected from a dredge were carefully removed. To examine pipe-dredge sediments for benthic organism, a single eight centremetre diameter PVC pipe was pushed into the sediment to a depth of 20 cm. The PVC sub-sample was then removed and its contents gently elutriated and passed through a 500 µm sieve. After sample acquisition for benthic ecology was complete, the contents of the epibenthic sled and pipe dredges were emptied into a container and checked for rocks. Recovered rocks were washed and sorted into different lithologies and processed as outlined for rocks recovered by the dredge technique described in 3.2.1.

### 3.2.5. Beam Trawl

A beam trawl was used at Station 06 to collect samples of benthic biota (Tables 3.1 and 3.8). Benthic biota were sorted, identified, catalogued, preserved and archived in a refrigerator. The beam trawl was bent during its initial deployment and not used again for the duration of the survey.

***Figure 3.7.*** *Photo of the deployment of the epibenthic sled from the aft deck.*

***Figure 3.8.*** *Photo of the deployment of the beam trawl off the aft deck.*

**Table 3.7.** Sample acquisition information for the epibenthic sled (BS) including start and end locations and water depths and the recovery success of physical samples.

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 027 | GA2476/027BS001 | Houtman Sub-basin | -25.7934 | 110.92 | 2,981 | -25.7969 | 110.9227 | 2,975 | N | N | Y |
| 028 | GA2476/028BS002 | Houtman Sub-basin | -24.7939 | 110.9082 | 2,175 | -24.7997 | 110.91063 | 2,149 | Y | N | Y |
| 029 | GA2476/029BS003 | Houtman Sub-basin | -24.5280 | 110.9746 | 1,959 | -24.5357 | 110.9746 | 1,948 | Y | N | Y |
| 055 | GA2476/055BS004 | Cuvier Plateau | -24.3650 | 107.8172 | 3,113 | -24.3659 | 107.8131 | 3,032 | Y | N | Y |

**Table 3.8.** Information regarding the deployment of the beam trawl (BT) including start and end locations and water depths and the recovery success of physical samples

| Station | Sample ID | Locality | Start Latitude | Start Longitude | Start Depth (m) | End Latitude | End Longitude | End Depth (m) | Rock Sample Y/N | Sediment Sample Y/N | Biology Sample Y/N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 006 | GA2476/006BT001 | Houtman Canyon, Houtman Sub-basin | -28.3663 | 112.8993 | 1,130 | -28.3591 | 112.8763 | 1,618 | N | N | Y |

### 3.2.6. Zooplankton sampling

During Leg 3 of the survey, a novel method was tested to examine the sub-surface zooplankton of the Cuvier Plateau and Houtman Sub-basin (associated with the Perth margin) study areas. During vessel transits, deckwater (from a depth of approximately 5 m) was passed through the hull of the ship and sampled for zooplankton at four locations on the part of the northern Perth margin underlain by the Houtman Sub-Basin (2 x day, 2 x night) and sixteen locations on the Cuvier Plateau (8 x day, 8 x night) (Appendix M). Each sampling period lasted 1 hour, and the same flow rate was used (0.143 litres $sec^{-1}$), such that 514 litres of seawater were sampled for each sampling period. These samples were collected only from 11:30 – 12:30 (day) or 23:30 – 00:30 (night).

Zooplankton samples were also acquired whilst the vessel was stationary at Station 56 (24.0162°S-24.0263°S, 109.8033°E-109.7973°E). At this location six-paired deckwater and surface samples were taken over a 12-hour period and encompass four day and two night samples (Appendix M). The surface samples were collected with a 100 µm plankton net (mouth size: 500 x 250 mm) lowered over the side of the vessel such that approximately 500 litres of seawater were filtered. Due to the rolling of the ship, the volume of surface water passed through the net could only be estimated.

## 3.3. OCEANOGRAPHIC AND METEOROLOGIC DATA

Oceanographic data was acquired using Conductivity-Temperature-Depth profilers (CTDs) and Expendable Bathythermographs (XBTs). Details of samples were entered into Geoscience Australia's Marine Samples database (MARS; http://www.ga.gov.au/oracle/mars).

### 3.3.1. Conductivity-Temperature-Depth (CTD) Profiler

CTD profilers are a tool used to determine the physical properties of sea water. They give precise measurements of the variation of water temperature, salinity and density with depth. Conductivity-Temperature-Depth (CTD) data were collected with two Sea-Bird CTD profilers - one installed on a rosette of Niskin bottles (SBE-9) and one installed on the OFOS Camera system (SBE-19) (Figs. 3.9 and 3.2a). The manufacturer-quoted accuracies for the conductivity, temperature and pressure sensors on each profiler are listed in Table 3.9.

Eight profiles were acquired from CTDs installed with the rosette of Niskin bottles (Table 3.10) and 17 profiles were acquired during OFOS deployments (Table 3.3). The conductivity, temperature and depth data were used to generate sound velocity profiles for the EM120 multibeam sonar. They were also used to image water column properties (summarised in section 9).

**Table 3.9.** Manufacturer-quoted accuracies for the two Sea-Bird CTD profilers used on the RV Sonne.

| SENSOR | SEA-BIRD SBE-9 | SEA-BIRD SBE-19 |
|---|---|---|
| Conductivity | 0.0003 S $m^{-1}$ | 0.0005 S $m^{-1}$ |
| Temperature | 0.001°C | 0.005°C |
| Pressure | 0.015% of full scale | 0.02% of full scale |

**Table 3.10.** Sample acquisition information for the CTD including location, water depth and the recovery of data and physical samples.

| Station | Sample ID | Locality | Latitude | Longitude | Water Depth (m) | Water Sample Y/N | Profiler Data Y/N |
|---|---|---|---|---|---|---|---|
| 001 | GA2476/001CTD001 | Indian Ocean | -8.7553 | 105.0090 | 6,300 | Y | Y |
| 003 | GA2476/003CTD002 | Indian Ocean | -24.3039 | 106.7060 | 3,533 | Y | Y |
| 004 | GA2476/004CTD003 | Indian Ocean | -31.0665 | 114.5623 | 2,345 | Y | Y |
| 013 | GA2476/013CTD004 | Indian Ocean | -28.8073 | 112.3634 | 4,525 | Y | Y |
| 030 | GA2476/030CTD005 | Houtman Sub-basin | -24.2591 | 110.8349 | 2,200 | Y | Y |
| 035 | GA2476/035CTD006 | Cuvier margin | -21.7758 | 112.4783 | 4,848 | Y | Y |
| 059 | GA2476/059CTD007 | Cuvier Plateau | -24.5736 | 108.6951 | 2,612 | Y | Y |
| 060 | GA2476/060CTD008 | Cuvier Plateau | -25.5225 | 109.1829 | 3,834 | Y | Y |

### 3.3.2. Water Samples

The CTD on the RV Sonne is made up of a set of small probes attached to a large metal rosette wheel (Fig. 3.9). The rosette is lowered on a cable down to a specific depth and scientists observe the water properties in real time via a conducting cable connecting the CTD to a computer on the ship. A remotely operated device allows the Niskin bottles to be closed selectively as the instrument ascends. Water sampling is often done at specific depths so scientists can learn the physical properties of the water column at that particular place and time.

Water samples were collected from throughout the water column on two CTD deployments (Table 3.11). Upon retrieval of the CTD, water samples were transferred directly into poisoned (25 µL HgCl) 8 mL glass vials with ground glass stoppers. Vials were stored under seawater at in situ temperatures until transported to the Geoscience Australia laboratory.

### 3.3.3. Expendable Bathythermograph (XBT)

Expendable Bathythermographs (XBT) are a device for obtaining a record of temperature as a function of depth from a moving ship. They are used to obtain information on the temperature structure of the ocean. The XBT is dropped from the ship and measures the temperature as it falls through the water column. XBTs are designed to fall through the water column at a known rate, so that the depth of the probe can be inferred from the time since it was launched. By acquiring temperature data as a function of depth, it is possible to infer the speed of sound through the water column. Since the deployment of an XBT does not require the ship to slow down or otherwise interfere with normal operations, XBTs are often used in preference to CTDs.

Two XTBs were deployed during survey GA2476 (Table 3.12). They were not widely used due to accuracy of the sound velocity profiles obtained by the SVP builder software and because the acquired CTD data were sufficient for maintaining high-quality multibeam bathymetry data.

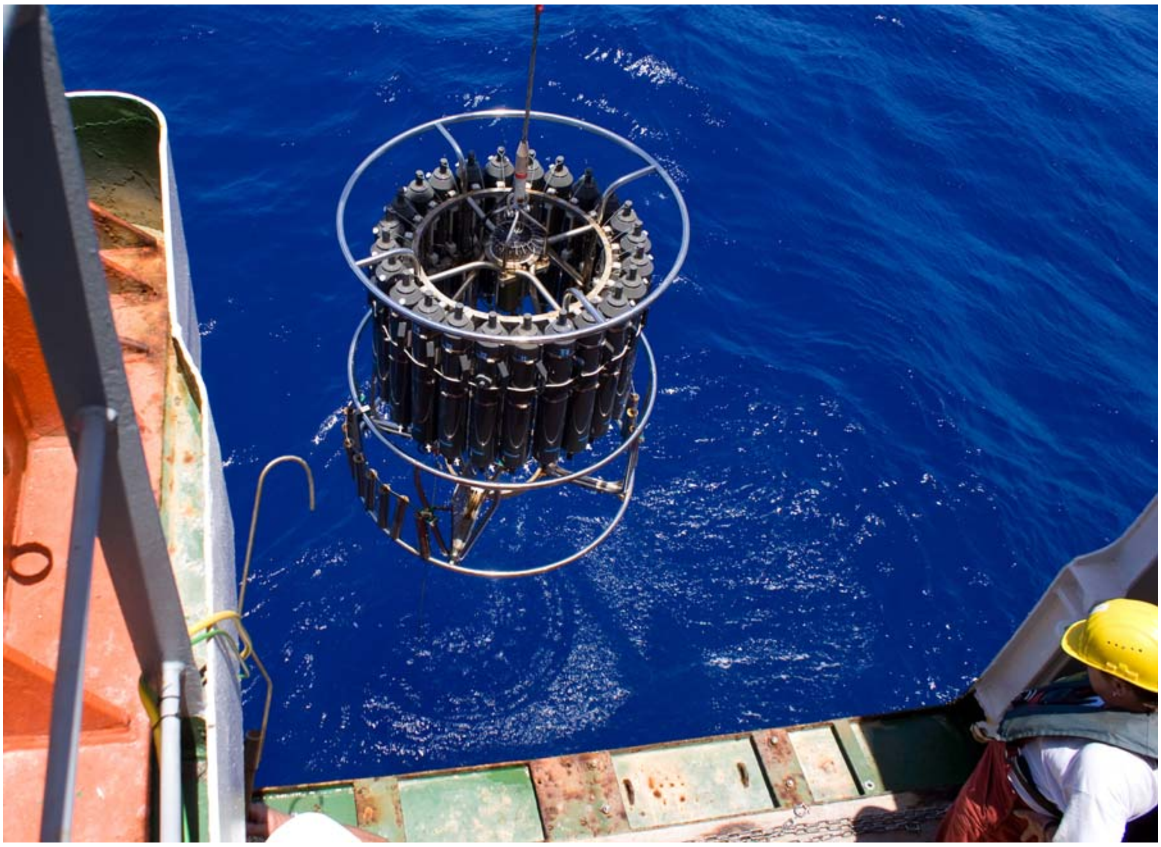


***Figure 3.9.*** *Photo of the deployment of the RV Sonne's CTD off the starboard side.*

**Table 3.11.** Water sample locations, water depths and descriptions.

| SAMPLE ID | STA-TION | LOCALITY | DATE | LATITUDE | LONGITUDE | WATER DEPTH (M) | FILTER PAPER NO. | SAMPLE DESCRIPTION |
|---|---|---|---|---|---|---|---|---|
| GA-2476/001CTD001_WS1988 | 001 | Indian Ocean | 11/11/2008 | -8.75533 | 105.009 | 1,988 | - | Filter # 1532 |
| GA-2476/001CTD001_WS20 | 001 | Indian Ocean | 11/11/2008 | -8.75533 | 105.009 | 20 | - | Filter #1531 |
| GA-2476/003CTD002_WS2488 | 002 | Indian Ocean | 11/11/2008 | -24.30385 | 106.70595 | 2,488 | - | Filter # 1533 |
| GA-2476/004CTD003_WS1534 | 004 | Indian Ocean | 11/11/2008 | -31.0665 | 114.56233 | 13.5 | - | Filter #1534 |
| GA-2476/004CTD003_WS2343 | 004 | Indian Ocean | 11/11/2008 | -31.0665 | 114.56233 | 2,343 | - | Filter # 1535 |
| GA-2476/013CTD004_WS15 | 013 | Indian Ocean | 11/11/2008 | -28.807333 | 112.36343 | 15 | - | Filter # 1538 |
| GA-2476/013CTD004_WS4525 | 013 | Indian Ocean | 11/11/2008 | -28.807333 | 112.36343 | 4,525 | - | Filter #1536 |
| GA-2476/013CTD004_WS500 | 013 | Indian Ocean | 11/11/2008 | -28.807333 | 112.36343 | 500 | - | Filter # 1537 |
| GA-2476/030CTD005_WS0010 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 10 | 12 | 2 samples at each depth |
| GA-2476/030CTD005_WS0200 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 200 | 11 | 2 samples at each depth |
| GA-2476/030CTD005_WS0400 | 030 | Houtman Sub-basin | 30/11/2008 | -24.25908 | 110.83485 | 400 | 10 | 2 samples at each depth |
| GA-2476/030CTD005_WS0600 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 600 | 09 | 2 samples at each depth |
| GA-2476/030CTD005_WS0800 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 800 | 08 | 2 samples at each depth |
| GA-2476/030CTD005_WS1000 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,000 | 07 | 2 samples at each depth |
| GA-2476/030CTD005_WS1200 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,200 | 06 | 2 samples at each depth |
| GA-2476/030CTD005_WS1400 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,400 | 05 | 2 samples at each depth |
| GA-2476/030CTD005_WS1600 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,600 | 04 | 2 samples at each depth |
| GA-2476/030CTD005_WS1800 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,800 | 03 | 2 samples at each depth |
| GA-2476/030CTD005_WS2000 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 1,986 | 02 | 2 samples at each depth, Actual depth 1986m |
| GA-2476/030CTD005_WS2193 | 030 | Houtman Sub-basin | 29/11/2008 | -24.25908 | 110.83485 | 2,194 | 01 | 2 samples at each depth |
| GA-2476/035CTD006_WS1200 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 1,200 | - | 2 x samples |
| GA-2476/035CTD006_WS1600 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 1,600 | - | 2 x samples |
| GA-2476/035CTD006_WS2000 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 2,000 | - | 2 x samples |
| GA-2476/035CTD006_WS2400 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 2,400 | - | 2 x samples |
| GA-2476/035CTD006_WS2800 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 2,800 | - | 2 x samples |

| SAMPLE ID | STA-TION | LOCALITY | DATE | LATITUDE | LONGITUDE | WATER DEPTH (M) | FILTER PAPER NO. | SAMPLE DESCRIPTION |
|---|---|---|---|---|---|---|---|---|
| GA-2476/035CTD006_WS3200 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 3,200 | - | 2 x samples |
| GA-2476/035CTD006_WS3600 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 3,600 | - | 2 x samples |
| GA-2476/035CTD006_WS400 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 400 | - | 2 x samples |
| GA-2476/035CTD006_WS4000 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 4,000 | - | 2 x samples |
| GA-2476/035CTD006_WS4400 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 4,400 | - | 2 x samples |
| GA-2476/035CTD006_WS4850 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 4,850 | - | 2 x samples |
| GA-2476/035CTD006_WS800 | 035 | Cuvier margin | 6/12/2008 | -21.77578 | 112.47831 | 800 | - | 2 x samples |
| GA-2476/059CTD007_WS100 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 100 | - | Niskin bottle failed to fire, no sample |
| GA-2476/059CTD007_WS1002 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 1,002 | 32 | Filter paper weight= 0.1189g |
| GA-2476/059CTD007_WS1401 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 1,401 | 31 | Filter paper weight= 0.1212g |
| GA-2476/059CTD007_WS15 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 15 | - | Niskin bottle failed to fire, no sample |
| GA-2476/059CTD007_WS1598 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 1,598 | 30 | Filter paper weight = 0.1228g |
| GA-2476/059CTD007_WS1799 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 1,799 | 29 | Filter paper weight = 0.1240g |
| GA-2476/059CTD007_WS204 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 204 | 35 | Filter paper weight= 0.1245g |
| GA-2476/059CTD007_WS2192 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 2,192 | 28 | Filter paper weight = 0.1232g |
| GA-2476/059CTD007_WS2390 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 2,390 | 27 | Filter paper weight = 0.1217g |
| GA-2476/059CTD007_WS2597 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 2,597 | 26 | Filter paper weight = 0.1218g |
| GA-2476/059CTD007_WS406 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 406 | 34 | Filter paper weight= 0.1234g |
| GA-2476/059CTD007_WS705 | 059 | Cuvier Plateau | 12/01/2009 | -24.57355 | 108.69506 | 705 | 33 | Filter paper weight= 0.1294g |
| GA-2476/060CTD008_WS15 | 060 | Cuvier Plateau | 12/01/2009 | -25.5225 | 109.18286 | 15 | 36 | Surface water, filter paper weight= 0.1267g |
| GA-2476/060CTD008_WS3819 | 060 | Cuvier Plateau | 12/01/2009 | -25.5225 | 109.18286 | 3,819 | 37 | Bottom water, paper weight = 0.1168g |

**Table 3.12.** Sample acquisition information for the XBT including location, water depth and the recovery of data.

| STATION | SAMPLE ID | LOCALITY | LATITUDE | LONGITUDE | WATER DEPTH (M) | PROFILER DATA Y/N |
|---|---|---|---|---|---|---|
| 002 | GA2476/002XBT001 | Indian Ocean | -22.0518 | 106.7075 | 4,414 | Y |
| 013 | GA2476/013XBT002 | Indian Ocean | -29.5962 | 113.3144 | 2,866 | Y |

### 3.3.4. Underway Acoustic Doppler Current Profiler (ADCP)

Current velocity data were collected with an RD Instruments 'Ocean Surveyor' acoustic doppler current profiler (ADCP). The system installed on the *RV Sonne* was a 38.4 kHz system with a beam angle of 30°. The instrument was setup to log data from 50 bins with a bin size of 24 m, and the first bin was at 41.23 m depth. The instrument provided a depth-averaged, 3-D velocity vector for each depth-bin. The manufacturer-quoted velocity accuracy is ±1%.

### 3.3.5. Underway Oceanographic, Meteorologic and Hydrographic Data

Several oceanographic, meteorological and hydrographic parameters were measured while the ship was underway (Table 3.13). The data were updated once a minute along the ship's track (Fig. 1.1), resulting in approximately 126,000 records.

**Table 3.13.** List of oceanographic, meteorological and hydrographic parameters measured while underway on the RV Sonne.

| | | |
|---|---|---|
| Date | True wind speed (m $s^{-1}$) | Air pressure (mb) |
| Time | Beaufort sea state | Air temperature (°C) |
| Depth (m) | Conductivity (mS $cm^{-1}$) | Humidity (%) |
| Position (latitude, longitude) | Salinity | Wind gust (m $s^{-1}$) |
| True wind direction (°) | Temperature (°C) | |

# 4. Geology: Rock Samples

## 4.1. BACKGROUND

This geological sampling program was the first attempt to dredge rocks from the frontier areas of the Houtman Sub-basin. It was also an additional attempt to dredge rocks from the frontier areas of: 1) the Cuvier margin study area (encompassing the deepwater margins of the Exmouth Sub-basin and Southern Carnarvon Basin; dredged in 1990 by BMR survey 96 (Colwell et al., 1990)); 2) the Zeewyck Sub-basin (dredged in 1986 by BMR Survey 53 (Choi et al., 1987), in 1986 by BMR Survey 57 (Marshall et al., 1989a) and in 1988 by BMR Survey 80 (Marshall et al., 1989b)); and 3) the Cuvier Plateau (dredged in 1979 by survey SO-8 (Exon 1979, von Stackelberg et al., 1980) and in 1990 by BMR Survey 96 (Colwell et al., 1990; Colwell et al., 1994)). Results from this geological sampling program are important in providing a basis to further understand the stratigraphy and petroleum potential of frontier depocentres in the region. A primary objective of the survey was to obtain rock samples deposited before the breakup of Australia and Greater India. Obtaining samples from the pre-breakup succession is particularly important for understanding basin history and assessing its petroleum prospectivity. Targets were identified using a combination of pre-existing seismic lines, planned seismic lines of the GA310 survey and the newly acquired swath bathymetry, sub-bottom profiler records and camera tows (see 3.2. Rock, Sediment and Benthic Sampling and Appendix E). Preliminary biostratigraphic ages obtained from selected 'high priority' samples confirm that pre-breakup rocks were successfully recovered at a number of locations in the Houtman and Zeewyck sub-basins and from the Cuvier margin. The majority of rock samples were recovered from dredges; however, some important rock samples were also recovered using grabs, benthic sleds and box cores (Fig. 4.1; Appendix P). Camera tracks associated with the OFOS and BODO systems captured in video and still a lot of target rock outcrops in situ but are not discussed here (Appendix E, N and O).

Dredging operations were undertaken at 53 sites to target canyon walls, scarps and volcanic peaks in the survey area (Fig. 4.1; Appendix E). Most of the dredge sites were located in canyons where steep slopes provided the best opportunity for sampling a thicker section of sedimentary strata (Fig. 4.2). Dredging operations were undertaken in water depths ranging from 1,000 to 5,000 m and 51 dredges recovered rock samples (Fig. 4.1; Appendix P). Dredge tracks were typically 500 m or less in length and dependent on the extent of suitable outcrop and weather conditions. Of the 28 grab deployments, 13 recovered rock samples from water depths between 2,000 and 4,500 m (Fig. 4.1; Appendix P). The grab and box cores were mostly deployed at the base of steep slopes, cliffs and scarps and occasionally recovered additional lithologies to the dredges. Of the four benthic sled deployments, three recovered rock samples in water depths between 2,000 and 3,100 m from two sites in the Houtman Sub-basin and one site on the Cuvier Plateau (Fig. 4.1; Appendix P). Only one box core (BC001) recovered rock samples from the base of the Houtman Canyon (Houtman Sub-basin) in 2,000 m water depth (Fig. 4.1; Appendix P). Table 3.2 shows the full list of sample techniques used and stations visited during the survey.

The Houtman Canyon incises the sedimentary section of both the Zeewyck and Houtman sub-basins. The lower part of the Houtman Canyon cuts through the stratigraphy in the Zeewyck Sub-basin and is referred to in the text as the Lower Houtman Canyon. The upper part of the Houtman Canyon incises the stratigraphy in the Houtman Sub-basin and is referred to in the text as the Upper Houtman Canyon.

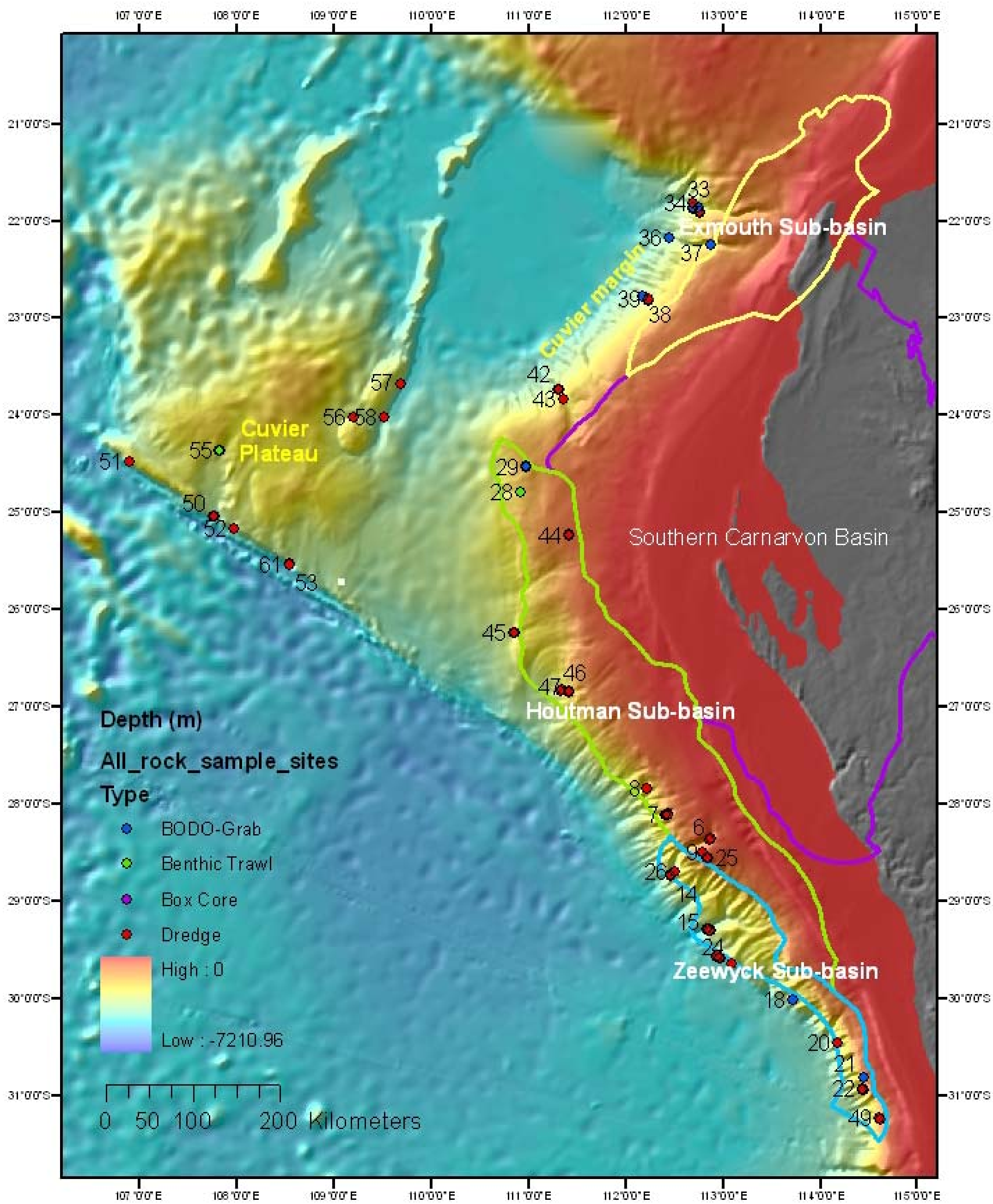



*Figure 4.1.* *Bathymetric map showing the locations of all sites where rock samples were recovered within the study areas.*

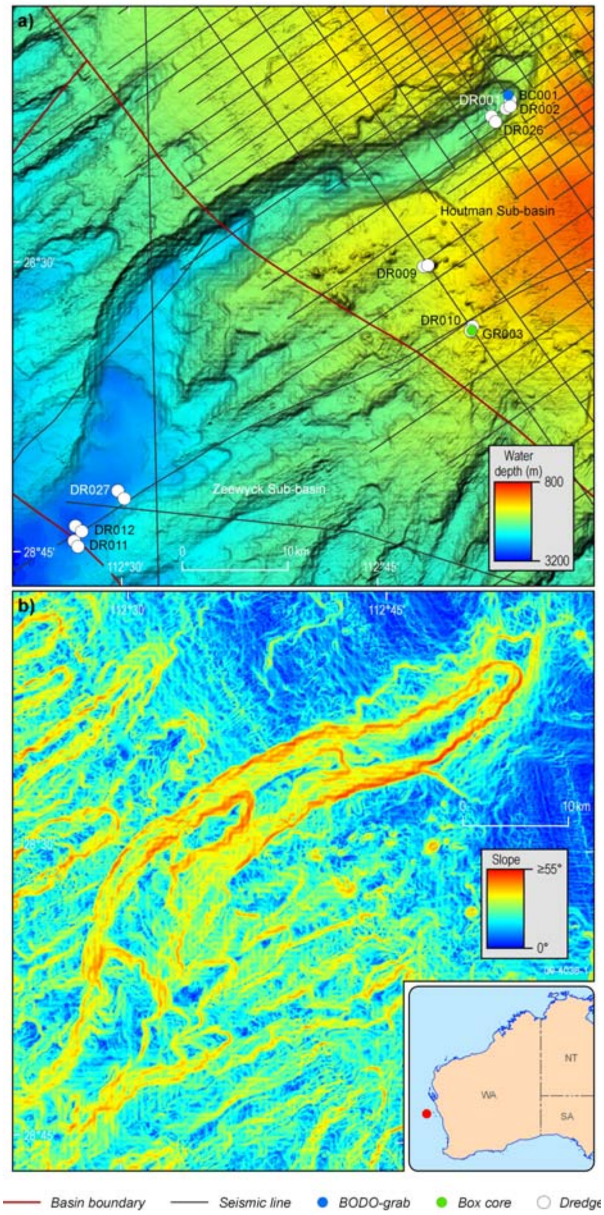



***Figure 4.2.*** *Newly acquired bathymetry (a – top) from this survey and slope analysis (b - bottom) over the Houtman Canyon that allowed sampling of the Houtman and Zeewyck sub-basins. These datasets were evaluated with pre-existing seismic lines to target dredge locations.*

### 4.2. SAMPLE PROCESSING

All the rock samples recovered were briefly described and carefully logged aboard the RV Sonne. On return to Geoscience Australia, sample descriptions for rock samples recovered on all three survey legs were checked and re-described to eliminate inconsistencies in the original descriptions. Suitable samples were then selected, prepared, photographed and submitted for geochemical, petrographic and biostratigraphic analyses (Appendix P). Each rock sample was assigned to a basic ‘rock type’ (often called lithofacies) based on lithology. Examples of these include sandstones, siltstones, claystones and limestones. Each rock sample was further assigned to a particular ‘type’ based on composition and sedimentary structures and features – thus two quartz-rich sandstones of identical colour and lithology but containing different sedimentary structures would be assigned to different ‘types’. For each sample recovery (e.g. dredge, grab), each ‘type’ can contain one to multiple rock samples and each were assigned labels according to the procedure outlined in Section 3.2. Samples containing plant material and/or fossils were selected for biostratigraphic analysis (palynology, nannofossil, foraminiferal and macrofossil analyses). Potentially organic-rich samples were selected for geochemical analyses. Igneous samples were selected for petrographic analysis (see Appendix P). At the time of publication of this report, results for these analyses were only available for a small subset of ‘high priority’ samples that were fast tracked and analysed immediately after the survey. The results from these rock descriptions and ‘high priority’ palynological analyses are summarised below for each of the surveyed areas. Full descriptions of the recovered samples are given in Appendix P.

## 4.3. RESULTS

### 4.3.1. Zeewyck Sub-Basin

The Zeewyck Sub-basin consists of a series of depocentres containing over four kilometres of sedimentary fill. This frontier sub-basin has had little previous exploration and its stratigraphic framework is poorly constrained. Existing interpretations suggest that the sub-basin consists of Middle Jurassic to Lower Cretaceous pre-breakup strata overlain by up to three kilometres of Lower Cretaceous to Cainozoic post-breakup strata (Bradshaw et al., 2003). A key aim of the sampling program was to dredge rocks from a variety of stratigraphic intervals that help piece together and constrain understanding of the sub-basin’s chronostratigraphic framework. Specific dredge targets within the Zeewyck Sub-basin included:

- major canyons and scarps that incise a broad cross-section of strata, thus providing key information on the age and petroleum potential of the sub-basin;
- deeply incised canyons that potentially expose Jurassic and lowermost Cretaceous source rocks; and
- potential basement outcrops identified in seismic data that may clarify the nature of the underlying crust and the timing of continental breakup (e.g. Fig. 4.3).

Analysis of the seismic sections across the Zeewyck Sub-basin indicated that the pre-breakup succession is likely to be exposed in a number of canyon walls and scarps. The Houtman and Geraldton canyons are two key areas that incise deeply enough into the sedimentary strata to enable recovery of the pre-breakup succession. The potential for basement exposure on sufficiently steep slopes was interpreted on a number of seismic lines and several dredges were attempted at those locations (Appendix E).

Dredging and grab operations in the Zeewyck Sub-basin were undertaken in water depths ranging from 1,600 to 4,600 m. The 16 dredge and three grab sites (Fig. 4.4) yielded 53 rock types from eleven main rock categories. These encompassed a wide range of sedimentary rocks (predominantly siliciclastics and carbonates) and some metamorphic and igneous rocks. Sandstone was ubiquitous across the sub-basin whilst limestone was only abundant in the southern Zeewyck Sub-basin (Fig. 4.4). Dredges were deployed in the incised deeper parts of the Houtman (DR011, DR012, DR027) and Geraldton canyons (DR013, DR014, DR015), in water depths of 3,600 to 4,600 m. These dredge hauls yielded a variety of rock types including sandstone, claystone, siltstone, basalt and limestone. Deepwater dredges and grabs along scarps (DR016 to DR020, DR025, GR005, GR006) recovered sandstone, claystone and siltstone from water depths of 3,300 to 4,800 m. Dredges DR021 to DR024 and DR042 and grab GR009 sampled scarps in 1,600 to 2,800 m water depth and yielded samples of abundant limestones and minor chert. Seven sites (DR016 to DR019, DR025, GR005, GR006) were located in deep water that is seaward of the currently mapped western boundary of the Zeewyck Sub-basin. Camera transects have shown that this part of the continental slope is underpinned mostly by sub-cropping sedimentary successions. Samples recovered at these locations yielded only sedimentary rocks and indicates that the basin fill extends all the way to the base of slope. These findings suggest that the previously mapped boundaries of the Zeewyck Sub-basin may require some revision (Fig. 4.4).

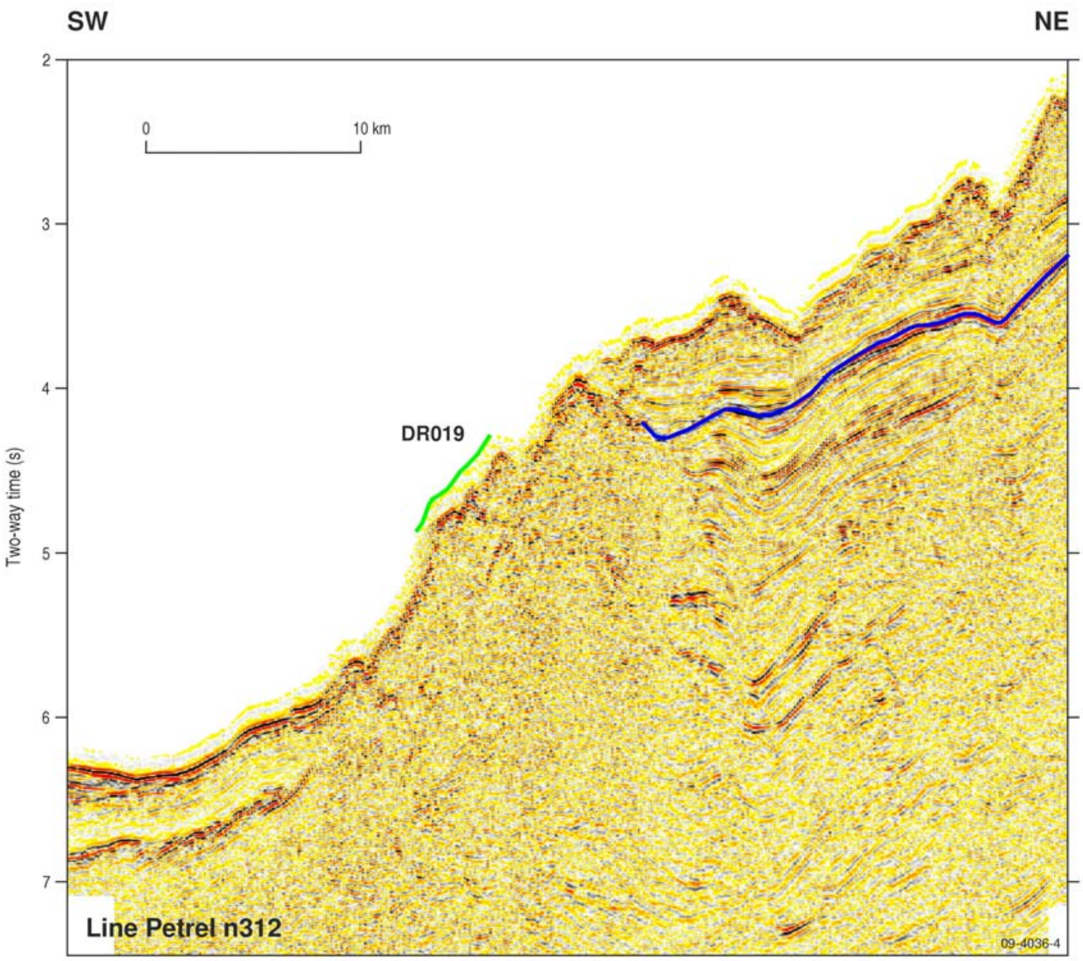



***Figure 4.3.*** *Potential basement outcrop identified in seismic line n312 (Petrel Survey) that was the target of dredge DR019. The green line shows the approximate dredge profile for DR019.*

***Sandstones***

Twenty types of quartz-dominated sandstones were recovered from seven dredges and one grab across the Zeewyck Sub-basin. Mica and carbonaceous grains were common in most of these sandstones. Intraclasts (<5 cm) of siltstone and/or claystone were found in three of the sandstones (DR020G, DR020H, DR025C). Thirteen sandstone types were required to categorise the minor variations observed for the commonly recovered massive sandstone. These massive sandstones were comprised of predominately very fine- to coarse-sized sand grains and minor granule-sized grains. Carbonaceous grains, where apparent, were usually coarser (medium- to coarse-sized sand grains). No macrofossils were observed in the massive sandstones.

Seven sandstone types contained sedimentary structures - three with bedding (poorly defined to 4 cm; DR012A, DR013A, DR020G), four with laminae (<0.1 to 0.6 cm; DR012E, DR019B, DR027E, DR027F), two with cross-laminae (DR012E, DR020G) and a single sandstone type with cross-bedding (DR012A). These sandstone types were comprised of predominantly very fine- to medium-sized sand grains and a minor coarse-sized sand grain component. The carbonaceous fraction consisted of primarily fine- to medium-sized sand grains with some coarser granules. Coaly, wood fragments were found in one grey, laminated sandstone type from the Lower Houtman Canyon (DR027E).

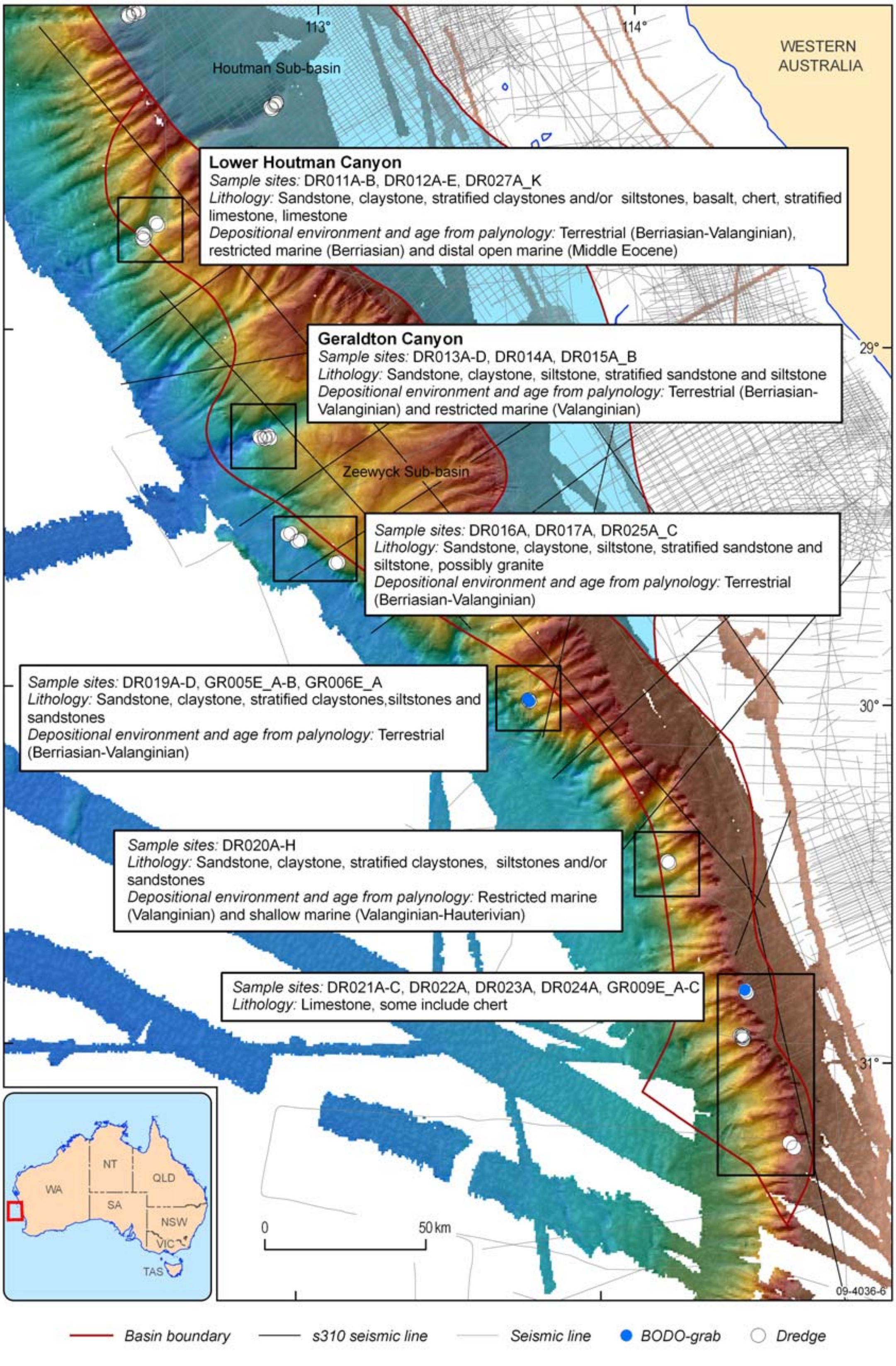



**Figure 4.4.** *The rock samples and rock types recovered from the Zeewyck Sub-basin. Preliminary ages and depositional environments shown were obtained from high priority palynological analysis.*

***Limestones***
Twelve limestone types were recovered from five dredges and one grab. Nine of these types were recovered from the southern Zeewyck Sub-basin. Seven limestone types were micrites (DR021C, DR022A, DR023A, DR027B, DR027K, GR009E-B, GR009E_C), four limestone types were fossiliferous micrites (DR021A, DR021B, DR024A, GR009E_A) and one limestone type was a stratified micrite (DR027D). Six limestone types (DR021A, DR021C, DR027B, DR027D, GR009E_B, GR009E_C) contained rare to minor quartz, carbonaceous and/or opaque grains. Four limestone types (DR021C, GR009E_A, GR009E_C, DR027B) showed silicification of the limestone matrix. The majority of limestone samples exhibited sedimentary structure, typically laminae (<1 cm). Bedding, ranging from poorly defined to well defined (up to 6 cm thick), was recorded in four types (DR021B, DR021C, DR023A, DR027D). Only two limestone types were massive (DR027A, DR027K). Bioturbation was observed in two limestone types (DR027D, GR009E_A) and macrofossils (shell fragments) were noted in four types (DR021A, DR021B, DR024A, GR009E_A). Extensive bioturbation and trace fossils were observed in the stratified micrite (DR027D). A number of samples from these dredges were selected for foraminiferal and nannofossil analyses.

***Claystones***
Seven grey to black claystone types were collected from six dredges across the Zeewyck Sub-basin. The claystones commonly had a significant carbonaceous fraction as both distinct grains as well as part of the finer matrix. Three claystones had a minor fine-sized sand grain component (DR012B, DR019C, DR027I) while the carbonaceous fraction was slightly coarser (medium- to coarse-sized sand grains). Six of the seven claystone types were massive and the remaining claystone (DR025A) had fine laminae (<0.1 cm). Two claystone types were fissile (DR019C, DR025A). No macrofossils were observed.

***Siltstones***
Three siltstone types were obtained from two dredges from the northern Zeewyck Sub-basin. Carbonaceous material and laminae were common in all siltstones. Two siltstones contained small amounts of very fine- to fine-sized sand grains (DR013B, DR013D). One siltstone (DR013B) had bedding (3-8 cm); one siltstone (DR013D) had poorly defined laminae; and the remaining siltstone type (DR016A) was massive. No macrofossils were observed.

***Stratified lithologies***
In addition to the single lithology types, there were eight stratified siliciclastic lithologies sampled from the Zeewyck Sub-basin (for the one stratified limestone type, see Limestones heading). Three types were stratified claystone-sandstone (DR011A, DR019D, DR020A); two types were stratified sandstone-siltstone (DR025B, DR027G); one type was a stratified claystone-siltstone (DR013C), one type was a stratified siltstone-sandstone (DR020C); and one type was a stratified claystone-siltstone-sandstone (GR005E_B). Very fine- and fine-sized sand grains dominated all the sandstone components of the stratified rock types. As with the individual sandstone, siltstone and claystone types, carbonaceous grains were common and were generally coarser than the siliciclastic component (fine- to coarse-sized sand grains). All of the stratified types displayed sedimentary structures - seven types contained laminae (<0.1 to 0.9 cm) varying among planar, wavy and/or cross-stratified, three types (DR011A, DR013C, DR019D) were bedded (1 to >3 cm) and one type of stratified claystone-sandstone (DR011A) exhibited trough and planar cross bedding.

***Other rock types***
Two types of basalts, one type of chert and a possible granite sample were recovered from the northern Zeewyck Sub-basin. The basalts were dark grey to black – one type of basalt (DR027A) was vesicular and porphyritic (with an aphanitic groundmass and fine to medium sized

phenocrysts) and the other type of basalt (DR027L) was composed of equigranular, aphanitic crystals. The chert and both basalt types were dredged from the Lower Houtman Canyon.

***Initial Palaeontological Results (Zeewyck Sub-basin)***

*Palynology*

Twenty-five samples (listed in Appendix Q) of suitable lithology (typically fine-grained siliciclastics) from the Zeewyck Sub-basin were chosen for initial palynological analysis. Twenty of the samples revealed diverse, reasonably well preserved palynomorph assemblages and five are palynologically barren or nearly barren, containing only dark brown to black woody debris (Appendix Q). The majority of well preserved assemblages were spore-pollen dominated and assignable to the Berriasian-Valanginian *Ruffordiaspora australiensis* Zone (Helby et al., 1987) or *Biretisporites eneabbaensis* Zone (Backhouse, 1988) (Appendix Q). Four of these samples (DR013D, DR020G1, DR027I, DR020C1) also contained sparse dinocyst assemblages which are assignable to the Berriasian *Fusiformacysta tumida* and Valanginian *Gagiella mutabilis* zones respectively. These samples contained rare, low diversity assemblages of thin-walled dinocysts that are considered indicative of restricted marine environments. The remaining Berriasian-Valanginian samples (listed in Appendix Q) are all considered to be of terrestrial origin, although some contain rare spiny acritarchs that are usually considered indicative of shallow marine environments. However, it is most likely these spiny acritarchs are reworked from the Early Triassic as they contain common *Veryhachium* species that are identical to those that occur so prominently in Lower Triassic *K. saeptatus* Zone assemblages. Reworked Early Triassic and early Permian spore-pollen taxa are also present as a major component of these Early Cretaceous samples. Fully marine assemblages were only recorded from one late Valanginian-early Hauterivian (*S. tabulata* Zone) sample (DR020D1) and one Middle Eocene (*E. partridgei* Zone) sample (DR027D).

The samples selected for initial palynological analysis were collected from a 250 km length of the Zeewyck Sub-basin (Fig. 4.4) **-** from the Lower Houtman Canyon, Geraldton Canyon and further south to several sites along the lower continental slope. The relatively restricted age interval of most samples (Berriasian-Valanginian) suggests a widespread and relatively thick, lowermost Cretaceous sequence. It is likely that the goal of targeting pre-rift sections has also preferentially sampled this sequence.

*Foraminifera*

Six productive samples (listed in Appendix Q) were processed for foraminifera and examined by Dr Patrick Quilty (University of Tasmania). They are all assigned Late Paleocene to Early Oligocene ages and all samples were deposited in distal, open marine environments (Appendix Q). As is typical for carbonates along the western margin of Australia, the majority of samples are of a Middle Eocene age (E7-E13 foraminiferal zones).

*Nannofossils*

Eight productive samples (listed in Appendix Q) were examined by Dr John Rexilius whom assigned Late Paleocene-Late Oligocene ages to all samples and considered that the sediments were deposited in distal marine environments. The majority of samples are considered to be Middle Eocene (CP13b-CP14a nannoplankton zones).**-** a result confirmed by the ages ascribed to the foraminiferal assemblages from the same samples.

### 4.3.2. Houtman Sub-basin

The Houtman Sub-basin consists of a large northwest to south-southeast trending, segmented depocentre that contains up to 14 km of sedimentary fill (Symonds and Cameron 1977; Copp et al., 1994). Current data coverage in the Houtman Sub-basin varies from sparse regional seismic lines in the north to extensive seismic coverage and three wells (Gun Island-1, Houtman-1 and

Charon-1) in the south. The southern part of the sub-basin is currently being explored for Jurassic petroleum systems (Gorter et al., 2004). Little is known about the exploration potential of the northern part of the sub-basin. The key aim of the geological sampling program in the Houtman Sub-basin was to recover rocks that increase the understanding of the geology and exploration potential of the data-poor northern part of the sub-basin. Specific dredge targets within the Houtman Sub-basin included:

- major canyons and scarps that potentially expose Mesozoic strata of the northern Houtman Sub-basin;
- deeply incised canyons in the southern Houtman Sub-basin that potentially expose Jurassic and lowermost Cretaceous source rocks (e.g. Fig. 4.5); and
- seafloor peaks in the southern Houtman Sub-basin that may have an origin related to either igneous activity, mud diaperism or carbonate build-up (e.g. Fig. 4.6).

The geological sampling operations in the Houtman Sub-basin were undertaken in water depths ranging from 900 to 3,300 m. Sixty-one rock types from 13 main rock categories were collected from 14 dredges, two grabs, one box core and two benthic sleds (Fig. 4.7). Limestone was most common in the southern parts of the sub-basin whilst basalts and mineral precipitates were predominant in the northern half of the sub-basin (Fig. 4.7). Dredges (DR009, DR010) and grab (GR003) samples were recovered from two 200-300 m high peaks (initially identified on seismic lines) located immediately southeast of the Houtman Canyon and yielded basalt, volcaniclastic breccia and limestones (Fig. 4.6). The origin of these peaks was uncertain until the dredge and grab hauls yielded basalt and volcaniclastic breccia. Another peak, 380 km further north, was sampled by DR038 and similar rock types of volcaniclastic conglomerate and basalt were recovered. Dredges (DR001-DR008, DR026, DR040, DR041) were recovered from steep canyon walls in water depths of 1,700 to 3,000 m and included dredges from the Upper Houtman Canyon (DR001-DR002, DR026; Fig. 4.5). These dredges yielded a variety of rock types including sandstone, claystone and limestone. A box core (BC001) deployed within the Houtman Canyon yielded loose sediments and rock samples from the canyon floor.

No suitable canyons exist in the northern Houtman Sub-basin for collecting pre-breakup sedimentary rocks. A dredge (DR039) along an exposed scarp facing the Wallaby Saddle in water depths of 3,137 to 3,285 m recovered basalt, limestone and mineral precipitates. This sample site was located outside the previously mapped basin boundary. A grab (GR014) and two benthic sleds (BS002, BS003) from scarps in water depths between 1,948 and 2,175 m yielded further basalts.

***Limestones***

Nineteen limestone types were described from nine dredges and one grab that were primarily from the southern half of the sub-basin. Seventeen limestone types were micrites (listed in Appendix P), one limestone type was a fossiliferous micrite (DR041B) and one limestone type was a sparse biomicrite (GR003E_A), which was collected from near the top of a volcanic peak. The sparse biomicritic limestone was comprised of granule- to very large pebble-sized biogenic grains in a carbonate mud matrix. Three limestone types (DR001B, DR004G and DR041B) contained rare to minor quartz, carbonaceous and/or opaque grains.  One limestone type (DR004G) was partially silicified. Most of the limestones were massive and had no obvious sedimentary structures. Three limestone types contained laminae (DR002D, DR006C, DR041B) with a fourth having poorly defined bedding (DR001C). Corals, spicules, spines, brachipods and serpulid tubes were noted in the sparse biomicrite (GR003E_A) and bivalve fragments and moulds were observed in a fossiliferous micritic limestone (DR041B).

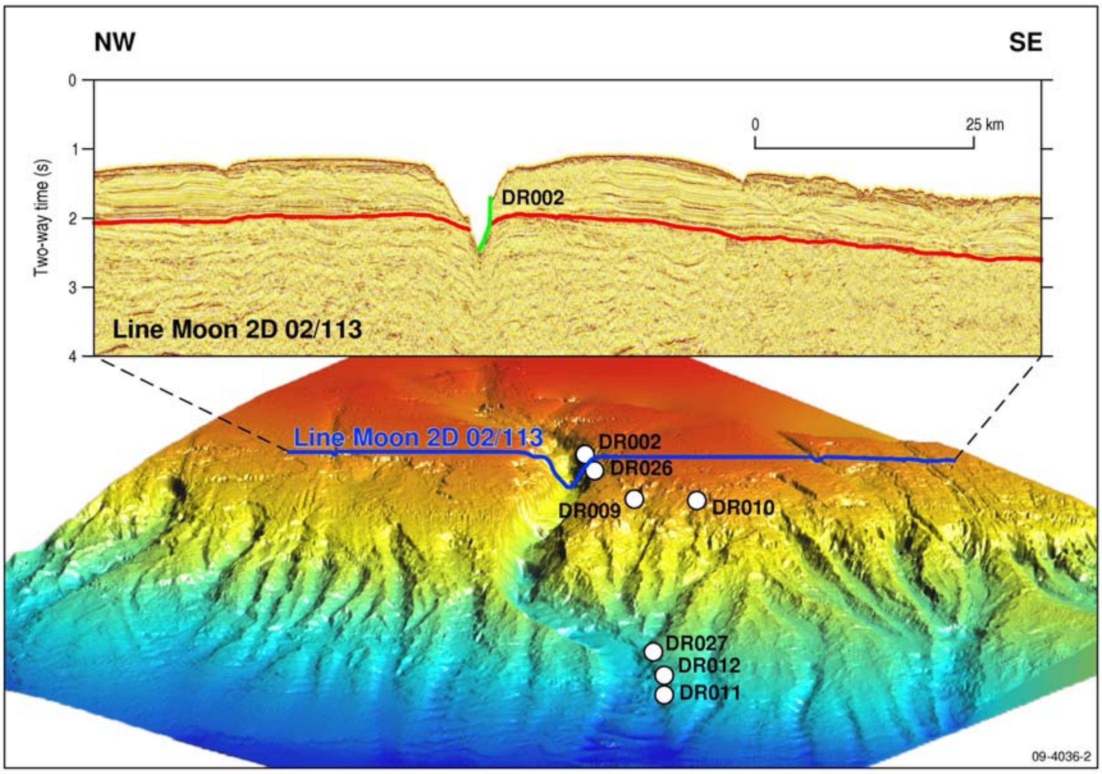



***Figure 4.5.*** *The Houtman Canyon in 3D that incises into the pre-breakup succession of the Houtman Sub-basin as shown on seismic line 02/113 (Moon 2D Survey). The target for dredge DR002 can be tied to seismic line 02/113 and the green line represents the approximate dredge profile of DR002.*

***Sandstones***

Ten sandstone types were recovered from six dredges and one box core that were mainly from the southern Houtman Sub-basin. The sandstones were quartz-dominated and commonly contained carbonaceous grains or carbonaceous laminae. These sandstones were comprised of predominantly very fine- to medium-sized sand grains. Five sandstone types were massive with the other five sandstones containing bedding (1-3 cm; DR001A, DR002H, DR006F, DR026B, DR040B) and/or laminae (<0.1-1 cm; DR001A, DR026B, DR040B). One sandstone type had cross bedding (DR001A) and another sandstone (DR026B) displayed ripple cross-laminae and soft sediment deformation. One pebbly sandstone (DR002A) included granule- to pebble-sized grains and a pebble-sized mudstone intraclast. No macrofossils were observed.

***Claystones***

Eight olive to very dark grey claystone types were described from six dredges that were primarily from the southern Houtman Sub-basin. Mica, quartz and carbonaceous grains were common. Four of the claystones were massive (DR001D, DR002B, DR026F, DR041C) and four claystones exhibited laminae ranging from poorly defined (DR002E, DR004B) to 0.2 cm thick (DR005C, DR026D). Two of the claystones also contained carbonate crystals or grains (DR002B, DR005C). No macrofossils were observed.

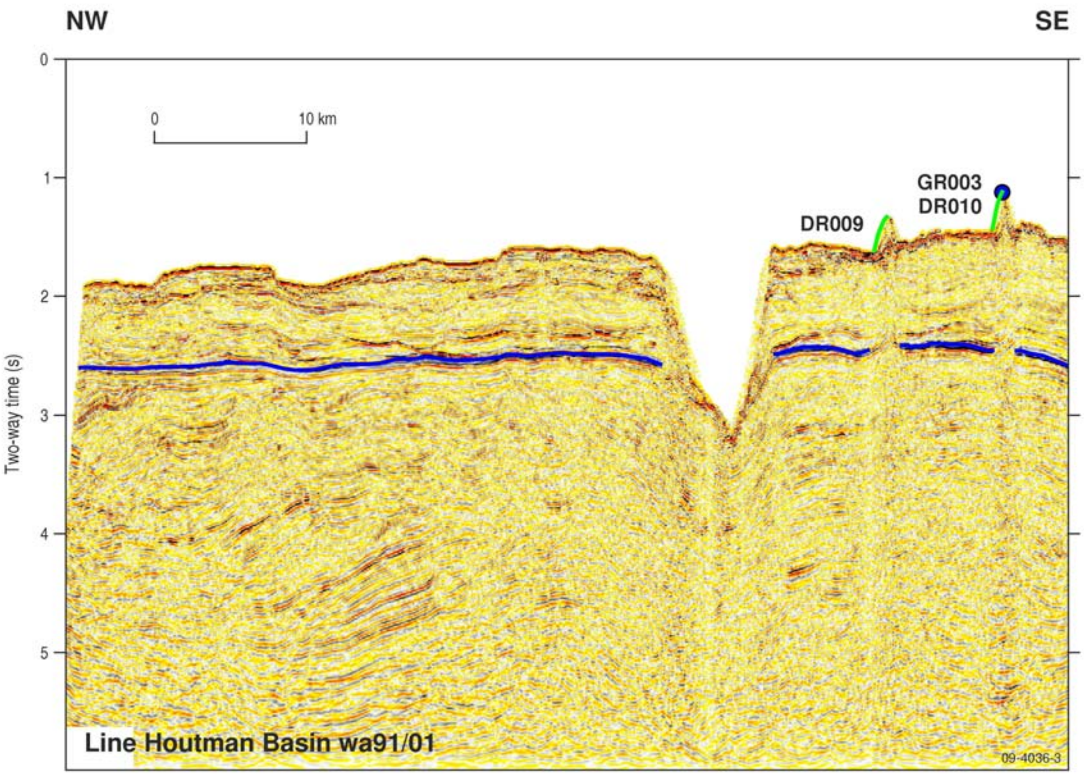



***Figure 4.6.*** *The two seafloor peaks identified on seismic line wa91/01 (Houtman Basin Survey) that were the targets of dredge DR009 (left feature), dredge DR010 and grab GR003 (right feature). The green lines represent the approximate dredge profiles of dredges DR009 and DR010 and the blue point the approximate target of grab GR003.*

***Siltstones***

Two siltstone types were recorded from one dredge and one box core from the southern Houtman Sub-basin. Glauconite grains were found in one siltstone type (DR041D). Both siltstones contained small amounts of very fine- to fine-sized sand grains. One siltstone type (DR041D) was massive and the other siltstone (BC001E_C) had laminae (<0.1 cm).

***Mudstones***

Three mudstone types were recorded from one dredge and one box core from the southern Houtman Sub-basin. Carbonaceous material was common in the mudstones. Two mudstone types (BC001E_D, BC001E_E) were massive and the other mudstone type (DR005D) contained fine laminae (<0.1 cm). Coaly wood fragments were found in a single mudstone (BC001E_E).

***Stratified lithologies***

Five stratified rock types containing more than one lithology were recovered from one dredge and one box core from the Upper Houtman Canyon. Two types were stratified siltstone-sandstone (DR026A, DR026G), two types were stratified claystone-sandstone (DR026E, BC001E_B) and one type was a stratified sandstone-siltstone (DR026C). Mica grains were common in all the stratified lithologies. Very fine- to fine-sized sand grains dominated all the sandstone components of the stratified rock types. All the stratified lithologies had laminae ranging from planar to wavy (<0.1 to 1 cm) with cross-laminae in one stratified siltstone-sandstone (DR026A). Bedding (1 to 3 cm) occurred in both the stratified claystone-sandstone lithologies.

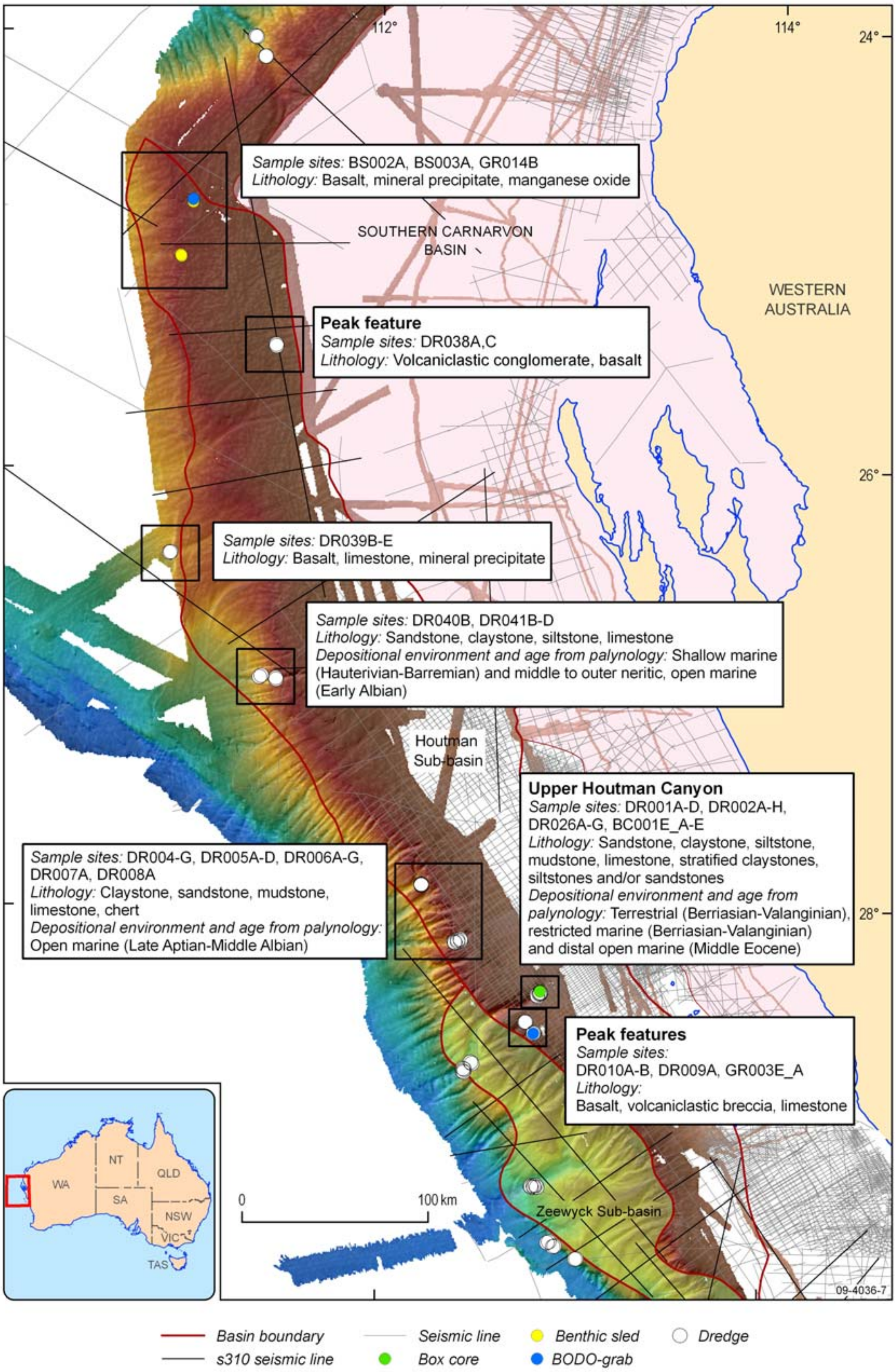



***Figure 4.7.*** *The rock samples and rock types recovered from the Houtman Sub-basin. Preliminary ages and depositional environments shown were obtained from high priority palynological analysis.*

***Basalts***

Six types of basalt, one type of volcaniclastic breccia and one type of volcaniclastic conglomerate were described from four dredges and one benthic sled from the Houtman Sub-basin. Most of the basalts were finely crystalline (too fine to determine the mineralogy in hand specimen), although glass was a common component. Four of the basalt types displayed vesicular fabrics (DR010A, DR010B, DR039D, BS002A) and one basalt was porphyritic (DR038C). All the vesicular basalts were aphanitic (crystals not visible to naked eye) and the porphyritic basalt had fine- to coarse-grained phenocrysts in an aphanitic groundmass. The volcaniclastic breccia (DR009A) comprised very angular to angular intraclasts of vesicular basalt within a carbonate-clay matrix. The volcaniclastic conglomerate (DR038A) consisted of weathered, sub-rounded to well-rounded intraclasts in a carbonate-clay matrix.

***Other rock types***

Three types of chert and three mineral precipitates were collected from three dredges, one benthic sled and one grab. One of the chert types contained minor silt-sized carbonate grains (DR006G). The three dark reddish brown to black mineral precipitates comprised primarily manganese and iron oxides.

***Initial Palaeontological Results (Houtman Sub-basin)***

*Palynology*

Twenty-three samples from the Houtman Sub-basin (listed in Appendix Q) have been chosen for initial palynological analysis, of which three samples (BC001E_D-E, DR040B1) were palynological barren or nearly barren. The remaining twenty samples (listed in Appendix Q) contained abundant, well to adequately preserved palynological assemblages. Five samples (BC001E_A, DR026B1, DR026C1, DR026C3, DR026E1) containing spore-pollen dominated microfloras are considered to have been deposited in fluvio-deltaic to estuarine or restricted marine environments and are assigned to the Berriasian-Valanginian *Biretisporites eneabbaenis* Zone. The remaining fifteen samples (listed in Appendix Q) all contain increasingly diverse dinocyst assemblages that indicate progressively more open marine settings. Five restricted marine samples (DR001A, DR002E, DR026A1, DR026D1, DR026G1) were assigned to either the Berriasian *Fusiformacysta tumida* or Valanginian *Gagiella mutabilis* zones; one sample (DR041C1) assigned to the Hauterivian-Barremian *Muderongia testudinaria-M. australis* zones is considered to be proximal, shallow marine; seven samples (DR004B1-2, DR004B4-5, DR005A, DR005C, DR041B1) assigned to Late Aptian-Middle Albian zones were deposited in open marine (probably still shelfal) environments; and two samples (DR002D, BC001E_B) from the Middle Eocene *Deflandrea heterophlycta* Zone represent distal, open marine facies. The older samples (terrestrial to restricted marine facies) were all collected from the more deeply incised strata exposed within the Upper Houtman Canyon.

*Foraminifera*

Six productive samples (listed in Appendix Q) were examined by Dr Patrick Quilty (University of Tasmania) and are assigned Late Paleocene (P4a/b) to Middle Eocene (E6-E13) ages and all were deposited in open marine environments.

*Nannofossils*

Thirteen samples (listed in Appendix Q) were examined by Dr John Rexilius for their nannofossil content. Six samples (listed in Appendix Q) are barren; five samples (DR001B, DR004C1, DR006E, DR007A1, DR039B1) are assigned Middle Paleocene (CP4 and CP8) to Late Eocene (CP10-CP15bi) ages; and two samples (DR005A, DR041B1) are considered to be Albian (KCN28 and KCN29). All samples are from a distal marine palaeoenvironment. The nannofossil ages closely match those from the foraminiferal and palynological analyses for most samples.

### 4.3.3. Cuvier margin

The Southern Carnarvon Basin incorporates a series of onshore and offshore depocentres of Palaeozoic age. In the offshore Southern Carnarvon Basin, data coverage is sparse with only two wells drilled (Pendock-1 in the north and Edel-1 in the south) and limited seismic coverage. A key aim of the sampling program in the Southern Carnarvon Basin was to infill the offshore data gaps to improve the understanding of Palaeozoic depocentres. The adjoining Exmouth Sub-basin (Northern Carnarvon Basin) contains up to 15 km of Triassic to Recent marine and non-marine siliciclastics. The northern Exmouth Sub-basin is an emerging Australian oil province, having yielded a number of discoveries in recent years.

The southern part of the Exmouth Sub-basin lies in deep water (1,000-4,000 metres) and has had little exploration with only one well drilled (Herdsman-1) and very sparse seismic coverage. Two large canyons (Cape Range and Cloates canyons) that incise the margin lie mostly seaward off the currently defined boundaries of the Southern Carnarvon Basin and Exmouth Sub-basin, and therefore no dredge targets were chosen in advance of the survey. The area also lacks seismic coverage, which makes it difficult to predict whether it is underpinned by sedimentary rocks or basement. Subsequent to swath acquisition and analysis, several dredges were planned in a wide range of water depths in the Cape Range and Cloates canyons. Sampling in these canyons was aimed at assessing the extent and thickness of the sedimentary succession in the outer part of the Exmouth Sub-basin, as well as at recovering basement rocks.

Further west, the lower part of the continental slope (1,500-5,000m) lies seaward of the previously mapped western boundaries of the Exmouth Sub-basin and South Carnarvon Basin (Fig. 1.3). This part of the margin had no previous exploration and is generally considered non-prospective. As all of the sampling in deepwater named and unnamed canyons occurred outside the previously mapped boundaries of the Southern Carnarvon Basin and Exmouth Sub-basin, the term ‘Cuvier margin’ is used herein when referring to these sampling sites. A key aim along the Cuvier margin was to find out whether it is underpinned by shallow basement or sedimentary strata, and the age and composition of these rocks.

Along the Cuvier margin, 52 rock types from nine main rock categories were collected from ten dredges and seven grabs (Fig. 4.8). Limestone was the predominant lithology collected (Fig. 4.8). Dredge and grab operations in the Cuvier margin were undertaken in water depths ranging from 2,100 to 4,700 m (Fig. 4.8). Dredges (DR028-DR031) and grabs (GR016-GR018) were deployed in the more deeply incised sections of the Cape Range Canyon. The dredge and grab hauls yielded a variety of rock types including sandstone, siltstone, claystone, limestone and some volcanics. Dredges (DR032 and DR033) and grabs (GR019 and GR020) also successfully recovered siltstones and stratified sandstone-siltstone from the Cloates Canyon, whilst dredges (DR036 and DR037) yielded sandstone, claystone, siltstone and limestone samples from the Carnarvon Canyon. Similar rock types were also recovered from an unnamed canyon at moderate water depths (3,250 to 3,950 m) using the dredge (DR034 and DR035) and grab (GR021 and GR022) techniques.

***Limestones***

Seventeen limestone types were identified from five dredges and three grabs. Sixteen limestone types were micrites (see Appendix P) and one limestone type was a fossiliferous micrite (GR022E_B). Six limestone types (DR033A, GR021E_D, GR021E_H-K) contain rare to minor quartz, carbonaceous and/or mica grains. Only one of the limestone types (GR021E_H) displayed sedimentary structures in the form of laminae (0.1-0.8 cm). The single fossiliferous micritic limestone (GR022E_B) contained rare bivalve fragments.

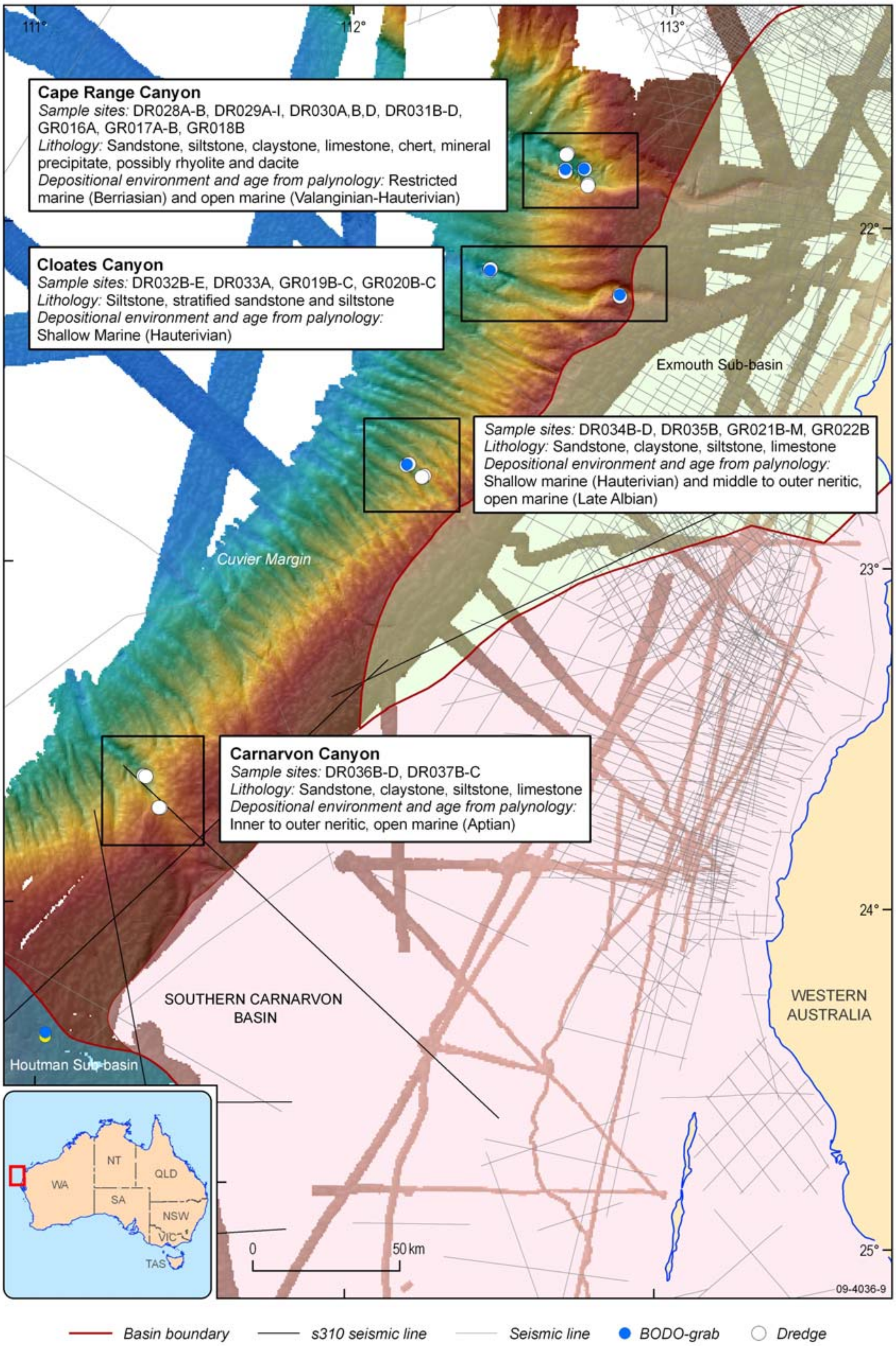



***Figure 4.8.*** *The rock samples and rock types recovered from the Cuvier margin that is outside the previously mapped boundaries of the Southern Carnarvon Basin and Exmouth Sub-basin. Preliminary ages and depositional environments are from high priority palynological analysis.*

***Siltstones***
Twelve siltstone types were recovered from five dredges and two grabs along the Cuvier margin. Mica grains occurred in nearly all the siltstones and glauconite grains were found in a single siltstone (GR021E_E). One siltstone type (DR034B) contained thin lenses of claystone (0.1-0.6 cm). Almost all the siltstones had minor amounts of very fine- to fine-sized sand grains and/or clay. Seven of the siltstones were massive and three siltstone types (GR019E_C, GR021E_E, DR034B) were bedded with either planar (1.2 cm) or lenticular bedding. One siltstone (DR037B) was distinctive due to extensive burrows and tracks that emphasise layering within the siltstone. One siltstone type contained bivalve fragments (DR032D).

***Sandstones***
Ten sandstone types were described from five dredges and three grabs along the Cuvier margin. Quartz, mica and carbonaceous grains were common constituents in all sandstone types. The sandstones consisted of predominantly very fine- to medium-sized sand grains. Nine of the sandstone types were massive, while one sandstone type (DR028A) had laminae (0.1-0.5 cm). One of the sandstone types (DR036B) contained coaly wood fragments, bivalve moulds and medium- to large cobble-sized carbonaceous and lithic intraclasts.

***Claystones***
Seven dark olive brown to black claystone types were recovered from four dredges and three grabs along the Cuvier margin. Five of the claystone types were massive; two claystones (DR029A, DR036C) had laminae (<0.1-0.5 cm); and a single claystone (DR036C) displayed bedding (3 cm). Three of the claystone types were fissile (DR029A, DR037C, GR016E_A) and one claystone was extensively bioturbated (DR036C). No macrofossils were observed.

***Other rock types***
A single stratified sandstone-siltstone type (DR032B) was obtained from the Cloates Canyon. The stratified lithology displayed bedding (1-4 cm) and laminae (0.5 cm). The sandstone layers consisted of predominately very fine-sized sand grains and a minor component of fine-sized micaceous grains. One type of chert (DR029F) and two mineral precipitates (DR029G, DR031C) were also recovered from two dredges in the Cape Range Canyon. Two volcanic rock types (DR029B, DR029D), possibly comprising rhyolite and dacite, were also collected from the Cape Range Canyon.

### *Initial Palaeontological Results (Cuvier Margin)*

*Palynology*
Twenty-one samples from the Cuvier margin have been analysed for their palynological content (listed in Appendix Q). One sample (DR029A2) was essentially barren and the remaining samples contained poorly to well preserved palynomorph assemblages (listed in Appendix Q). The oldest sample (GR016E_A1) was collected from the Cape Range Canyon - the most deeply incised canyon along the margin. It contained a spore-pollen dominated assemblage with rare, thin-walled dinocysts assignable to the Berriasian Fusiformacysta tumida Zone and typical of deposition in a marginal (restricted) marine setting. The remaining 19 samples (listed in Appendix Q) all represented fully marine facies and ranged from the Valanginian Systematophora areolata Zone to the Late Albian Endoceratium ludbrookiae Zone. This is a major contrast with the Houtman and Zeewyck sub-basins from the where the recovered samples were mostly older (Berriasian-Valanginian) with a dominant terrestrial input to the assemblages.

*Foraminifera*
Five samples (listed in Appendix Q) were processed for foraminifera and examined by Dr Patrick Quilty. Two samples (DR033A1, GR021E_B1) are assigned Late Paleocene (P4c) and Early Eocene (O1) ages; two samples (GR021E_D2, GR022E_B1) are of indeterminate Cretaceous ages; and one sample (GR021E_D1) is barren of age diagnostic foraminifera.

*Nannofossils*
Eleven samples (listed in Appendix Q) were examined by Dr John Rexilius for their nannofossil content. Four samples (GR019E_C1, DR032C1, GR021E_D2, GR021E_E2) are barren of age diagnostic nannofossils; two samples (DR033A1, GR021E_B1) are assigned Middle Paleocene (CP4) and Early Oligocene-Late Eocene (CP16b-CP16a) ages; three samples (GR021E_D1, GR021E_H, GR022E_B1) are considered to be Albian (KCN28 and KCN25c); and two samples (GR019E_C2, DR032E1) are of indeterminate Maastrichtian-Bajocian age. All samples with confident palaeoenvironmental picks are of distal marine facies. The nannofossil ages closely match those from the foraminiferal and palynological analyses for most samples.

### 4.3.4. Cuvier Plateau

While the nature and origin of the Cuvier Plateau remains speculative, the feature is thought to have a core of extended continental crust overlain by thick volcanic and volcaniclastic successions formed during the breakup between Australia and Greater India at about 135 Ma (Symonds et al., 1998; Sayers et al., 2002). Previous exploration and studies on the Cuvier Plateau are limited to seismic data collected by Geoscience Australia in 1994 (s135 AGSO survey) and two rock dredging surveys in 1979 (Exon 1979, von Stackelberg et al., 1980) and 1990 (Colwell et al., 1990; Colwell et al., 1994), which only recovered pelagic drape sediments, volcanic rocks and volcaniclastic rocks. The key aim of the geological sampling program on the Cuvier Plateau was to recover rocks from several locations identified on the seismic as potentially exposing pre-breakup strata. Some of the seismic lines show dipping sub-parallel reflectors beneath the breakup unconformity that may represent sedimentary strata or interbedded volcanics and volcaniclastics (Sayers et al., 2002). Furthermore, a comparison of seismic profiles between the Cuvier Plateau and the southern Exmouth Plateau shows visible similarities and possibly suggest a common origin of these successions (Symonds et al., 1998) or with those of the northern Perth Basin. The critical question for the Cuvier Plateau was to understand the origin of these sequences. If samples recovered from these locations proved to be Jurassic-Early Cretaceous sedimentary rocks, the hydrocarbon potential of the Cuvier Plateau would be significantly upgraded.

Specific dredge targets on the Cuvier Plateau included:

- the escarpment that forms the southern edge of the Cuvier Plateau (e.g. Fig. 4.9) of which the whole feature is known as the Wallaby-Cuvier Escarpment;
- the ridge on the northeastern edge of the Cuvier Plateau that potentially exposes basement and/or pre-breakup sedimentary strata; and
- scarps on the Cuvier Plateau that potentially expose sedimentary strata from within the proposed depocentres.

Dredge targets were pre-selected using existing seismic data (including brute stacks of concurrently operating seismic survey GA0310) and constrained with new swath bathymetry data acquired during the survey.

Rock sampling operations on the Cuvier Plateau were undertaken in water depths ranging from 3,000 to 5,000 m. Thirty-one rock types from eleven main rock categories were collected from 11 dredges, one grab and one benthic sled (Fig. 4.10). Basalt was the most common rock type recovered across the plateau whilst claystones, sandstones and limestones were also collected (Fig. 4.10). Dredges (DR043-DR047, DR061) were deployed along the Wallaby-Cuvier Escarpment on the southern edge of the Cuvier Plateau (Fig. 4.9), in water depths of 3,700 to 4,700 m. These dredges yielded a variety of rock types including sandstone, claystone, siltstone, basalt and volcaniclastic breccia. Deepwater dredges (DR051 and DR052) recovered from a ridge-like seafloor high on the northeastern edge of the plateau collected only basalts and altered basalts. Dredge (DR049 and DR050) and grab (GR028) samples were recovered from a seamount associated with this ridge-like feature and yielded limestone and further basalts. A benthic sled

(BS004) and a dredge (DR048) from a scarp in a valley on the plateau, in water depths of 3,000 to 3,200 m obtained sandstone, basalt and limestone.

***Basalts***

Ten basalt types were described from five dredges, one grab and one benthic sled. All the basalts were aphanitic (crystals not visible to naked eye) and thus their mineralogy could not be determined in hand specimen. Four of the basalts were vesicular (DR045B, DR047C, DR047E, BS004C) with one basalt containing vesicles filled with carbonate that is of clay size (DR045B).

***Sandstones***

Three olive-brown sandstone types were described from two dredges and one benthic sled from the escarpment on the southern edge of the Cuvier Plateau and a valley in the centre of the Cuvier Plateau. All the sandstones were massive and had carbonate cements. Very fine- to medium-sized sand grains dominated all the sandstone types, although large pebbles were also noted in some sandstone types. One sandstone (DR047D) contained medium-sized sand to medium-sized pebble bioclasts that included fragments of bivalves, bryozoans and echinoderm spines.

***Claystones***

Three pale yellow to dark greenish-grey claystone types (DR043A, DR053A, DR053B) were obtained from two dredges on the escarpment on the southern edge of the Cuvier Plateau. Only one of the claystones (DR043A) contained carbonaceous grains and two of the claystone types (DR043A, DR053B) also had a minor amount of very fine-sized sand grains. All the claystone types were bioturbated and two of the claystone types (DR043A, DR053A) contained whole and/or fragmented shelly debris.

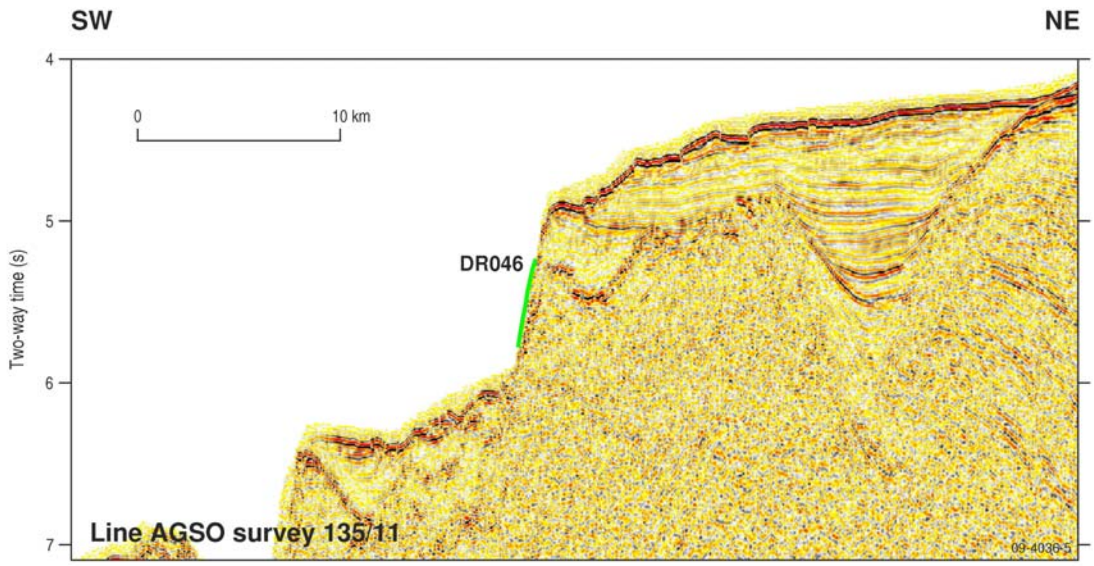



***Figure 4.9.*** *Part of the Wallaby-Cuvier Escarpment identified on seismic line 135/11 (AGSO survey) that was the target of dredge DR046. The red line shows the approximate dredge profile of dredge DR046.*

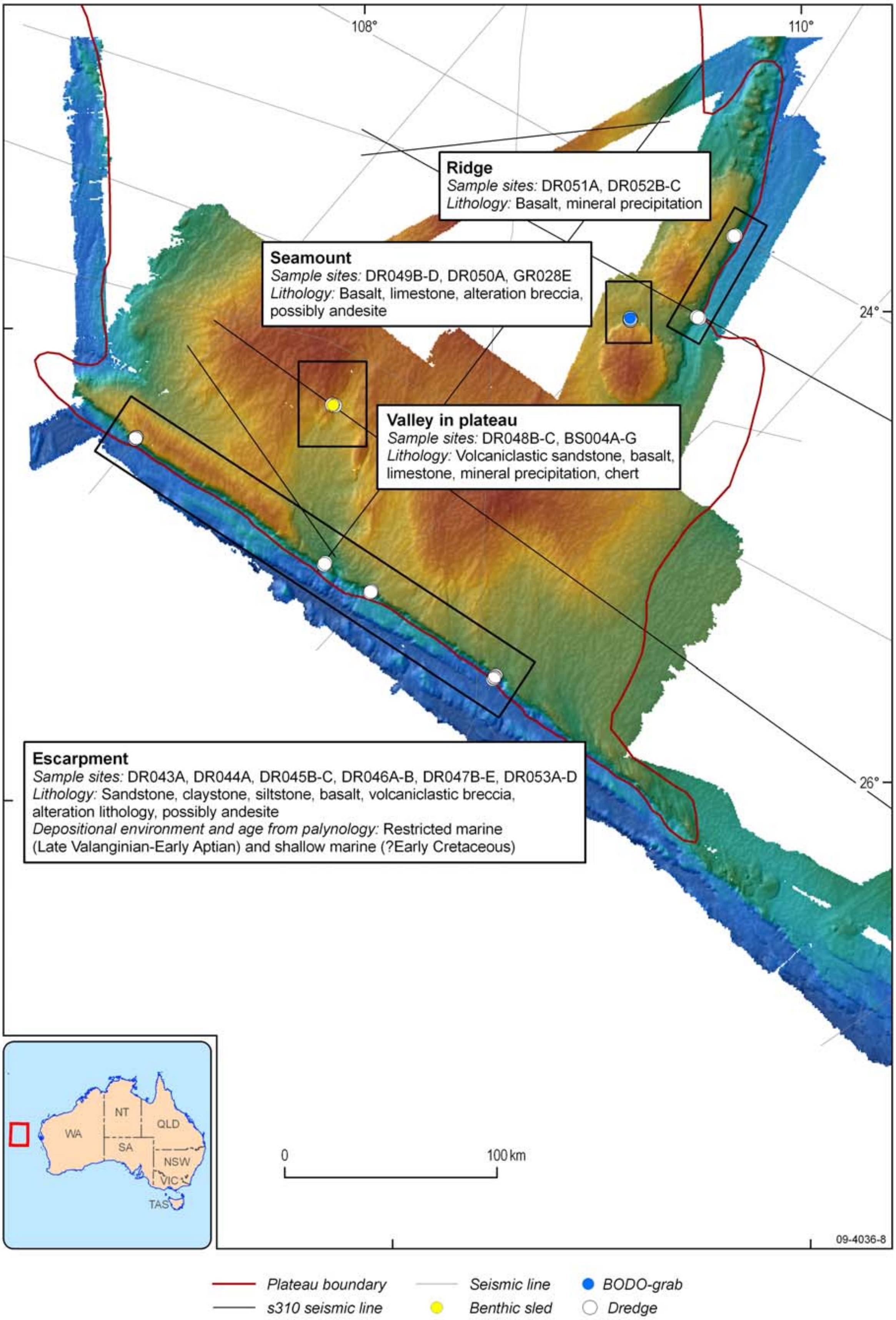



***Figure 4.10.*** *The rock samples and rock types recovered from the Cuvier Plateau. Preliminary ages and depositional environments are from high priority palynological analysis. Red outline represents the Wallaby Plateau (combined Quokka Rise and Cuvier Plateau).*

***Limestones***

Two limestone types were identified from a dredge and a benthic sled on a scarp on the Cuvier Plateau. Both limestone types (DR049D and BS004D) were massive (or structureless) micrites. One of the limestones (BS004D) contained a minor amount of mafic and lithic intraclasts that were medium-sized sand to granule in size.

***Siltstone***

A single siltstone type (DR046A) was obtained from one dredge on the escarpment on the southern edge of the Cuvier Plateau. The siltstone was massive and had a minor component of clay and very fine-sized sand grains.

***Other rock types***

Four volcanic rock types were recovered from four dredges on the Cuvier Plateau. Three of the volcanic rock types (DR046B, DR049B, DR053C) were possibly andesites; however, the aphanitic texture precludes a definitive assessment from hand specimens alone. The fourth volcanic rock type (DR047B) was a very poorly sorted volcaniclastic breccia that was comprised of angular to sub rounded, ash- to lapilli-sized intraclasts in an aphanitic matrix.

A chert type and mineral precipitate were also obtained from two dredges and one benthic sled from the centre and northern half of the plateau. The dark red to black mineral precipitate was mostly comprised of manganese and iron oxides.

Two types of alteration breccia and a highly altered/weathered lithology were also collected from three dredges on the Cuvier Plateau. These rocks were too weathered to determine their mineralogy or composition. The two types of breccia (DR049C, DR050A) were very poorly sorted and comprised of medium-sized sand to very large pebble-sized intraclasts in an aphanitic matrix.

***Initial Palaeontological Results (Cuvier Plateau)***

*Macrofauna*

One sample (DR053A1) contained a poorly preserved, low diversity bivalve assemblage preserved as molds and casts. Examination by Dr Jeffrey Stilwell (Monash University) has constrained the sample age to latest Jurassic-Early Cretaceous (no younger than Aptian; Appendix Q).

*Palynology*

Five samples (listed in Appendix Q) were processed for their palynological content. Two samples (DR053A1 and DR043A1) contain sparse, restricted marine-lacustrine assemblages that were dated as Late Valanginian to Early Aptian due to the presence of *Microfasta evansii* Morgan 1975; one sample (DR053B1) contains a depauperate, non-zone diagnostic Early Cretaceous marine assemblage; two samples (DR046A1 and DR047D2) were palynologically barren.

*Foraminifera*

Four samples (listed in Appendix Q) where examined for foraminifera by Dr Patrick Quilty (University of Tasmania). Two samples (DR053A1 and DR053B1) are likely Aptian/Albian in age; one sample (DR047D2) is considered to be Oxfordian; and one sample (DR046A1) is barren. The Oxfordian sample (DR047D2) represents the first evidence of a pre-rift sedimentary succession.

*Nannofossils*

Five samples (listed in Appendix Q) were processed for their nannofossil content and examined by Dr John P. Rexilius. Only one sample (DR053B1) contained a single nannofossil (*Watznaueria barnesae*) which ranges from Maastrichtian to Bajocian and may not be *in situ*.

## 4.4. SUMMARY

Fifty-one dredge, thirteen grab and three benthic sled hauls as well as one box core recovered several hundred individual rock samples and a diverse range of rock types. These rock samples indicate the success of the sampling program from the frontier areas of the west Australian margin, including the including the Zeewyck and Houtman sub-basins, Cuvier margin and the Cuvier Plateau. Several sampling stations were outside the previously defined boundaries of the Zeewyck, Houtman and Exmouth sub-basins. Preliminary analysis of the available seismic data together with the first results on the age of the samples suggests that basinal successions extend further seaward than previously mapped. Following the integration of all rock sample results with magnetic and gravity data, and the new seismic data acquired by the concurrent seismic acquisition program, a revision of the western boundaries of the Zeewyck, Houtman and Exmouth sub-basins will be undertaken.

The samples recovered during the survey will provide useful information to establish a tectonostratigraphic framework and to assess petroleum systems elements in the frontier depocentres of the region. The sampling program targeted mostly pre-breakup successions and the oldest rocks exposed in the canyons and scarps. Preliminary palynological analyses have shown that the majority of the sedimentary samples fall within a relatively narrow stratigraphic interval from the Berriasian to Late Aptian. Depositional environments derived from palynological analyses are consistent with the breakup history of the region. In the Zeewyck Sub-basin, Berriasian-age samples were deposited in a terrestrial environment, possibly fluvial or lacustrine, while Valanginian-age samples were deposited in a marginal marine environment. In the northern Houtman Sub-basin and on the Cuvier margin, the Berriasian appears to be characterised by marginal marine deposition that changes to shallow marine in the Hauterivian-Barremian and open marine in the Aptian. This might be related to the gradual opening of the Indian Ocean from the north to the south with the progressive onset of marine conditions in the same direction.

An important discovery arising from the sampling program in the Houtman Sub-basin was the previously undocumented recent volcanism. Basaltic rocks were recovered at a number of locations (stations 009, 012, 028, 044, 045) from peak-shaped bathymetric features. The shape of these constructions, the absence of substantial sedimentary cover and apparent freshness of some samples indicate that volcanism occurred during the recent geological past. The potential impact of this volcanism on the existing petroleum system is still to be evaluated.

The bulk of dredge samples recovered across the Cuvier Plateau contain volcanic rocks that are consistent with the known extensive volcanism across this area at the time of continental breakup. Importantly, for the first time, sedimentary rocks composed of clastics weathered from terrigenous environments into the marine realm have been recovered in several locations on the Cuvier Plateau. These rocks include fossiliferous claystones, quartz-dominated sandstones and siltstones. Several sedimentary samples are indicative of relative shallow water environments indicating the plateau was at or near sea-level in the geologic past. Initial palynological analyses have shown they contain extremely rare fragments of spores, pollen and dinocysts and two samples are dated as Late Valanginian to Early Aptian. Sparse bivalve and foraminiferal assemblages supported an Early Cretaceous age. Interestingly, one foraminiferal assemblage was considered to be of Oxforidan age (Appendix Q). This would indicate deposition prior to known rifting in the area. Samples recovered from the Cuvier Plateau are both a result of deposition and extensive volcanism within the Plateau. Further analyses of both sedimentary and volcanic samples are anticipated to provide evidence for continental depocentres and further insights into the volcanic history of the Cuvier Plateau.

# 5. Geomorphology

## 5.1. BACKGROUND

This chapter describes the seabed geomorphology of the west Australian margin study areas (Fig. 5.1). Preliminary geomorphic mapping is based on a 200 m horizontal resolution grid derived from the multi-beam (swath) sonar data. The total areas covered by geomorphic mapping were 176,900 km$^2$ - 109,700 km$^2$ over the inner margin study area and 67,200 km$^2$ over the Cuvier Plateau study area. Two distinct geomorphic components are recognised in the study areas that conform to standard nomenclature for describing the geomorphology of continental margins (Kennett, 1982). First, a geomorphic *province* is used to define the broad divisions of shelf, slope, rise and adjacent abyssal plain/deep ocean floor, and; second, a geomorphic *feature* is used to define individual features superimposed on provinces. The distinction between provinces and features is based on spatial extent, with the former covering tens of thousands of square kilometres of the study area, and the latter covering tens to thousands of square kilometres. Definition and classification of seabed geomorphic features mapped in the study area are based on those of the International Hydrographic Organisation (IHO, 2001) (Table 5.1). Additional terms for features not defined by the IHO are taken from relevant literature.

**Table 5.1.** Definitions for geomorphic provinces and features mapped in the survey area, as specified by the International Hydrographic Organisation (2001).

| GEOMORPHIC PROVINCE | DEFINITION |
|---|---|
| Slope | The slope seaward from the shelf edge to the upper edge of a continental rise or the point where there is a general reduction in slope |
| Rise | A gentle slope rising from the oceanic depths towards the foot of a continental slope |
| Abyssal plain | An extensive, flat, gently sloping or nearly level region at abyssal depths |
| **GEOMORPHIC FEATURE** | |
| Canyon | A relatively narrow, deep depression with steep sides, the bottom of which generally has a continuous slope, developed characteristically on some continental slopes |
| Escarpment (scarp) | An elongated, characteristically linear, steep slope separating horizontal or gently sloping sectors of the sea floor in non-shelf areas. |
| Plateau | A flat or nearly flat area of considerable extent, dropping off abruptly on one or more sides |
| Peak | A prominent elevation either pointed or of a very limited extent across the summit. |
| Ridge | An elongated narrow elevation of varying complexity having steep sides. |
| Saddle | A broad pass, resembling in shape a riding saddle, in a ridge or between contiguous seamounts |
| Seamount | A discrete large isolated elevation, greater than 1,000 m in relief above the sea floor, characteristically of conical form. |
| Terrace | A relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side |
| Trough | A long depression of the seafloor characteristically flat bottomed and steep sided and normally shallower than a trench |
| Valley | A relatively shallow, wide depression, the bottom of which usually has a continuous gradient. |

The following preliminary description of the geomorphic provinces and features on the west Australian margin has, for convenience, been subdivided into two survey areas - the Cuvier Plateau survey area and the inner west Australian margin survey area, which consists of from north to south parts of the Cuvier margin, the Carnarvon slope and the Perth margin (Fig. 5.1). This geomorphic description refers to established geographic names for specific parts of the margin (e.g. Cuvier margin, Wallaby Saddle, Fig. 5.1) but does not directly refer to the structural basins that underlie these areas because most provinces and some features extend across a number of basins. The upper slope feature within the inner west Australian margin study area corresponds to the Carnarvon Terrace (Symonds and Cameron, 1977).

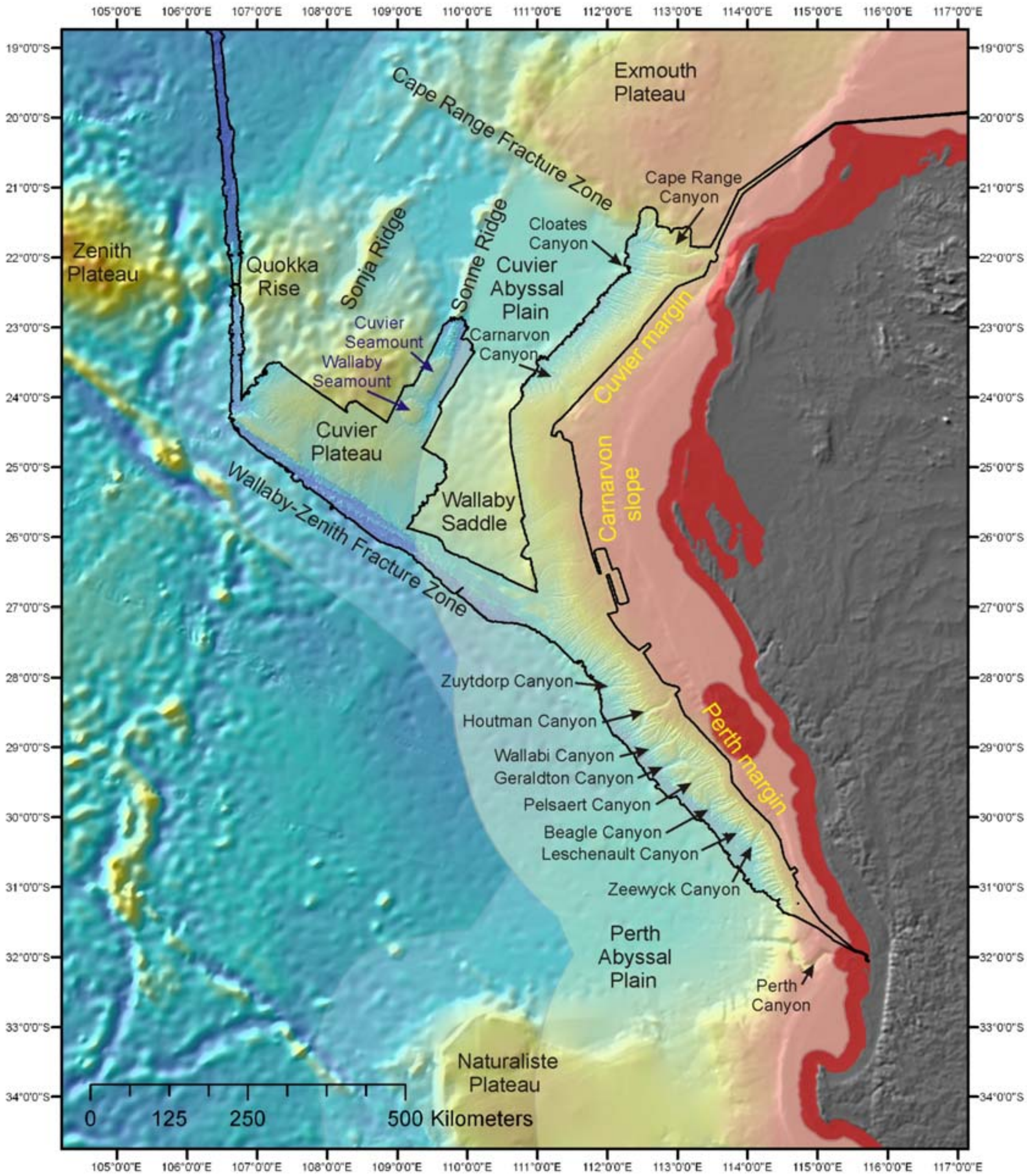



*__Figure 5.1.__ False colour bathymetry map showing geomorphology of the west Australian margin. Geomorphic features cited in the text are shown, including new features revealed by new multibeam data, which is also shown. Outline of newly acquired multibeam data is shown is black. Limits of Australia's Exclusive Economic Zone (transparent yellow) and Extended Continental Shelf (transparent blue) also shown.*

## 5.2. INNER WEST AUSTRALIAN MARGIN SURVEY AREA

### 5.2.1. General Characteristics

The inner west Australian margin survey area mostly encompasses the continental slope, extending onto the inner edge of the continental rise in some places (Fig 5.2). The northern part of the mapped area incorporates the Cuvier margin, the central area corresponds to the Carnarvon slope and the southern area encompasses the Perth margin (Fig 5.1). The total area of continental slope mapped covers 105,650 km$^2$ and the area of the rise covers 4,050 km$^2$ (Table 5.2.). The geomorphology of the slope is characterised by extensive areas that are incised by canyons, areas that reveal widespread slumping and areas on the upper slope that are non-incised and generally featureless. The upper slope that is non-incised corresponds to the upper slope feature known as the Carnarvon Terrace (Symonds and Cameron, 1977). Other geomorphic features of local extent include volcanic peaks and escarpments.

**Table 5.2.** Surface area of major geomorphic features on the inner west Australian margin (note: the sum of percentage values for geomorphic features exceeds 100% because canyons, scarps and peaks are superimposed on some slope features).

| GEOMORPHIC PROVINCE | AREA (KM$^2$) | % OF MAPPED AREA |
|---|---|---|
| Slope | 105,650 | 96 |
| Continental Rise | 4,050 | 4 |
| **Total** | **109,700** | **100** |
| **GEOMORPHIC FEATURE** | | |
| Incised Slope | 50,700 | 46 |
| Non-incised Slope | 34,500 | 31 |
| Slumped Slope | 20,400 | 19 |
| Named Canyons (n = 7) | 7,700 | 7 |
| Scarp (n = 1) | 410 | 0.4 |
| Peaks (n = 4) | 10 | 0.01 |

### 5.2.2. Geomorphic Provinces

Figure 5.3 shows the location of high resolution bathymetry images of geomorphic provinces and features on the inner west Australian margin that are described below and illustrated in Figures 5.4 – 5.9.

***Incised Slope***

The most extensive geomorphic province within the survey area is the incised portion of the continental slope, which covers 50,700 km$^2$ (46% of the mapped area), divided between the Cuvier margin and Perth margin (Fig. 5.2). The intervening area of the Carnarvon slope is not incised. On the Cuvier margin, an area of 18,000 km$^2$ of the lower part of the slope is deeply incised by a series of 46 canyons, including the Cape Range, Cloates and Carnarvon canyons (Fig. 5.4). This part of the slope extends 360 km along the margin and is approximately 50 km wide with an average gradient of two degrees across water depths of 2,000 – 4,900 m. Along the Perth margin, the incised portion extends 600 km along the slope and ranges in width from 20 km to 65 km on a gradient of 2.5 to 5 degrees in 1,500 – 4,900 m water depth (Figs. 5.5, 5.6). A total of 63 canyons are mapped within this 32,700 km$^2$ area, including Houtman, Wallabi, Geraldton and Pelsaert canyons (described in section 5.1.3).

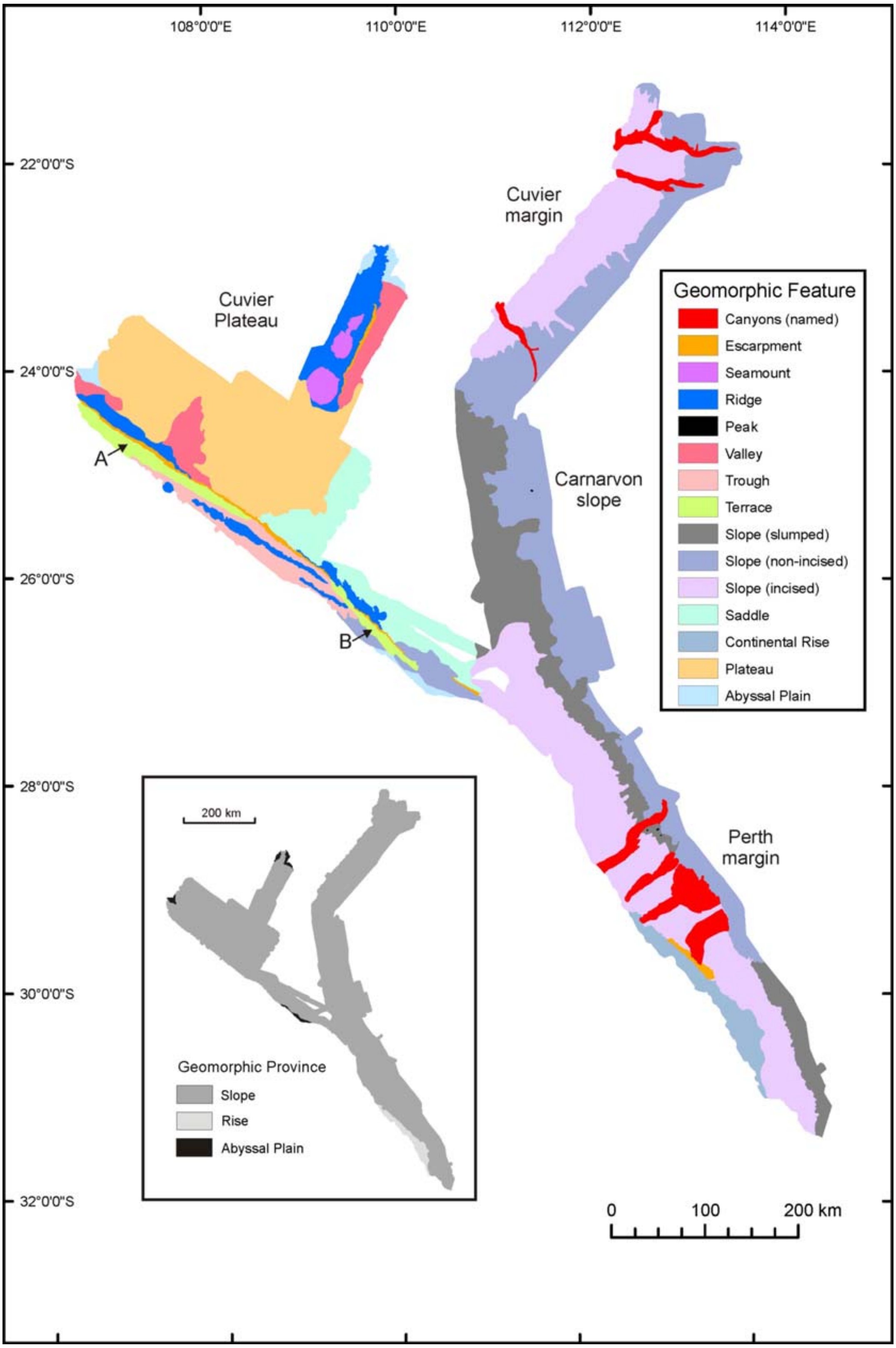



***Figure 5.2.*** *Geomorphic features map of the west Australian margin that highlights the inner west Australian margin and Cuvier Plateau survey areas. Features were mapped from the newly collected multibeam bathymetry data. Only officially named canyons are shown. Numerous unnamed canyons lie within areas mapped as incised slope. "A" and "B" indicate two terraces discussed in section 5.3.3.Inset: Geomorphic province map of the survey area. Three provinces are identified, dominated by the slope.*

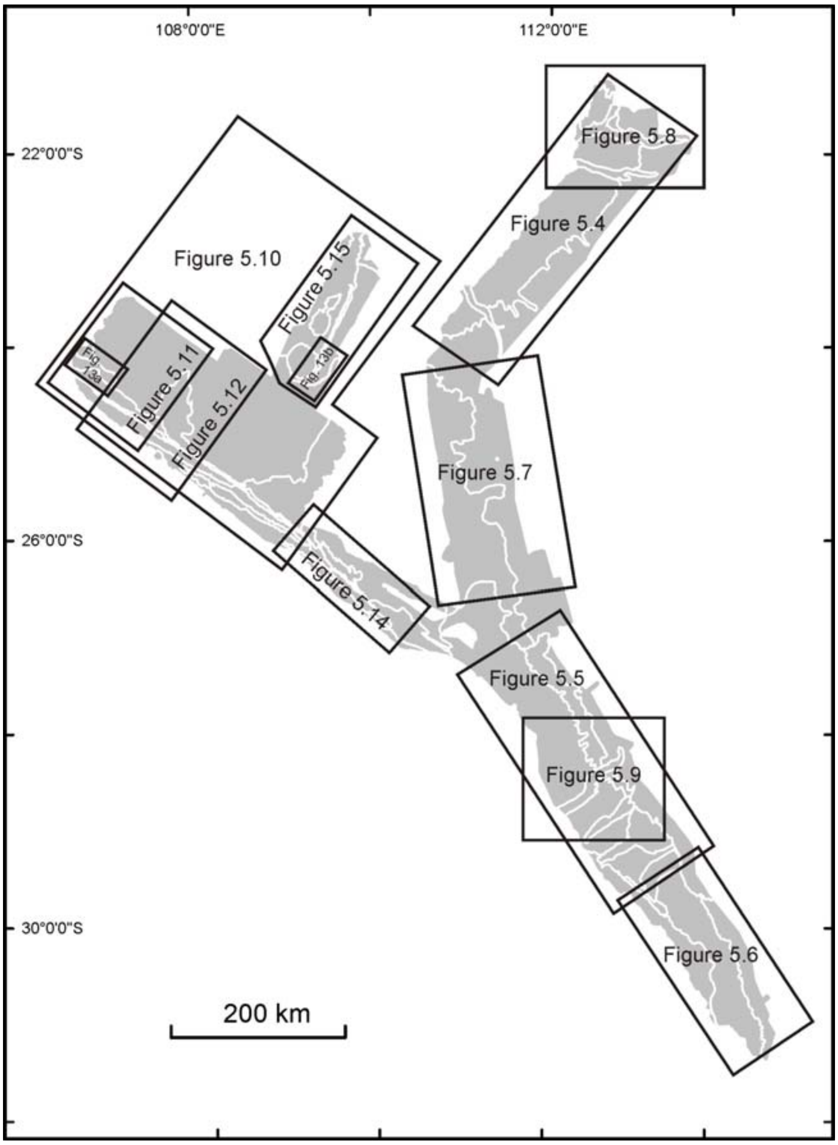



***Figure 5.3.*** *Map showing locations of false-colour bathymetry images shown in Figures 5.4 – 5.13.*

***Non-incised Slope***

The part of the continental slope that is not incised by canyons or affected by major slumps covers an area of 34,500 km$^2$ (31% of the mapped area) and extends 1,000 km along the upper slope (Fig. 5.2). This geomorphic feature is continuous, spanning the Cuvier margin, Carnarvon slope and northern Perth margin, mostly in water depths that range between 1,000 m and 1,700 m and corresponds to the upper slope feature known as the Carnarvon Terrace (Symonds and Cameron, 1977) (Figs. 5.4 – 5.7). One area of non-incised slope, located across the boundary between the Cuvier margin and the Carnarvon slope, extends the width of the mapped area to 2,900 m water depth. Overall, the gradient of the non-incised part of the slope ranges from 0.5 to 2.0 degrees and is broadly convex in profile, with negligible local relief.

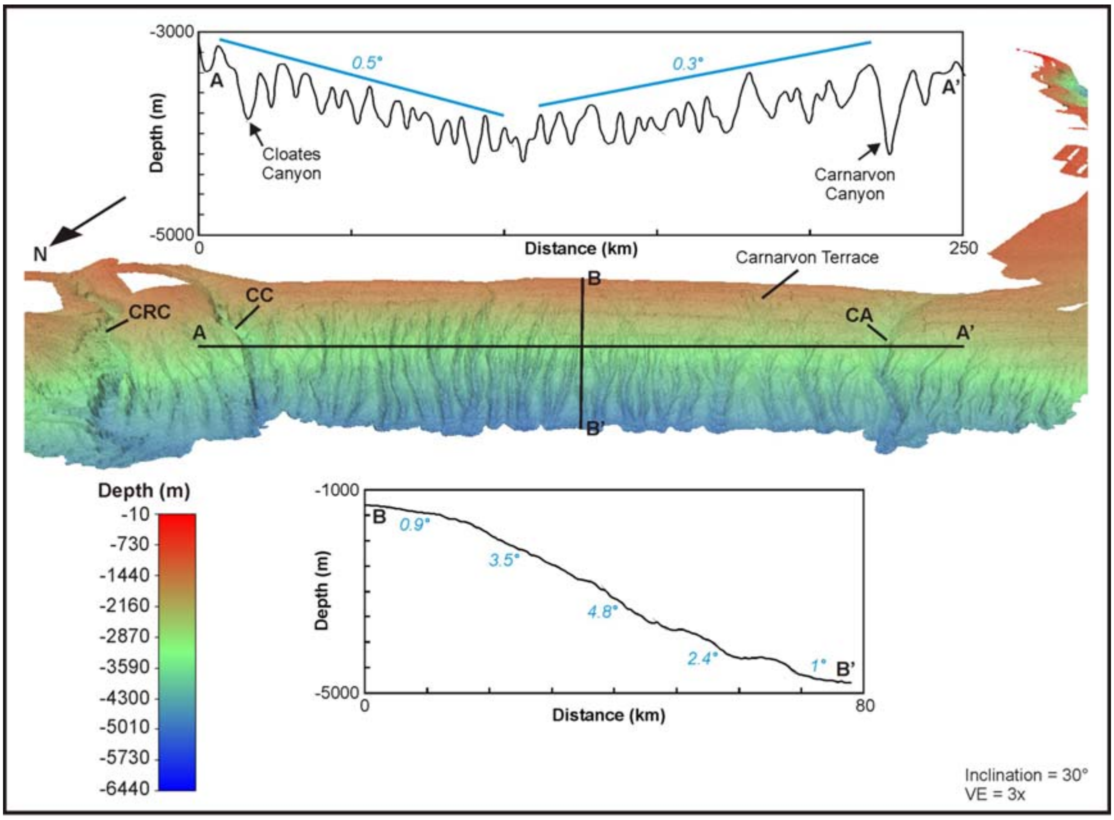



***Figure 5.4.*** *Oblique, false-colour bathymetry image of Curvier margin (see Fig. 5.3. for location) showing major geomorphic features, including Cape Range Canyon (CRC), Cloates Canyon (CC), Carnarvon Canyon (CA), and 43 smaller unnamed canyons. Inset: Representative along- and cross-slope profiles.*

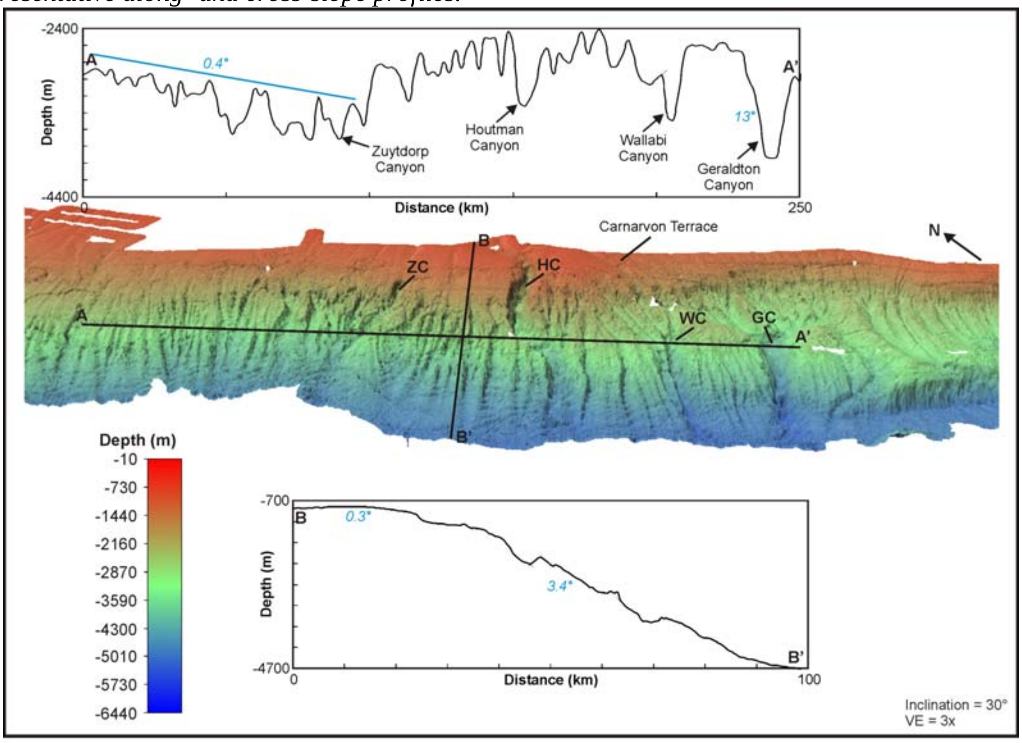



***Figure 5.5.*** *Oblique, false-colour bathymetry image of northern Perth margin (see Fig. 5.3. for location) showing major geomorphic features, including Houtman Canyon (HC), Wallabi Canyon (WC), Geraldton Canyon (GC) and the newly named Zuytdorp Canyon (ZC) plus numerous smaller unnamed canyons. Inset: Representative along- and cross-slope profiles.*

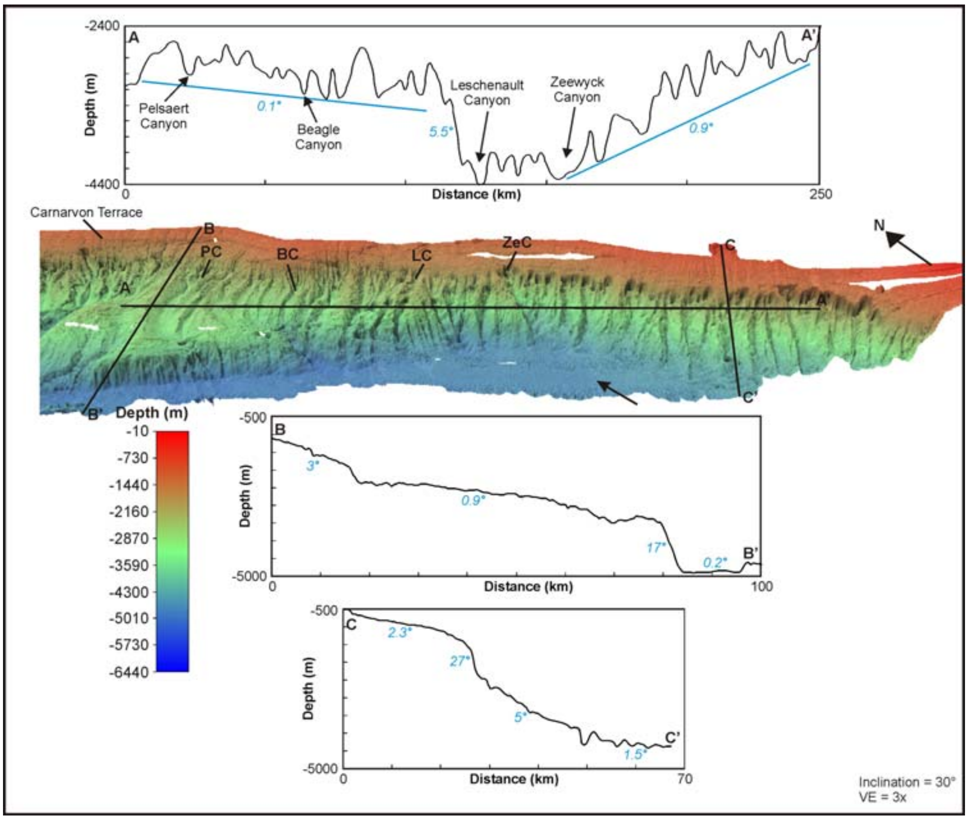



***Figure 5.6.*** *Oblique, false-colour bathymetry image of southern Perth margin (see Fig. 5.3. for location) showing major geomorphic features, including Pelsaert Canyon (PC) and newly named Beagle (BC), Leschenault (LC) and Zeewyck (ZeC) Canyons. Arrow shows location of the continental rise. Inset: Representative along- and cross-slope profiles.*

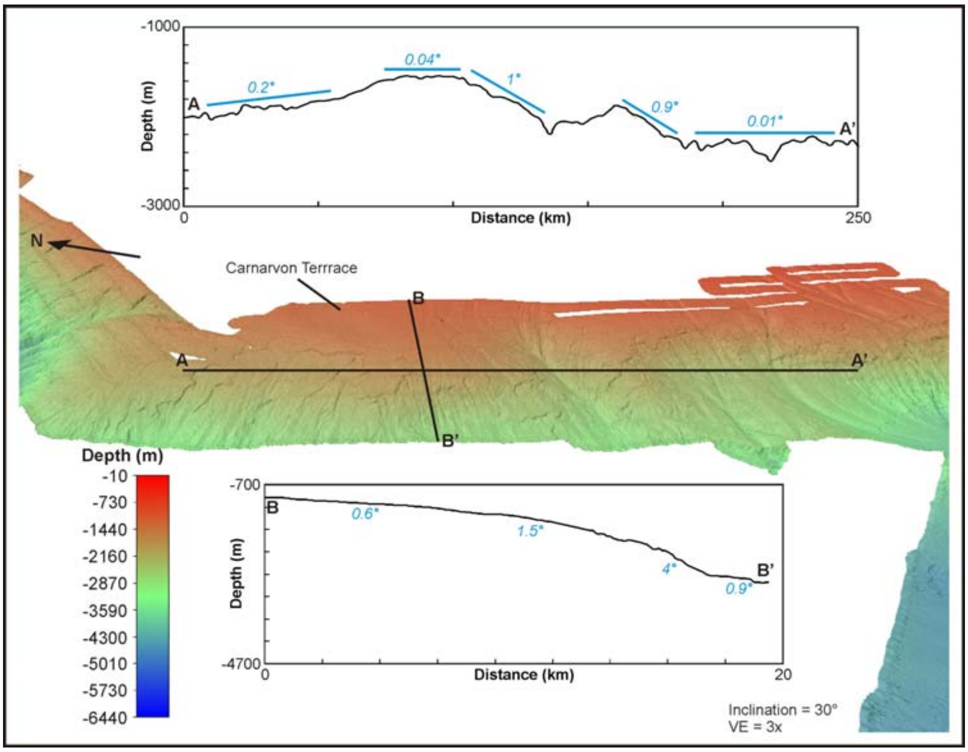



***Figure 5.7.*** *Oblique, false-colour bathymetry image of the Carnarvon slope (see Fig. 5.3. for location) showing major geomorphic features including large slumps, scarps and depressions on the middle to lower slope. Inset: Representative along- and cross-slope profiles.*

***Slumped Slope***

Areas of slumped slope characterise the Carnarvon slope and parts of the Perth margin (Figs. 5.2, 5.7). On the Carnarvon slope and northern Perth margin, slumping extends 540 km along the mid to lower slope, covering 16,400 km$^2$ in 1,200 – 3,200 m water depth. The slumped area of the southern Perth margin extends 200 km along the upper slope in water depths that range from 700 – 1700 m, covering 3,450 km$^2$. In both areas, slumps are defined by a scalloped headwall scarp that extends for tens of kilometres, although mapping coverage of the far southern feature does not encompass its full extent. The slump scarps are up to 100 m high and vary in orientation so that the outline of the up-slope edge of the slump is highly irregular. Downslope of the scarp, the gradient of the seabed ranges between 1.5 and 2.0 degrees but is locally steeper where shorter scarps have formed, producing an overall low-gradient stepped morphology to this part of the continental slope. In places, these steps are crossed by short ridges and valleys that extend downslope and add local relief of tens of metres, with the deepest valley incised up to 120 m.

***Rise***

The only part of the continental rise mapped is a section that covers 4,050 km$^2$ (4% of mapped area) along the outer edge of the southern Perth margin (Figs. 5.2, 5.6). This section of the rise adjoins an incised part of the continental slope and extends 250 km along the foot of the slope. Along this distance, the top of the rise sits in 4,500 – 4,800 m water depth and has a gradient of approximately 0.1 degrees with negligible local relief.

***Abyssal Plain***

No part of the abyssal plain was mapped within the study area of the inner west Australian margin.

### 5.2.3. Geomorphic Features

***Previously Named Submarine Canyons***

The survey area includes seven previously named submarine canyons, three on the Cuvier margin and four on the Perth margin (Table 5.3, Fig. 5.1). On the Cuvier margin, the canyons are (from north to south) Cape Range, Cloates and Carnarvon canyons that together cover 2,630 km$^2$. Each of these canyons extends across the width of the continental slope, with headwalls located in water depths of 1,500 m to 1,900 m and lower reaches that terminate near the foot of the slope in 4,600 m to 4,800 m water depth. All three canyons on the Cuvier margin are straight to slightly sinuous in planform, with Cape Range Canyon also having a tributary on its northern side. Cape Range Canyon is the largest canyon on the Cuvier margin, with a length of 140 km and maximum incision depth of 1,300 m (Fig. 5.8). A prominent characteristic of each canyon is one or more knick-points that are located along the upper reaches. Knick-points are up to 500 m high with gradients of 40 - 50 degrees and have a depression at their base that is up to one kilometre in diameter and 100 m deep.

The previously named canyons on the Perth margin are Houtman, Wallabi, Geraldton and Pelsaert canyons. The combined area of these canyons is 5,080 km$^2$, with Geraldton Canyon the largest at 2,090 km$^2$. Houtman Canyon has the greatest incision depth, however, reaching 1,700 m below the adjacent slope (Fig. 5.9). Houtman Canyon is the only canyon in this group that extends across the entire continental slope, ranging in water depth from 1,000 m to 4,700 m. The other three named canyons have headwalls in deeper water (1,500 – 2,100 m) and extend to the foot of the continental slope in 5,000 m water depth. The planform and length of the canyons on the Perth margin also differs, with Houtman Canyon extending 110 km along a straight to sinuous path without tributaries. In contrast, the Wallabi, Geraldton and Pelsaert canyons are 60 – 80 km long, straight in planform and have multiple tributaries. In the case of Geraldton Canyon, these tributaries form a broad branching, or dendritic, pattern that extends 60 km along the slope. The canyons on the Perth margin also have at least one knick-point along their main valley. Houtman Canyon has four knick-points along its length, with the highest of 500 m and a gradient of 15 – 30 degrees that is located in the upper reaches. In the Wallabi and Geraldton canyons knick-points are formed at the convergence of tributaries and reach heights of 200 – 300 m with slopes of 15 – 25 degrees.

**Table 5.3.** Dimensions of previously named canyons within the survey area.

| CANYON | AREA ($KM^2$) | LENGTH (KM) | WIDTH (KM) | WATER DEPTH RANGE (M) | MAXIMUM INCISION DEPTH (M) |
|---|---|---|---|---|---|
| Cape | | | 7 - 9 | 1,500 – 4,600 | 1,300 |
| Range | 1,410 | 140 | | | |
| Cloates | 700 | 97 | 4 - 10 | 1,800 – 4,800 | 900 |
| Carnarvon | 520 | 100 | 5 - 7 | 1,900 – 4,700 | 600 |
| Houtman | 1,080 | 110 | 6 - 9 | 1,000 – 4,700 | 1,700 |
| Wallabi | 710 | 73 | 7 - 29 | 1,700 – 5,000 | 600 |
| Geraldton | 2,090 | 80 | 10 - 60 | 1,500 – 5,000 | 1,300 |
| Pelsaert | 1,200 | 60 | 13 - 20 | 2,100 – 5,000 | 400 |

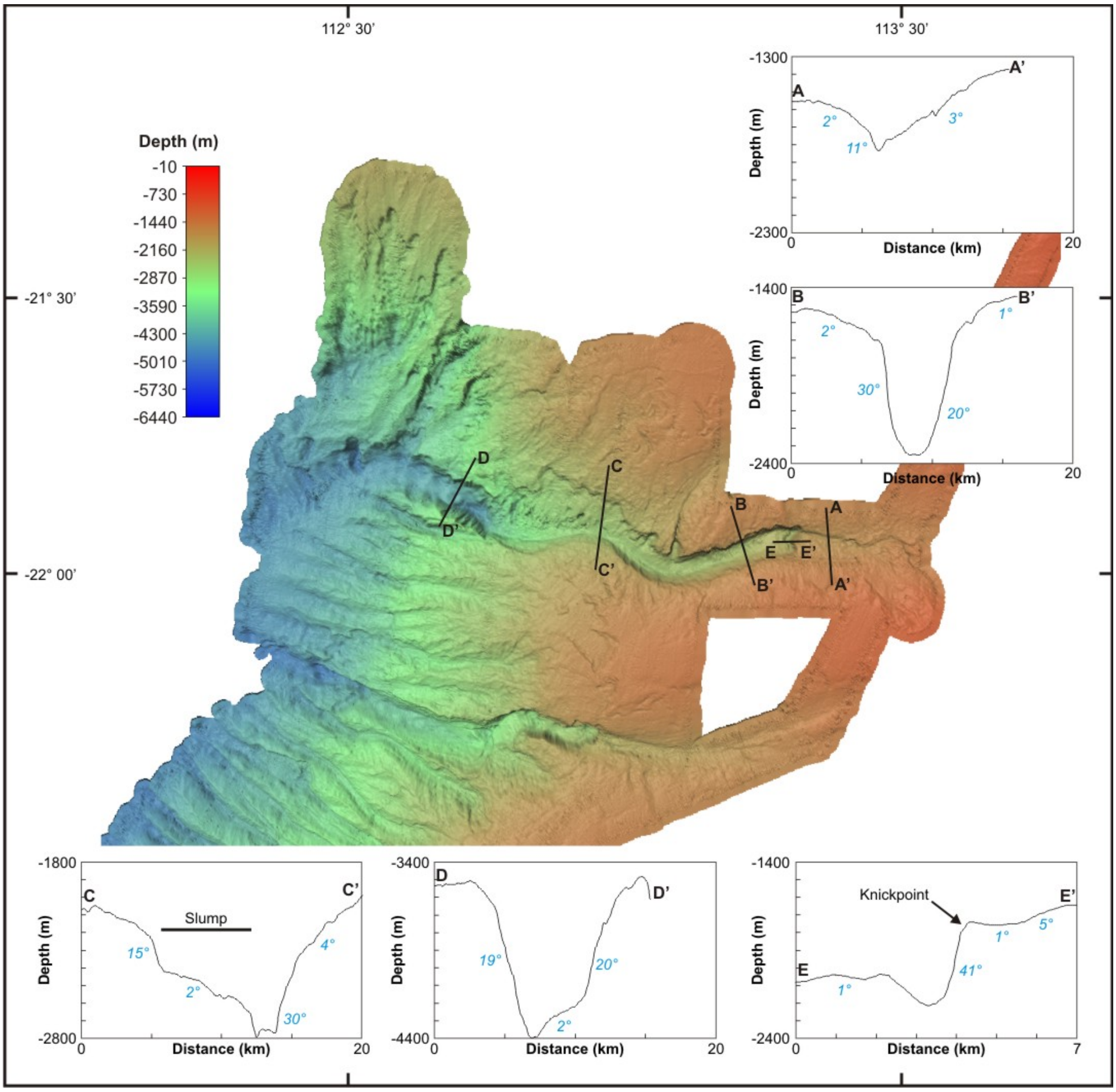



*__Figure 5.8.__ False-colour bathymetry image of Cape Range Canyon and Cloates Canyon (see Fig. 5.3. for location). Representative profiles of the Cape Range Canyon show incised canyon morphology (A-D) and knick-point in upper reaches (E).*

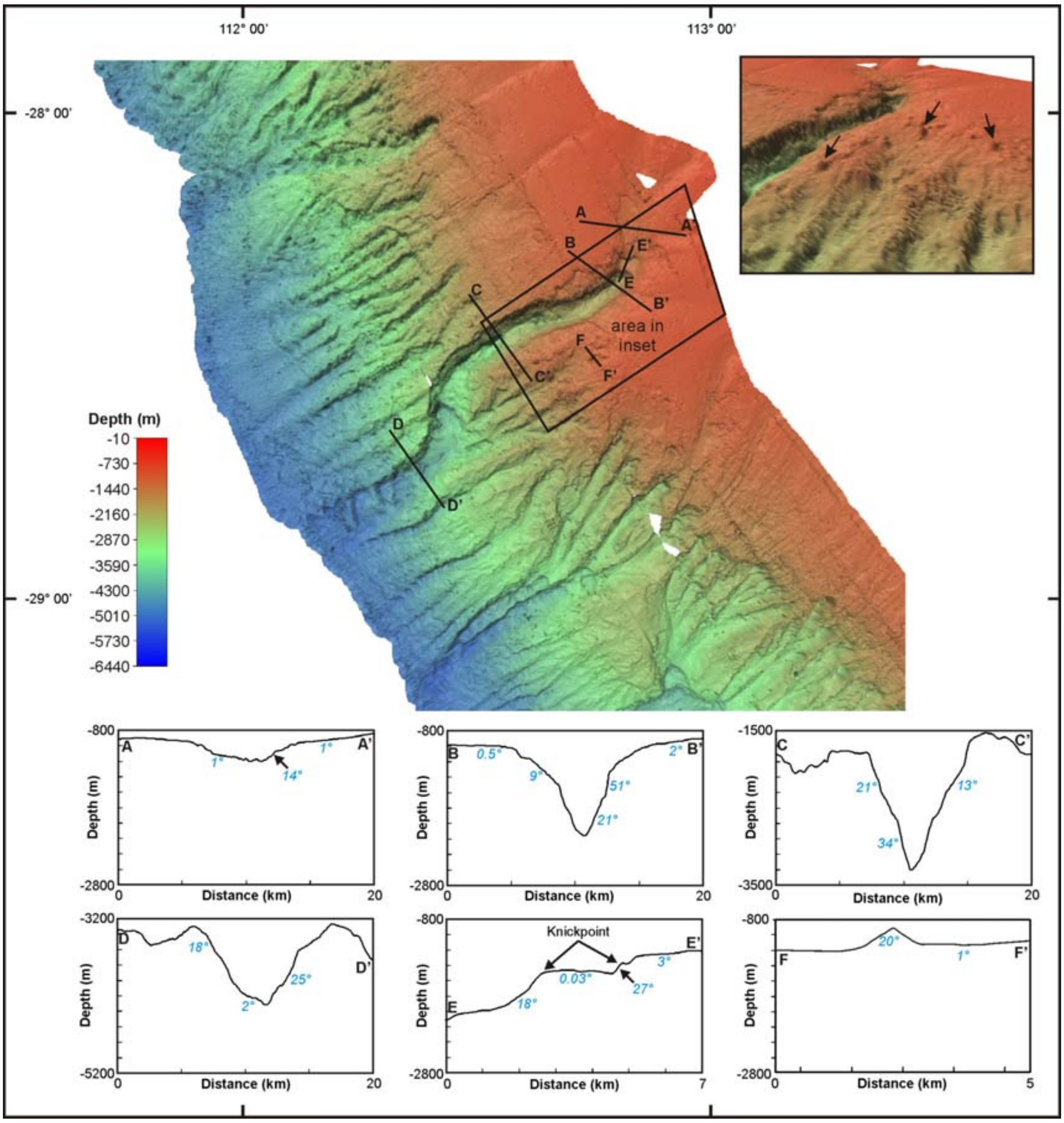



*__Figure 5.9.__ False-colour bathymetry image of Houtman Canyon and other unnamed canyons on the Perth margin (see Fig. 5.3. for location). Representative profiles of the Houtman Canyon show incised canyon morphology (A-D) and two shallowest knick-points in upper reaches (E). Inset box shows a perspective view of three small peaks (arrows) located to the south of Houtman Canyon. Profile F is across the central peak.*

***Newly Named Submarine Canyons***

New names are proposed for four previously unnamed canyons on the Perth margin. From north to south these are: Zuytdorp Canyon; Beagle Canyon; Leschenault Canyon, and; Zeewyck Canyon (Fig. 5.1). At the time of writing, these names have not been formalised. As such, they are incorporated into the mapped area of incised slope (Fig. 5.2). All four of these canyons are relatively straight and narrow, ranging in width from 3 – 10 km and are incised 600 – 900 m into the slope with lengths of 30 – 62 km (Table 5.4). Zuytdorp Canyon and Zeewyck Canyon extend onto the middle slope, with headwalls in water depths of 1,600 m and 1,700 m, respectively. In contrast, Beagle Canyon and Leschenault Canyon sit in slightly deeper water with headwalls at 1,800 m and 2,000 m, respectively. All four of the newly named canyons extend to at least 4,300 m water depth, with the mouth of Beagle Canyon at 5,000 m.

**Table 5.4.** Dimensions of newly named canyons within the survey area.

| CANYON | AREA ($KM^2$) | LENGTH (KM) | WIDTH (KM) | WATER DEPTH RANGE (M) | MAXIMUM INCISION DEPTH (M) |
|---|---|---|---|---|---|
| Zuytdorp | 330 | 62 | 4 – 8 | 1,600 – 4,700 | 800 |
| Beagle | 390 | 53 | 4 -10 | 1,800 – 5,000 | 800 |
| Leschenault | 145 | 30 | 4 - 5 | 2,000 – 4,500 | 600 |
| Zeewyck | 215 | 30 | 3 - 9 | 1,700 – 4,300 | 900 |

***Escarpment (Scarp)***

One major scarp is mapped in the survey area of the inner west Australian margin and is located within the southern Perth margin at the foot of the continental slope, covering an area of 410 $km^2$ (Fig. 5.2). The scarp is 64 km long and has a maximum height of 1,200 m, with the base of the scarp at a water depth of 4,900 m. The northern half of the scarp is steepest, with gradients of 15 to 25 degrees. Midway along the scarp, it is cut by Pelsaert Canyon, which has incised the feature by 700 m to a width of four kilometres. To the south of this incision, the scarp grades to a slope of about ten degrees that terminates against the lower end of an unnamed canyon.

***Volcanic Peaks***

Four volcanic peaks are mapped within the inner west Australian margin survey area, covering a combined area of 10 $km^2$ (Fig. 5.9, Table 5.5). One peak is located on the upper Carnarvon slope (-25.231$^o$S, 111.412$^o$E) at a water depth of 1,170 m. This peak is 170 m high and occurs within an area of the slope that is not incised and has a generally smooth seafloor. The other three peaks occur as a cluster to the immediate south of Houtman Canyon on a slumped area of the continental slope. The peaks here range in height from 230 m to 350 m and occur in water depths of 1,130 m to 1,380 m. In contrast to the isolated peak further north, these three peaks are surrounded by irregular seafloor that incorporates a number of smaller peaks and hills that are tens of metres in height.

**Table 5.5.** Location and dimensions of volcanic peaks in the survey area. Peaks are numbered in order of decreasing water depth at their base.

| PEAK | LATITUDE | LONGITUDE | HEIGHT (M) | WATER DEPTH AT SUMMIT (M) | WATER DEPTH AT BASE (M) |
|---|---|---|---|---|---|
| 1 | -28.506 | 112.685 | 230 | 1150 | 1380 |
| 2 | -28.497 | 112.798 | 350 | 900 | 1250 |
| 3 | -25.231 | 111.412 | 170 | 1000 | 1170 |
| 4 | -28.553 | 112.836 | 230 | 900 | 1130 |

## 5.3. CUVIER PLATEAU SURVEY AREA

Figure 5.3 shows the location of high resolution bathymetry images of geomorphic provinces and features of the Cuvier Plateau survey area that are described below and illustrated in Figures 5.10 – 5.13. The Cuvier Plateau survey area includes the Cuvier Plateau, the Wallaby-Zenith Fracture Zone and the Wallaby Saddle.

### 5.3.1. General Characteristics

The mapped survey area of Cuvier Plateau covers 67,200 $km^2$ in water depths ranging from 2,350 m on the eastern half of the plateau, to 5,700 m along the southern edge of the plateau where it adjoins the Wallaby-Zenith Fracture Zone (Figs. 5.1, 5.2). This area incorporates the geomorphic provinces of the continental slope and small areas of abyssal plain.

### 5.3.2. Geomorphic Provinces

***Slope***

The continental slope is the dominant geomorphic province within the Cuvier Plateau survey area, covering 65,500 $km^2$ or 97% of the mapped area (Table 5.6, Fig. 5.2 inset). The slope incorporates a variety of superimposed geomorphic features, including a plateau and saddle plus valleys, ridges, escarpments, seamounts, terraces and troughs. These are described in more detail in section 5.3.3.

***Rise***

No part of the rise was mapped within the Cuvier Plateau survey area.

***Abyssal Plain***

A total area of 1,700 $km^2$ of abyssal plain was mapped in three locations, representing 3% of the mapped area (Fig. 5.2 inset). Two of the mapped areas of abyssal plain are located at the far northern and western ends of the survey area, where water depths range from 4,900 - 5,000 m and 5,000 - 5,400 m, respectively. The third area of abyssal plain is located to the south of the Wallaby Saddle where water depths range from 5,200 - 5,700 m. Surface relief across each of these abyssal areas is slightly irregular to flat with gradients of 0.1 to 1.5 degrees. No superimposed geomorphic features are identified within the mapped areas of abyssal plain.

**Table 5.6.** Surface area of major geomorphic features on Cuvier Plateau, Wallaby Saddle and Wallaby-Zenith Fracture Zone.

| GEOMORPHIC PROVINCE | AREA ($KM^2$) | PERCENTAGE OF MAPPED AREA |
|---|---|---|
| Slope | 65,500 | 97 |
| Abyssal plain | 1,700 | 3 |
| **Total** | **67,200** | |
| **GEOMORPHIC FEATURE** | | |
| *Cuvier Plateau* | | |
| Plateau | 28,800 | 43 |
| Ridge | 5,850 | 9 |
| Valley | 5,600 | 8 |
| Seamount | 1,650 | 2 |
| Scarp | 1,100 | 2 |
| *Wallaby-Zenith Fracture Zone* | | |
| Trough | 4,150 | 6 |
| Terrace | 3,500 | 5 |
| Non-incised slope | 2,550 | 4 |
| Ridge | 2,250 | 3 |
| Scarp | 150 | 0.2 |
| *Wallaby Saddle* | | |
| Saddle | 9,900 | 15 |

### 5.3.3. Geomorphic Features

A total of nine geomorphic features are identified on the Cuvier Plateau and adjoining areas of the Wallaby Saddle and Wallaby-Zenith Fracture Zone (Fig. 5.2, Table 5.6).

***Plateau***

The plateau of the Cuvier Plateau is the most extensive geomorphic feature on the outer continental slope, covering 28,800 $km^2$ (43% of the mapped area, Fig. 5.2). The plateau is approximately 270 km across in a southeast to northwest direction with no significant slope (average gradient 0.003 degrees) across a water depth range of 2,400 – 3,700 m (Fig. 5.10). The plateau margins are locally steepened to roughly one degree along the southeastern edge, where it grades south-eastwards into the Wallaby Saddle, and 1.5 degrees along the northwestern margin that adjoins the abyssal plain. In contrast, the southwestern edge of the plateau is sharply defined by an escarpment that has an average slope of 30 degrees. The plateau extends approximately 140 km to the northeast from the escarpment, merging with a ridge and seamount chain that is aligned with the Sonne Ridge, located to the northeast of the survey area. The steepest gradient along this axis is 0.3 degrees, rising to the northeast.

The plateau incorporates two broad hills that rise approximately 400 m above the rest of the plateau and are separated by a north-south valley that crosses the middle of the plateau (Fig. 5.10). In the northwest-southeast direction, these hills are each about 60 km across. At the local scale, the seafloor is characterised by scarps up to 60 m high and small ridges that add 100 - 400 m to the plateau relief. Elsewhere, the plateau surface is generally smooth.

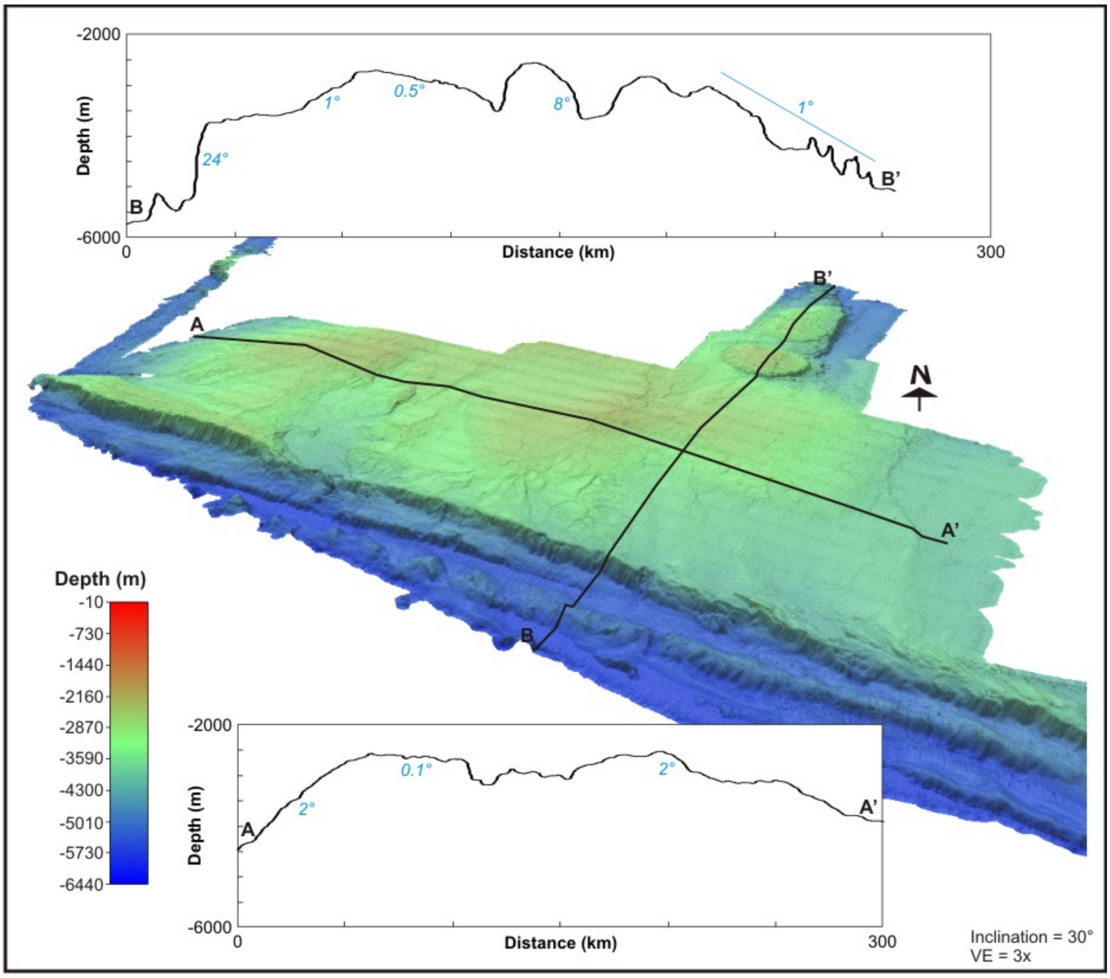



***Figure 5.10.*** *Oblique, false-colour bathymetry image of Cuvier Plateau survey area (see Fig. 5.3. for location) showing major geomorphic features. Inset: Representative profiles showing key geomorphic features cited in the text (A-B). Ridges and escarpments near B in profile B-B' form part of the Wallaby-Zenith Fracture Zone.*

***Saddle***

Within the Cuvier Plateau survey area, only the western and southern parts of the Wallaby Saddle are mapped, covering 9900 $km^2$ (15% of the mapped area, Fig 5.2). Water depths across the saddle range from 3,800 m along its western boundary with the plateau to 4,700 m at the southern edge of the saddle. The seafloor across the Wallaby Saddle is generally smooth to flat, except for a localised slump and 100 m high scarp located toward the southern edge of the saddle.

***Ridges***

Ridges cover a total of 8,100 $km^2$ or 12% of the survey area. The largest ridge extends about 190 km to the northeast from the plateau, forming the southern extension of the NE-SW trending Sonne Ridge (Figs. 5.1, 5.2). The mapped area of the Sonne Ridge extension covers 4,300 $km^2$ in ~3,000 m to 5,000 m water depth and has a longitudinal axial profile that dips to the north on an overall gradient of 0.5 degrees and steepens slightly to 1 degree along the northern part (Fig. 5.10). This profile is irregular as it incorporates to two large seamounts (described below) and a series of hills and knolls, up to 200 m high, located along the northeast part of the ridge where it is flanked by abyssal plain. Another ridge trends NW-SE and covers an area of 1,500 $km^2$ along the southwest-facing edge of the plateau (Figs 5.10 and 5.11). The ridge is 150 km long, up to 15 km wide and rises approximately 500 m above the adjacent plateau to 2,800 m water depth. The longitudinal profile of this ridge is regular, with less than 50 m of local relief. In cross-section, the ridge profile is smooth with gradients of three to four degrees, but with an abrupt termination of the southwest slope at the top of a large escarpment (Fig 5.11).

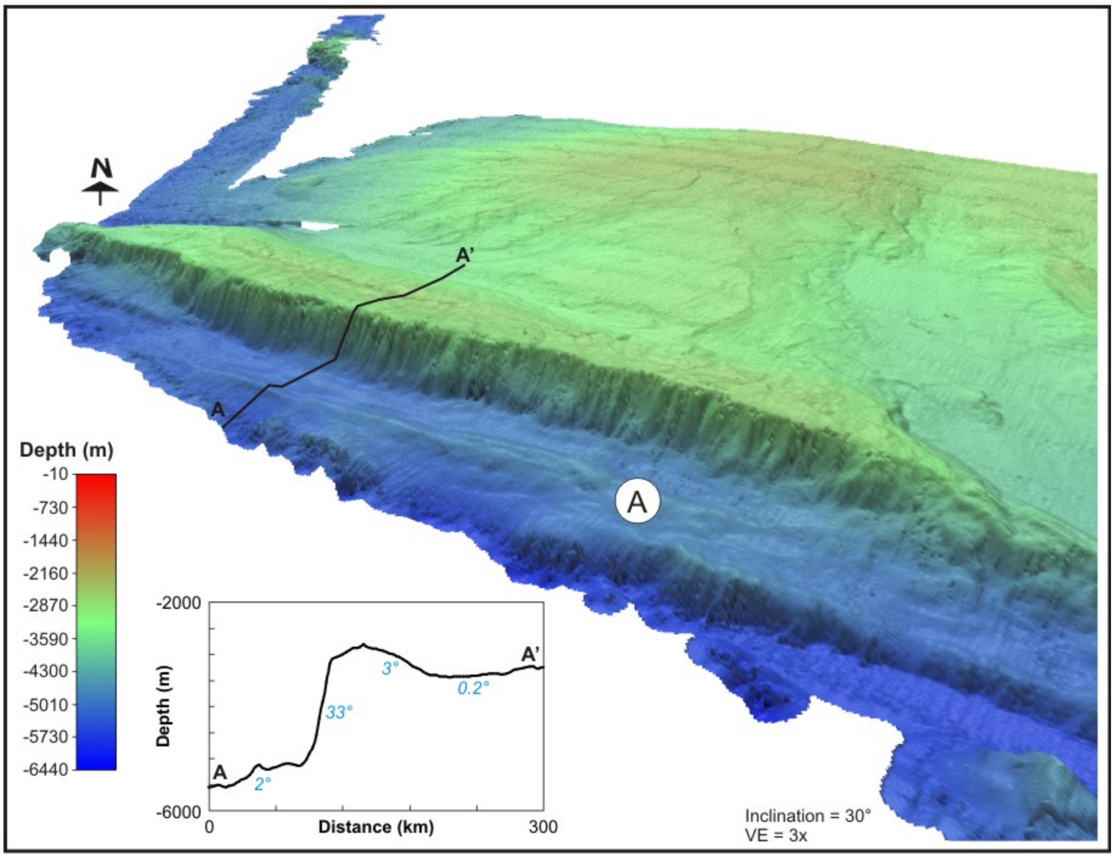



***Figure 5.11.*** *Oblique, false-colour bathymetry image of the second largest ridge in the Cuvier Plateau survey area (see Fig. 5.3. for location). Inset: Cross-section shows slopes over 30° denoting SW edge of plateau. "A" marks terrace A with associated ridge forming part of the Wallaby-Zenith Fracture Zone.*

The other ridges in the Cuvier Plateau survey area comprise a series of four northwest to southeast trending features within the Wallaby-Zenith Fracture Zone that have a combined area of 2,250 km$^2$ (Fig. 5.2). These ridges range in length from 11 km to 170 km, are less than 10 km wide and are 150 m to 600 m high. Water depths across the ridges mostly range from 5,000 – 5,600 m (Figs 5.10 and 5.11). In longitudinal profile, the ridges are highly irregular, however, with local relief of several hundred meters associated with narrow breaks across the ridge crest. In contrast, the side slopes of these ridges are generally smooth with gradients of six to seven degrees, except where localised scarps occur to steepen the gradient to 25-35 degrees.

***Valleys***

Three valleys are mapped within the Cuvier Plateau survey area, together covering 5,600 km$^2$ (8% of the mapped area, Fig. 5.2). The largest valley (2,400 km$^2$) extends 100 km across the middle of the plateau, with the head of the valley in 3,000 m water depth and the mouth at the top of the major escarpment along the southern edge of the plateau in 4,200 m (Fig. 5.12). The valley widens from eight km at its northern end where it is about 150 m deep, to 50 km along its southern reach where it cuts 700 m into the plateau. In cross-section the valley is broadly U-shaped with smooth slopes of one to two degrees that steepen to approximately six degrees at the mouth, where a 200 m high knick-point occurs at the top of the escarpment (Fig. 5.12).

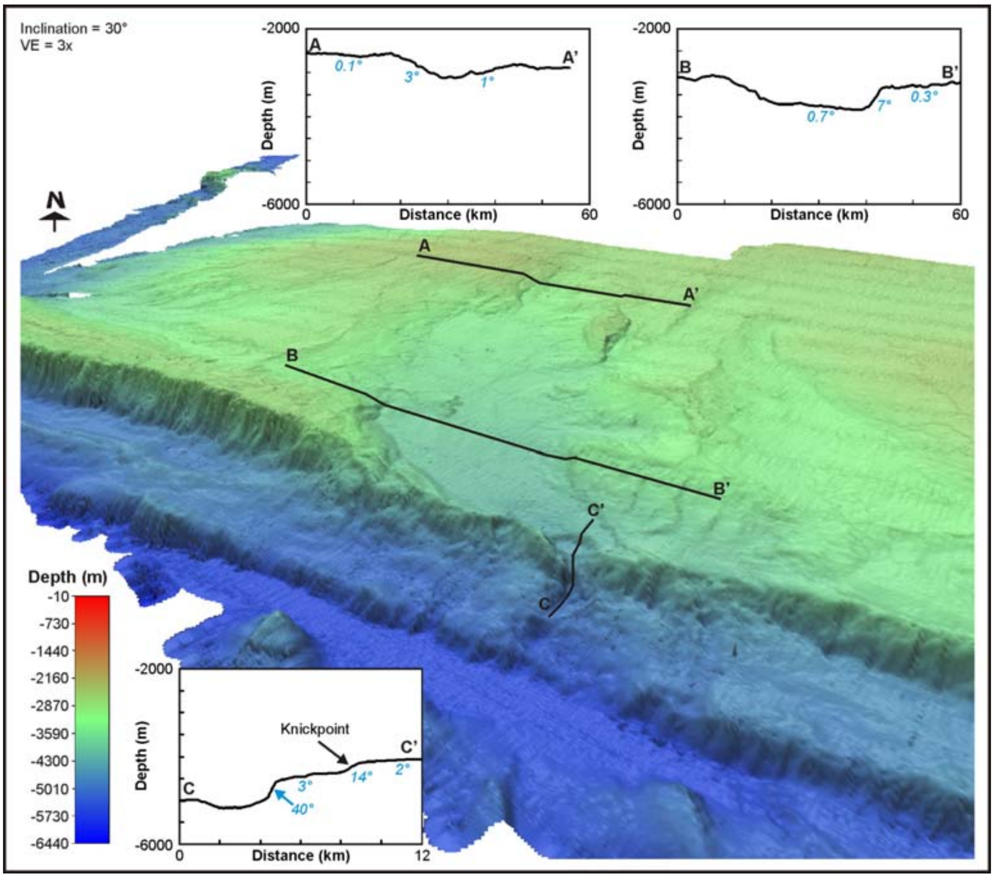



***Figure 5.12.*** *Oblique, false-colour bathymetry image of the largest valley on Cuvier Plateau (see Fig. 5.3. for location). Inset: Valley profiles showing cross-sections and knick-point at the top of the scarp.*

The other two valleys extend from the western and northern edge of plateau, respectively (Figs. 5.2, 5.13). The western valley is 55 km long and 5 – 20 km wide, with a water depth range along the valley of 3,400 to 5,100 m. In cross-section, the valley is asymmetric with its steeper southern side of roughly five degrees defined by a bounding ridge. The northern valley extends

145 km in a northeast direction from the edge of plateau and is bound on its western side by a ridge and scarp feature that rises 1,100 m above the valley floor. Water depths along the valley floor range from 4,000 to 4,600 m. The eastern side of this valley was not fully mapped during the survey, but the geomorphic features map of this area (Fig. 8 of Heap and Harris, 2008) shows this valley extends to the foot of the continental slope and is about 75 km wide.

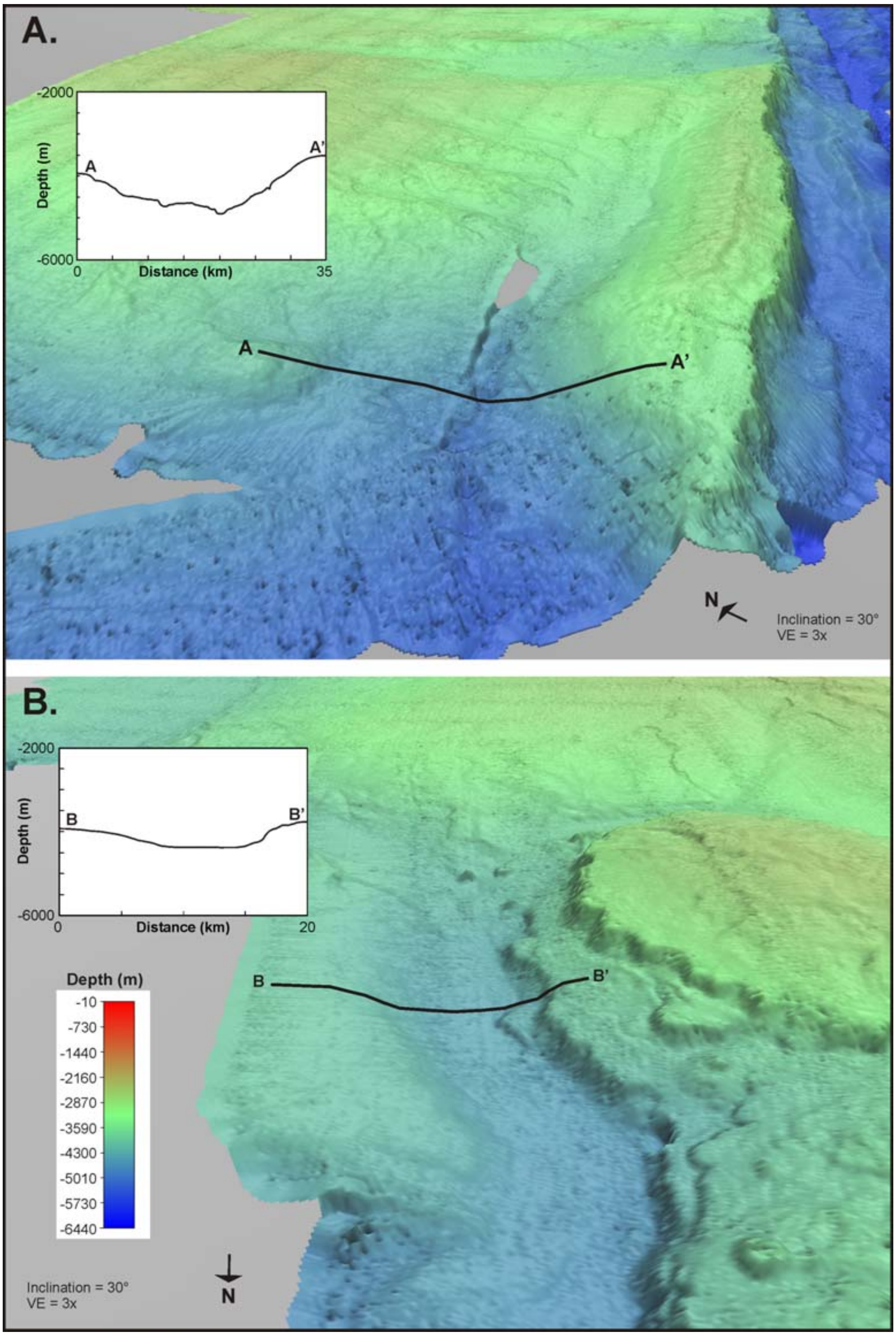



***Figure 5.13.*** *Oblique, false-colour bathymetry images of shallow valleys that extend from the western (A) and northern (N) edge of the Cuvier Plateau (see Fig. 5.3. for location). Insets: Profile showing cross-sections across each valley.*

***Troughs***
Troughs are restricted to the Wallaby-Zenith Fracture Zone where they occupy 4,150 km$^2$ (6% of the mapped area). In this zone, two flat-floored linear troughs are oriented in a northwest-southeast direction and are bound variously by ridges, terraces and scarps (Fig. 5.2). The two troughs measure 225 km by 10 km and 180 km by 9 km, and are up to 600 m and 300 m deep, respectively. Water depths within the troughs increase to the northwest from approximately 5,300 m to 5,700 m and they have smooth to locally irregular floors, where relief is up to 150 m.

***Terraces***
Two terraces (A and B) occur in the survey area (Fig. 5.2), covering a total of 3,500 km$^2$ (5% of the mapped area). Terrace A is 230 km long, up to 15 km wide and is located at the foot of the main escarpment that forms the edge of the Cuvier Plateau and part of the Wallaby-Zenith Fracture Zone (Figs 5.2 and 5.11). This terrace dips to the northwest on an average slope of 0.3 degrees in water depths of 4,600 m to 5,400 m and incorporates a narrow, 150 m high, ridge that extends 70 km along the western half of the terrace (Fig. 5.11). Elsewhere, local relief across terrace A is about 50 m.

Terrace B is located to the southeast of the Cuvier Plateau within the Wallaby-Zenith Fracture Zone (Fig. 5.2, 5.14). This terrace is 134 km long, approximately 10 km wide and sits at the foot of a northwest trending ridge and scarp complex. The outer edge of terrace B is defined by a slope of ~15 degrees that forms the northern margin of an adjacent trough. Water depths across the terrace range from about 4,600 m at its northwestern end to 5,300 m along an overall slope of 0.4 degrees. The terrace surface is generally featureless and smooth.

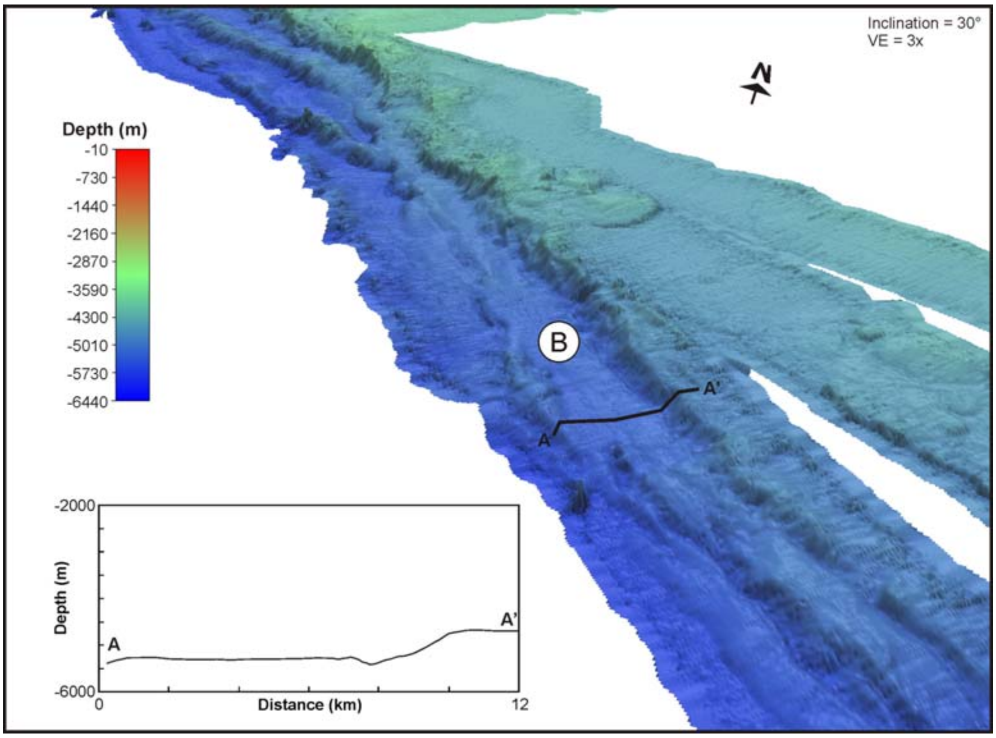



***Figure 5.14.*** *Oblique, false-colour bathymetry image of terrace B within the Wallaby-Zenith Fracture Zone (see Fig. 5.3. for location). Inset: Profile showing cross-sections across the terrace to the adjacent scarp.*

***Non-incised slope***
Two areas of non-incised slope, covering 2,250 km$^2$ (4% of the mapped area) are located along the southern edge of the Cuvier Plateau survey area and within the Wallaby-Zenith Fracture Zone (Fig. 5.2). Water depths in these areas range from 5,400 m where the slope adjoins the Wallaby Saddle, to 5,700 m at the foot of the slope.

### *Seamounts*

Two seamounts form part of the Cuvier Plateau, together covering 1,650 km$^2$ (2% of the mapped area, Fig. 5.2). Both seamounts, here named Cuvier Seamount and Wallaby Seamount (Fig. 5.1), are located at the southern end of the Sonne Ridge that extends onto the Cuvier Plateau (Fig. 5.15). The Wallaby Seamount is circular with a diameter of 40 km and rises 1,100 m from 3,600 m to a depth of 2,500 m. The Cuvier Seamount rises to 2,800 m from 3,600 m water depth and has an irregular outline with a long axis of 50 km. Both seamounts are domed, rather than of typical conical form, with broad convex summits with gradients of 1.5 to 2.0 degrees (Fig. 5.15). The sides of the seamounts are steeper, however, with gradients of up to 20 degrees on their eastern sides. Across the summit of each seamount the seafloor is slightly irregular, with local relief of less than 80 m where small ridges occur.

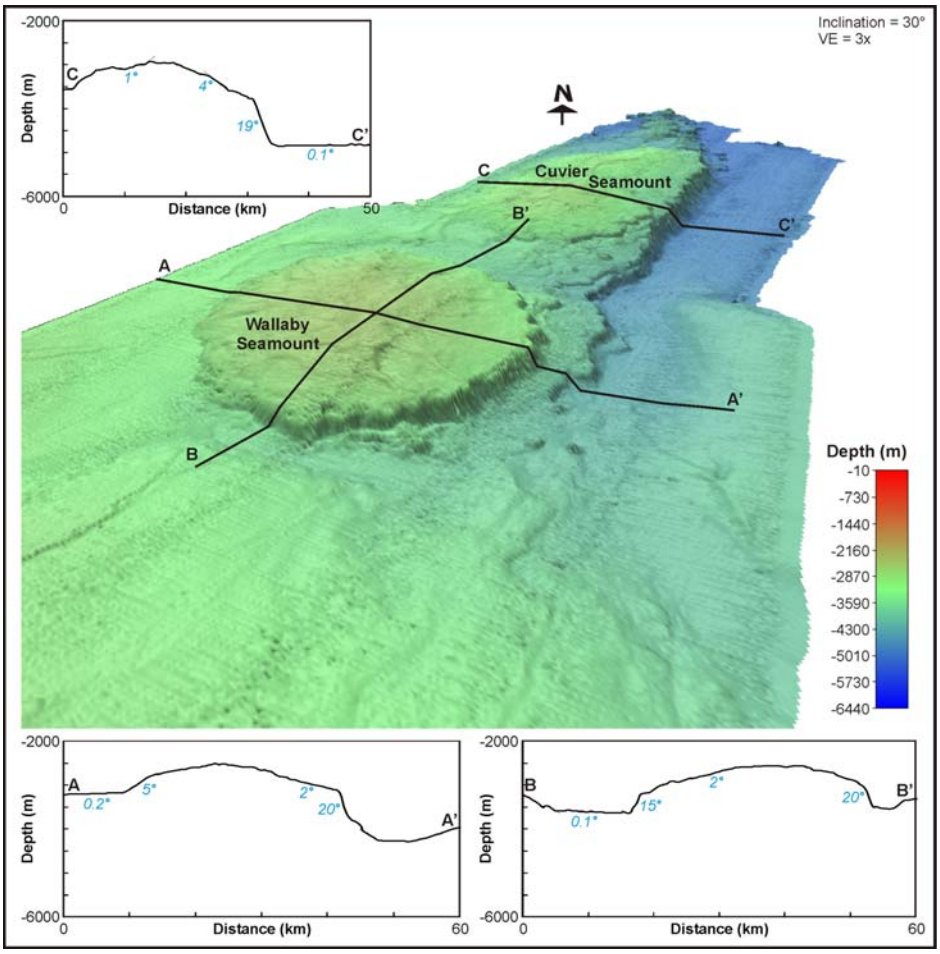



***Figure 5.15.*** *Oblique, false-colour bathymetry image of Wallaby and Cuvier seamounts on southern end of Sonne Ridge (see Fig. 5.3. for location). Inset: Cross-sections show dimensions of seamounts, with slopes up to 20°.*

### *Escarpments*

Four large escarpments occur within the Cuvier Plateau survey area, with a combined area of 1,250 km$^2$ (2% of the mapped area, Fig 5.2). The longest escarpment extends 340 km along the full length of the plateau, defining its southwestern boundary with the foot of the scarp sitting in water depths of 5,100 to 5,200 m (Fig 5.10). The height of the scarp decreases from 2,100 m at its western end to 700 m at its eastern limit, beyond which point it grades to a steep slope on the side of a ridge. Along most of its length, the top of the scarp is straight in planform, apart from short (3-4 km long) sections where it is scalloped by steep gullies that are incised into the edge of the plateau.

The second longest escarpment is located in the northern part of the mapped area along the eastern edge of the ridge (Fig 5.13). This scarp is 105 km long and increases in height to the north, from 400 m to 1,100 m with the base of the scarp in 4,700 – 4,900 m water depth. At its northern end, it defines the eastern flank of the higher portion of the Sonne Ridge. To the north of this point, the edge of the Sonne Ridge is defined by a series of low (100 - 400 m high), discontinuous scarps that sit in 5,000 m water depth.

The two other escarpments in the mapped area are located to the southeast of the main escarpment, along the same northwest-southeast orientation as the main escarpment and within the Wallaby-Zenith Fracture Zone. These scarps are 73 km and 35 km in length, respectively, up to 800 m high with their base at 5,300 m water depth.

## 5.4. SUMMARY

The geomorphology of the west Australia margin, which includes the inner west Australia margin and Cuvier Plateau study areas, incorporates extensive parts of the continental slope, covering 96% and 97% of each study area, respectively. The remaining areas of the survey cover parts of the rise and abyssal plain. On the inner west Australian margin, the slope is characterised by large areas that are deeply incised by a total of 109 canyons and separate areas that are characterised by low-angle slumps and scarps. Together, incised and slumped areas of the slope cover 65% of the west Australian margin survey area. Other geomorphic features on the slope include small volcanic peaks and short escarpments of local extent.

Geomorphic features of the Cuvier Plateau and adjacent mapped areas are more varied than on the inner margin, and include plateau, saddle, ridge, valley, seamount, scarp, trough and terrace features. Of these, the central plateau is the dominant feature, covering 43% of the mapped area, followed by the Wallaby Saddle (15%). All other features each occupy less than 10% of the survey area. Despite covering relatively small areas of the Cuvier Plateau some of these features add considerable relief and rugosity to the geomorphology of this area. Escarpments and seamounts in particular, have relief of hundreds to thousands of metres and extend along the seafloor for tens to hundreds of kilometres. Greatest geomorphic complexity exists within the Wallaby-Zenith Fracture Zone where ridges, scarps, troughs and terraces are juxtaposed to form the most complex bathymetry of the survey area. Overall, the dominant geomorphology of the mapped area is the low relief and gently sloping plateau.

# 6. Sedimentology

## 6.1. BACKGROUND

This chapter presents preliminary findings from the textural and compositional analyses of seabed sediments obtained during survey GA2476 (Appendix F). A total of 73 samples were collected from depths ranging from 900 to 5,200 m in the west Australian margin: 25 samples from the Zeewyck Sub-basin of the Perth margin; 18 samples from the Houtman Sub-basin of the Perth margin; 18 samples from the Cuvier margin and; 12 samples from the Cuvier Plateau. A range of equipment was used during the sampling program with seabed sediment samples obtained from 22 grabs, 43 dredges and 8 boxcores. Sediment samples were sent to the Geoscience Australia's Sedimentology Laboratory for textural and chemical analyses.

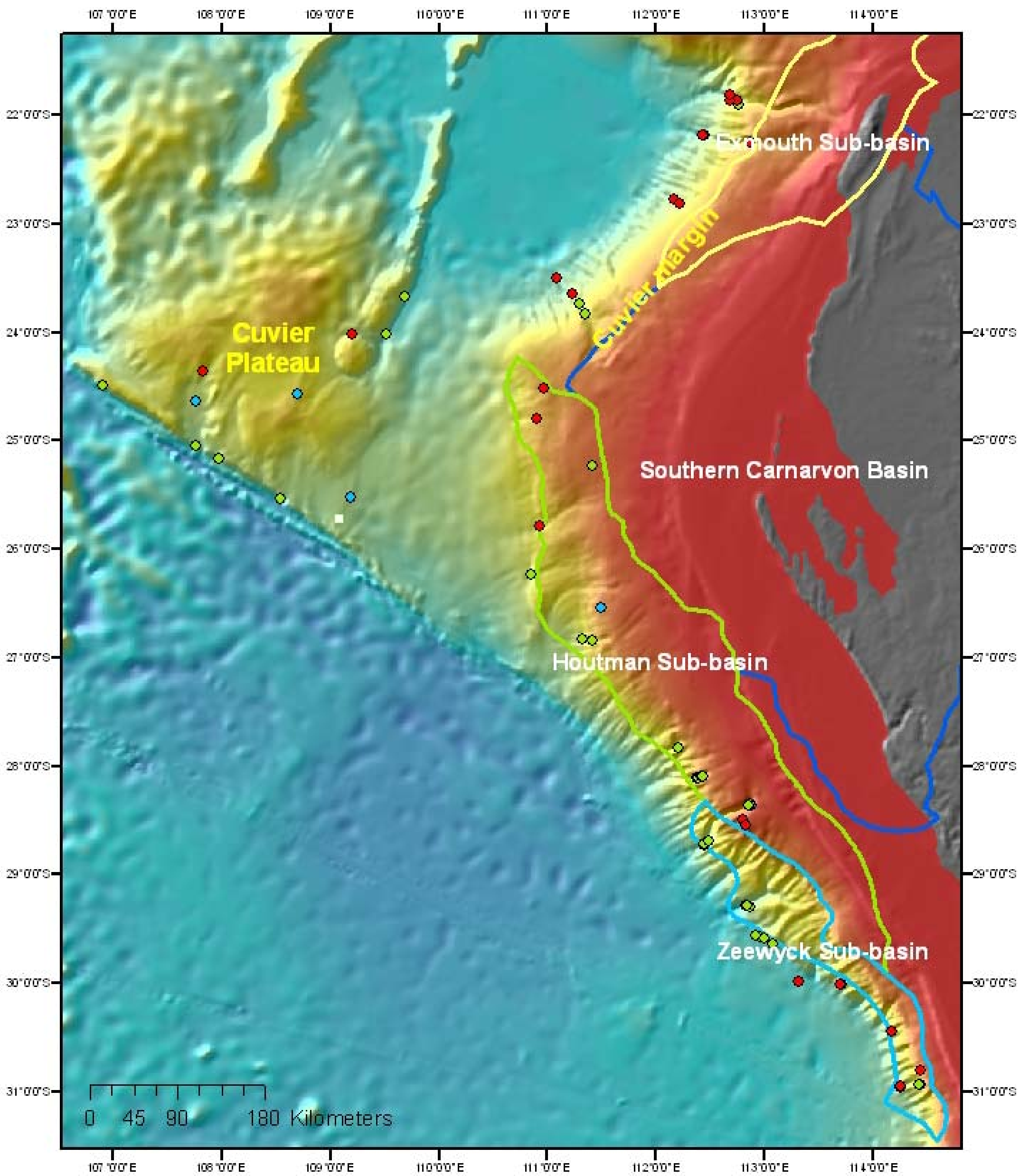



***Figure 6.1***. *Location of seabed sediment samples from survey GA2476 (Dredges = green dots, grabs = red dots and boxcores = blue dots).*

## 6.2. SAMPLE PROCESSING

### 6.2.1. Sieve Grainsize

Samples were oven dried at 40$^{o}$C and soaked in a 5% calgon solution to aid breakdown. They were then washed through stainless steel sieves into the following fractions to establish particle size distribution: mud <63 µm; sand 63-2,000 µm; and gravel >2,000 µm. After being dried, the dried material for each fraction was then weighed with an analytical balance to obtain the amount of mud, sand and gravel in each sample. One in every ten samples was analysed in duplicate for quality assurance purposes.

### 6.2.2. Laser Grainsize

Bulk grainsize distributions were determined using the Malvern Mastersizer 2000 laser particle size analyser. The instrument uses laser diffraction to calculate the volume weighted percentage of particles in the sample. Samples were initially treated with a 10% hydrogen peroxide solution to remove organic matter from the sample. Any particles over 1.7 mm in size were noted and removed from the samples prior to analysis. The particle size produces histograms of grain size ranging from 0.02 µm to 2,000 µm. Additional statistics such a mean, median, standard deviation, skewness and kurtosis were also calculated. One in every ten samples was analysed in duplicate for quality assurance purposes.

### 6.2.3. Calcium Carbonate Content

Carbonate concentrations were determined on the bulk sample and the mud and gravel sieve grainsize fractions using the carbonate digestion method. The samples were ground to a fine powder and reacted with 25% orthophosphoric acid in a canister connected to a digital pressure gauge. The pressure of $CO_2$ gas release for a known quantity of sample was converted into percentage calcium carbonate. This is calculated from formulas derived from regular pure calcium carbonate calibration runs. One in every ten samples was analysed in duplicate for quality assurance purposes. Calcium carbonate percentage for gravel fractions was estimated through visual inspection.

### 6.2.4. Observations of sediment composition

The gravel and sand fractions from twelve sediment samples were described from observations made under a microscope. The samples were selected to represent the range of sediment compositions acquired. The mud fraction was not described due to its fine grainsize.

## 6.3. RESULTS

### 6.3.1. Sieve Grainsize

A ternary plot of the gravel, sand and mud analyses indicate that the sediments from all four study areas had a typically muddy composition (Fig. 6.2). This fine sediment composition is consistent with the low energy, pelagic sedimentation of the outer shelf, continental slope and marginal plateaus, although some relatively coarse sediments were recovered from the Cuvier Plateau. A further classification of the sieve analyses using Folk's (1954) textural groupings show a majority of the sediments have a sandy mud (51 samples) or mud (11 samples) composition. Other classes identified were muddy sand (4 samples), gravelly mud (3 samples), slightly gravelly mud (2 samples), sandy gravel (1 sample) and slightly gravelly sand (1 sample). Results from the sieve analysis of the sediment samples are found in Appendix F.

Plots of percent mud with sample depth and latitude (Fig. 6.3) indicate no regional trends within the acquired samples.

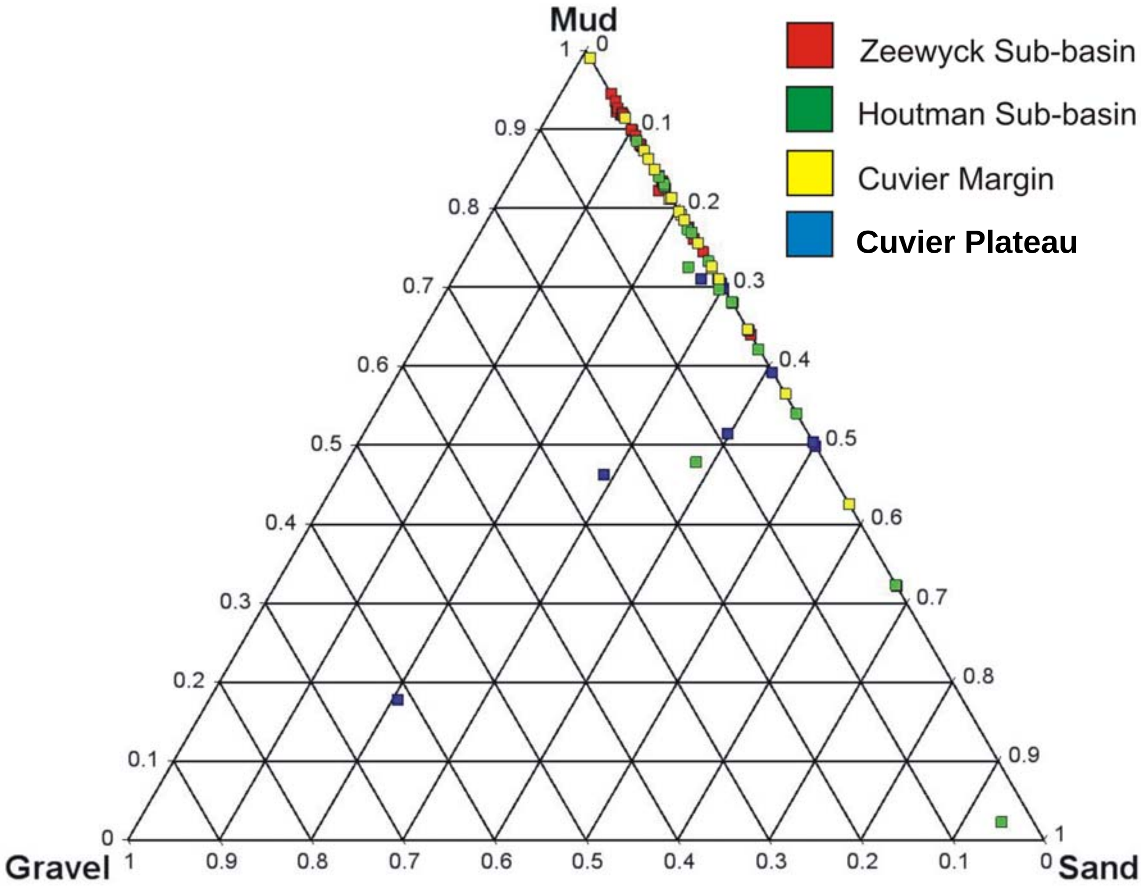



***Figure 6.2.*** *Ternary plot of sediment sample textural composition. Note the typically high mud content of the majority of samples.*

### 6.3.2. Laser Grainsize

Mean grain size ranges from 505.4 to 3.5 μm with only four samples with mean grain sizes greater than 50 μm (Fig. 6.4). Grain size distributions indicate that most sediment samples are poorly sorted; 43 samples have tri-modal distributions, 20 samples have bi-modal distributions, 9 samples have uni-modal distributions, and 1 sample has a poly-modal distribution. Complete laser analyses of the 77 samples are found in Appendix F.

Plots of mean grainsize with sample depth and latitude (Fig. 6.3) indicate no regional trends within the acquired samples.

### 6.3.3. Calcium Carbonate Content

The bulk calcium carbonate ($CaCO_3$) content of the sediment samples ranges from 89.7 to 1.5% (Fig. 6.5) with an average of 66.3%. The mud and sand $CaCO_3$ content is also typically high with averages of 70.6% and 75.1% respectively (Table 6.1). However, the gravel fraction is generally lower in $CaCO_3$ (37.8%) and indicates the presence of large lithic fragments in some of the sediment samples.

The plot of bulk carbonate composition with latitude indicates a typically higher $CaCO_3$ content in the mid latitudes (~25°S) (Fig. 6.3). The plot of bulk carbonate composition with water depth indicates decreasing $CaCO_3$ content with water depth (Fig. 6.3). One sample (061DR053SSA1.1) from the Cuvier Plateau, has a carbonate content of 7.8% despite its acquisition depth of 5,159 m. The precise location of the Carbonate Compensation Depth (CCD) west of Australia is unknown but appears to be greater than 5,000 m at this location. Results from the carbonate composition analysis of the sediment samples are found in Appendix F.

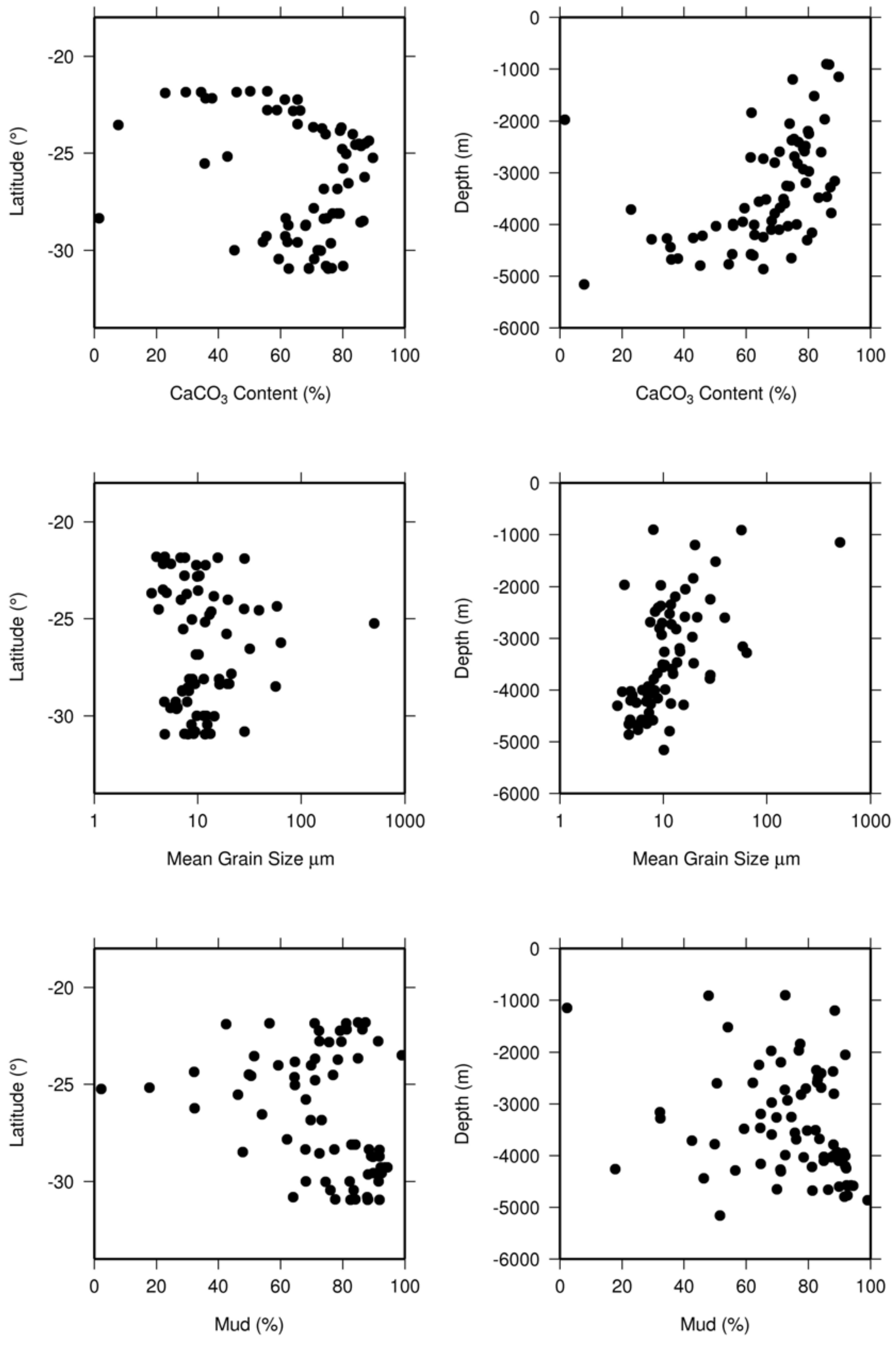



***Figure 6.3.*** *Variations of percent mud, mean grain size, and bulk calcium carbonate ($CaCO_3$) with depth and latitude.*

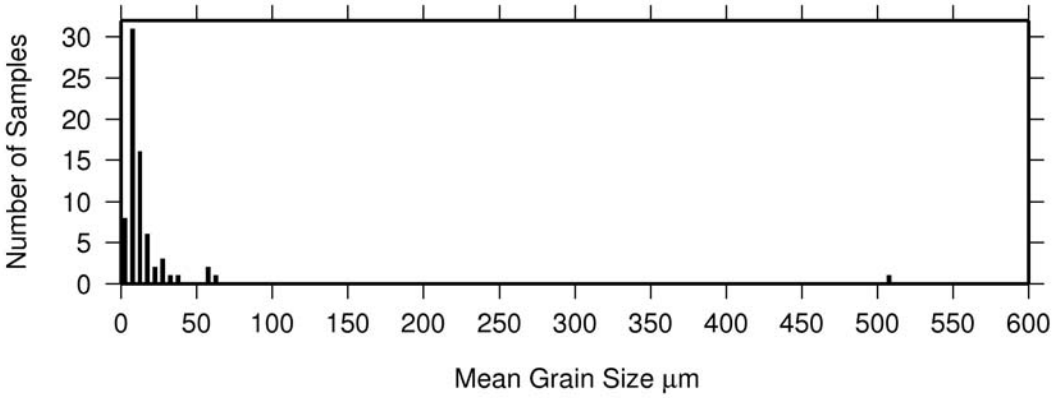



***Figure 6.4.*** *Histogram of mean sediment grainsize from Laser Grainsize analysis.*

### 6.3.4. Observations of sediment composition

Initial observations of sediment composition under a microscope confirm a typically high foraminifera presence in the sand fraction of most samples (Table 6.2). Non-carbonate material is generally lithic grains or sponge spicules but echinoid spines are observed in many samples at low concentrations. The sand fractions of sediments that are dominantly non-carbonate consisted of lithic fragments and quartz (031DR028 and 033GR030), or sponge spicules (017GR004). Gravel fractions are either typically limestone or lithic fragments and reflect the rocky substrate sampled by the dredges and grabs.

## 6.4. SUMMARY

A total of 73 samples were collected during survey GA2476 using a range of sampling equipment. Textural and compositional analyses show that the sediment is largely fine grained calcareous mud and calcareous sandy mud. This is consistent with the largely pelagic sedimentation occurring on the west Australian margin.

**Table 6.1.** Summary statistics for calcium carbonate compositional analysis.

| FRACTION | AVERAGE CACO$_3$(%) | STANDARD DEVIATION |
|---|---|---|
| Mud | 70.6 | 16.9 |
| Sand | 75.1 | 27.5 |
| Gravel | 37.8 | 46.5 |
| Bulk | 66.3 | 18.3 |

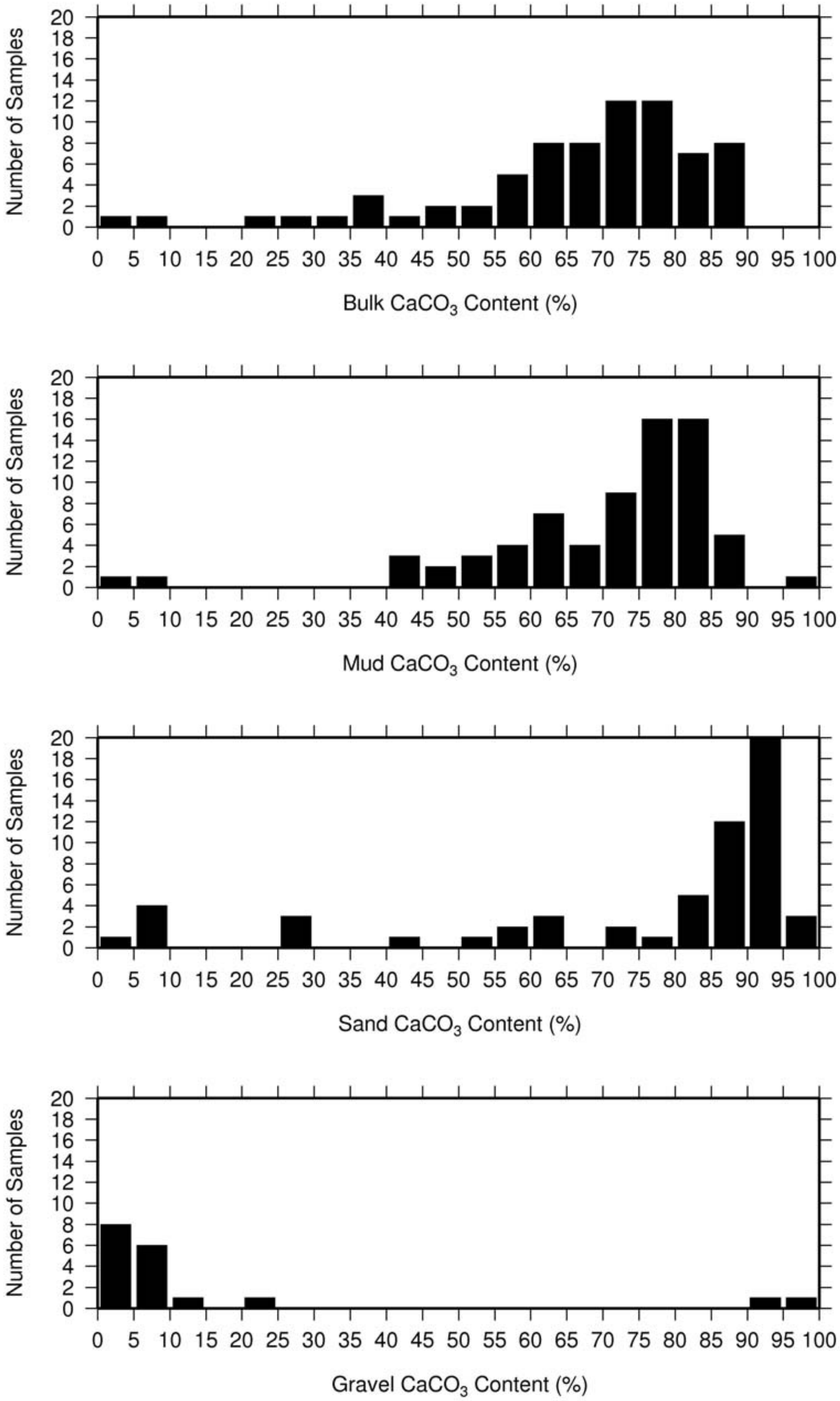



***Figure 6.5.*** *Histogram of $CaCO_3$ compositions for gravel, sand, mud and bulk samples. Note not all samples had sufficient sand or gravel content for analysis hence there is less than 77 samples represented in the histograms.*

**Table 6.2.** Observations of sediment sample composition (selected samples only)

| SAMPLE | OBSERVATIONS |
|---|---|
| 014DR011 | Sand: >90% foraminifera with some sponge spicules<br>Gravel: None |
| 017GR004 | Sand: >90% foraminifera with some sponge spicules<br>Gravel: None |
| 018GR006 | Sand: >90% foraminifera with some sponge spicules<br>Gravel: None |
| 031DR028 | Sand: Dominantly lithic fragments and quartz grains with some foraminifera<br>Gravel: None |
| 033GR030 | Sand: Dominantly lithic fragments and quartz grains with some foraminifera<br>Gravel: None |
| 038GR021 | Sand: >90% foraminifera with some sponge spicules and echinoid spines<br>Gravel: None |
| 045DR039 | Sand: >90% foraminifera with some sponge spicules<br>Gravel: None |
| 046DR040 | Sand: >90% foraminifera with some sponge spicules<br>Gravel: None |
| 047DR041 | Sand: >90% foraminifera with some sponge spicules and echinoid spines<br>Gravel: None |
| 050GR047 | Sand: Mostly foraminifera with angular limestone grains<br>Gravel: Angular limestone fragments |
| 051DR051 | Sand: Foraminifera with lithic grains, sponge spicules and echinoid spines<br>Gravel: Angular lithic fragments |
| 053GR047 | Sand: Mostly foraminifera with angular lithic fragments<br>Gravel: Angular lithic fragments |

# 7. Environmental Geochemistry

This chapter presents preliminary findings of biogeochemical analyses of seabed sediments and CTD samples sampled from the Perth margin (Zeewyck and Houtman sub-basins), the Cuvier margin and the Cuvier Plateau. Further work is being undertaken to improve our understanding of the geochemistry of these sediments and to establish surrogacy links with geomorphic, hydrodynamic and biological systems.

## 7.1. BACKGROUND

The overarching aim of the environmental geochemistry component of the Offshore Energy Security Initiative surveys is to characterise seabed sediments in the Australian Marine Jurisdiction from a geochemical/biogeochemical perspective, and to explore the potential of geochemical surrogates for benthic biodiversity. The choice of methods and suite of parameters measured to address these objectives was constrained to fit in with the frontier petroleum exploration focus. Consequently, it was not possible to deploy technologies such as benthic chambers on the seafloor.

The surrogacy problem is addressed from the perspective of the reactivity of carbon and the availability of potentially limiting factors (nutrients and trace elements). Carbon freshness and degradability are known to be coupled. Carbon (reactivity, quality) is assessed through core incubation experiments and by wet chemical methods to assess the degradability of chlorin pigments (Schubert et al., 2005). Changes in the concentrations of dissolved oxygen (DO) and metabolites (dissolved $CO_2$ and nutrients) are measured in core incubation experiments and these are used to determine the amounts of organic matter breaking down in the sediments.

The Chlorin Index is the ratio of the fluorescence intensity of a sediment sample extracted in acetone and subject to hydrochloric acid (HCl) treatment, to that of the original sediment extract. It indicates the ratio of chlorophyll and its degradation products within the sediments that could still be chemically transformed and those that are chemically inert. The method was chosen because it is analytically straightforward, and compares well with sulphate reduction rates and degradation indices based on amino acid composition (Schubert et al., 2005). Trace-element ratios and the stoichiometry of metabolites in core incubation experiments were also used to deduce redox conditions, which are known to have a bearing on marine species composition and diversity.

A 1 M HCl (one mole hydrochloric acid) extraction method was used to identify the key labile element phases (i.e., sorbed species and those found in association with Fe-Mn oxides, amorphous sulphides, labile organic matter and carbonates), which are most likely to influence biota (Snape et al., 2004). Samples for Total Organic Carbon (TOC), Total Nitrogen (TN), and their isotopes and major/minor element oxides were also collected to complete the chemical characterisation of the sediment.

## 7.2. SAMPLE PROCESSING

Surface and shallow (<0.20 mbsf) sub-surface sediments were sub-sampled for bulk sediment chemistry, porosity and bulk density, grain size/carbonate and vial incubation experiments. The number and combination of analyses undertaken were subject to the amount of sediment recovered. Bottom water samples for Total Carbon Dioxide (TCO2) and di-nitrogen gas (N2) were also taken at each of the CTD stations, and profiles of N2 were undertaken at selected stations. Only the TCO2, O2 and N2 analyses had been completed at the time this document was written. The methods pertaining to these analyses are described below. A summary of all the geochemical sub-sample acquired during survey GA2476 are listed in Table 7.1. Laboratory submissions have been made for the remaining analyses.

**Table 7.1.** Summary of geochemistry sub-samples acquired during survey GA2476

| Sample | Chlorins | Acid-extractable metals | sediment nutrients | XRF/XRD | porosity | Grain size/ %carbonate | Sediment/ Incubation cores | Archive |
|---|---|---|---|---|---|---|---|---|
| 006BC001 | y | y | y | y | y | y | n | y |
| 006BC002 | y | y | y | y | y | y | y | y |
| 009GR001 | y | y | y | y | n | y | n | y |
| 011GR003 | y | y | y | y | n | y | n | y |
| 017GR004 | y | y | y | y | n | y | n | y |
| 018GR005 | y | y | y | y | n | y | n | y |
| 018GR006 | y | y | y | y | n | y | n | y |
| 020GR008 | y | y | y | y | y | y | y | y |
| 021GR009 | y | y | y | y | n | y | n | y |
| 022BC003 | y | y | y | y | y | y | y | y |
| 023BC004 | y | y | y | y | y | y | y | y |
| 023GR011 | y | y | y | y | n | y | n | y |
| 027GR012 | y | y | y | y | n | y | n | y |
| 028GR013 | y | y | y | y | n | y | n | y |
| 029GR014 | y | y | y | y | n | y | n | y |
| 032GR016 | y | y | y | y | n | y | n | y |
| 033GR017 | y | y | y | y | n | y | n | y |
| 034GR018 | y | y | y | y | n | y | n | y |
| 036GR019 | y | y | y | y | n | y | n | y |
| 037GR020 | y | y | y | y | n | y | n | y |
| 038GR021 | y | y | y | y | n | y | n | y |
| 039GR022 | y | y | y | y | n | y | n | y |
| 040GR023 | y | y | y | y | n | y | n | y |
| 041GR024 | y | y | y | y | n | y | n | y |
| 048BC005 | y | y | y | y | y | y | y | y |
| 049GR026 | y | y | y | y | n | y | n | y |
| 054BC006 | y | y | y | y | y | y | y | y |
| 055GR027 | y | y | y | y | n | y | n | y |
| 056GR028 | y | y | y | y | n | y | n | y |
| 059BC007 | y | y | y | y | y | y | y | y |
| 060BC008 | y | y | y | y | y | y | y | y |

### 7.2.1 Core Incubation Experiments

One sediment core designated for incubation was collected from each of the boxcores. The sediment cores (and overlying water) were collected by hand-pushing 84 mm diameter PVC tubes into the top of the boxcore sample. Once in the sediment, the core liners were sealed at the bottom with plastic plugs fitted with o-rings. Sediment depths of 0.14–0.19 m and water column heights of 0.7–0.125 m were obtained in the core barrels. Gas-tight lids were used to seal the top of each core barrel. The lids were fitted on the underside with magnetic stirrers that were rotated by a second magnet on top of the lid driven by a small motor. The appropriate pre-incubation period necessitates that a balance be achieved between avoiding changes in bacterial populations while still allowing cores to recover from transient disturbances (Glud et al., 1994). A study by Glud et al. (1994) conducted over similar water depths relied on a three hour pre-incubation period, while in a subsequent study Glud et al. (1999) allocated 6-12 hours for pre-incubation. We allowed the cores to equilibrate for 4-6 hours prior to the initial sampling. The core incubations then proceeded in darkness and at *in situ* temperatures (2-3°C) for 1.1-2.5 days.

The dissolved oxygen concentrations of the water overlying the sediment cores were measured at approximately four hourly intervals using a HACH HQ40D metre and LDO Intellical probes. The accuracy of the probes is ± 0.1 mg $L^{-1}$ for concentrations 0-8 mg $L^{-1}$. A single sample for nutrients ($SiO_4^{2-}$, $NO_2^-$, $NO_3^-$, $NH_4^+$ and $PO_4^{3-}$) and triplicate samples for $N_2$ and $TCO_2$ were collected at the beginning ($t_0$) and end ($t_1$) of the incubations. The $TCO_2$ samples were filtered through 0.45 μM disposable filters into 3 ml gas-tight containers (Labco Exetainer's), that had been pre-charged with 0.025 ml of mercuric chloride (to poison the samples). Samples for $N_2$ analysis were collected in 8 ml glass vials that had ground-glass stoppers and that had also been pre-charged with 0.025 ml of mercuric chloride. Both the $N_2$ and $TCO_2$ samples were stored in the refrigerator prior to analysis. The $N_2$ samples were stored upside down in containers filled with seawater. Water for dissolved nutrient analyses was syringe filtered through 0.45 µm filters into clean environmental grade HDPE bottles. These samples were frozen immediately after collection.

$TCO_2$ was analysed using an AS-C3 DIC analyser (Apollo SciTech), which includes an infrared-based $CO_2$ detector (LiCor 7000). Certified seawater was used as a standard (A.G. Dickson, UC San Diego). The precision of the measurements were always less than or equal to 0.1%. Accuracy was assessed with the analysis of ~0.002 M $Na_2CO_3$ solutions with each of the 7 analytical runs, and the results were within 1.3 ± 1.1% of expected values. $N_2$ was measured using a Membrane Inlet Mass Spectrometer as described by Kana et al. (1994) with the following modifications. Gases were detected with a Balzers QMS422 quadrupole mass spectrometer and a water bath (±0.01° C) was used to stabilize sample temperature in the water line upstream of the membrane.

Analyses for Filterable reactive phosphate (FRP), Nitrogen Oxides ($NO_x$), Nitrate ($NO_3$), and ammonia ($NH_3$), will be performed simultaneously using an automated LACHAT 8000QC flow injection system using methodology based on: a) ascorbic acid reduction of phosphomolybdate for FRP (Standard Methods 2005–4500-P G, p. 4-156 to 4-157); b) cadmium reduction of nitrate to nitrite by diazotizing the nitrite with sulfanilamide and coupling with N-(1-naphthyl)ethylenediamine dihydrochloride for $NO_x$ (Standard Methods 2005–4500-$NO_3$ I, p. 4-127 to 4-129); and c) production of the indophenol blue colour complex for $NH_3$ (Standard Methods 2005–4500-$NH_3$ H, p. 4-116 to 4-117). The frozen silica samples will be left to equilibrate at ambient temperature for three days prior to analysis. Silica will be analysed using an automated LACHAT 8000QC flow injection system. This is based on an automated procedure whereby the silica species reacts with molybdate at 37° C and pH 1.2 to form a yellow silicomolybdate complex. This complex is subsequently reduced with stannous chloride to form a heteropoly blue complex which is measured spectrophotometrically at 820 nm (Standard Methods 2005–4500-$SiO_2$ F). The uncertainty on the dissolved inorganic nutrient analyses was 0.002 mg $L^{-1}$, based on In-House Reference Materials that were prepared at varying concentrations across the analysis range, and that were analysed with every analytical run.

The raw data for the core incubation experiments is presented in Table 7.2. Following the protocol of Glud et al. (1999), DO concentrations were never allowed to drop to below 35% of the initial concentration during the ~27 to ~56 hour incubations. Total Oxygen Uptake (TOU) was calculated from the slopes of the linear regressions through the data collected at four hourly intervals (Fig. 7.1; Table 7.2). $TCO_2$ fluxes were calculated from the two-point regression (t= 0 and t = 1).

### 7.2.2. Water Samples and CTD

Water samples were collected from throughout the water column during the deployment of two CTD sensors (CTD005 and CTD006, Figure 7.2). At CTD005, the water depth was approximately 2,000m and water column samples were collected every 200m. CTD006 was 4,830m deep and samples were collected every 400m. Upon retrieval of the CTD, water samples were transferred directly into poisoned (25 µL HgCl) 8 mL glass vials with ground glass stoppers. Vials were stored under seawater at *in situ* temperatures until transported to the Geoscience Australia laboratory. Analysis of dissolved $N_2$ and $O_2$ was determined using a Membrane Inlet Mass Spectrometer (MIMS) using methods described by Kana et al. (1994) (see above).

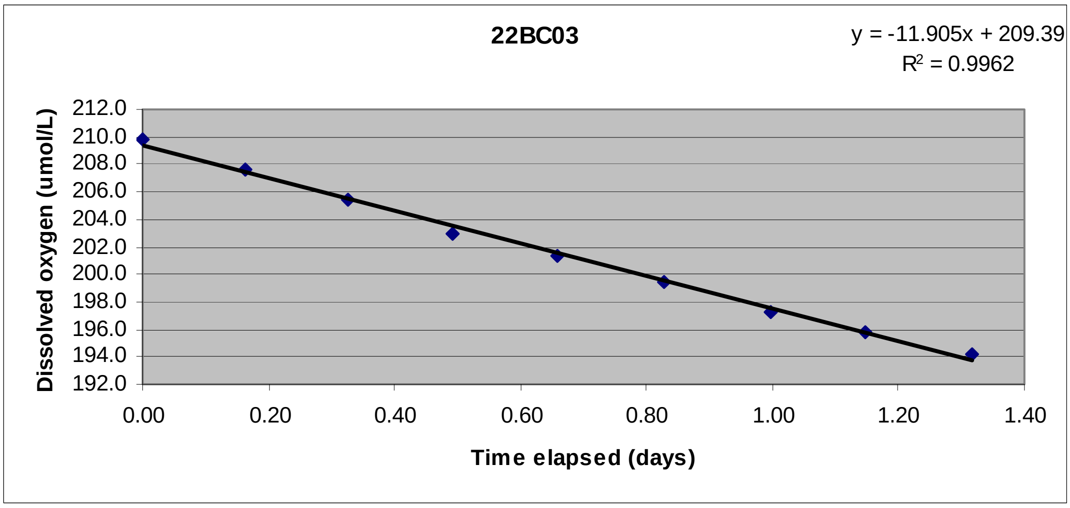



***Figure 7.1.*** *Example results of the core incubation experiment conducted on boxcore 022BC003. The slopes of the regression lines are used in combination with incubation volumes to calculate the dissolved oxygen fluxes.*

**Table 7.2.** Raw data from the dissolved oxygen (DO) component of the core incubation experiments.

| Sample | Start (t=0) | Finish (t=1) | Incubation time (hours) | Slope DO (umol/L per day) | Incubation Area ($m^2$) | Incubation volume (L) | Y-intercept (umol/L) | DO drop (%) |
|---|---|---|---|---|---|---|---|---|
| 006BC002 | 3/11/2008 13:10 | 4/11/2008 17:53 | 28.7 | -16.311 | 0.00503 | 0.276 | 193.5 | 10.9 |
| 020GR009 | 17/11/2008 5:50 | 18/11/2008 15:34 | 33.7 | -11.349 | 0.00503 | 0.452 | 235.4 | 6.6 |
| 022BC003 | 18/11/2008 18:22 | 19/11/2008 21:54 | 27.5 | -11.905 | 0.00503 | 0.377 | 209.4 | 7.1 |
| 023BC004 | 20/11/2008 3:45 | 21/11/2008 14:00 | 34.3 | -22.737 | 0.00503 | 0.402 | 241.5 | 14.9 |
| 048BC005 | 16/12/2008 14:30 | 18/12/2008 9:50 | 43.3 | -5.03 | 0.00503 | 0.402 | 233.4 | 3.6 |
| 054BC006 | 30/12/2008 14:00 | 2/01/2009 0:00 | 58.0 | -7.703 | 0.00503 | 0.352 | 214.2 | 8.9 |
| 059BC007 | 8/01/2009 14:30 | 10/01/2009 4:30 | 38.0 | -11.696 | 0.00503 | 0.352 | 231.3 | 8.1 |
| 060BC008 | 9/01/2009 20:30 | 12/01/2009 4:30 | 56.0 | -6.54 | 0.00503 | 0.578 | 215.9 | 7.2 |

## 7.3. RESULTS

### 7.3.1. Core Incubation Experiments

DO and TCO2 fluxes from the core incubation experiments are presented in Table 7.3. DO fluxes ranged from -9.7 – -43.7 mmol m-2 d-1, reflecting the oxygen demand of the sediment as the organic matter is remineralised. In comparison, the TCO2 fluxes had both negative and positive values (-22.4 to 35.2 mmol m-2 d-1). The negative TCO2 fluxes were likely due to the precipitation of calcium carbonate (CaCO3), which is caused by an increase in the saturation state of CaCO3 in the water overlying the cores driven by a lowering of water pressures. It is interesting that CaCO3 precipitation was observed in some of the experiments but not in others (Table 7.3). The dichotomy in the observations may be related to kinetic factors (such as inhibitors) or to differences in the chemistry of the bottom waters. It is noteworthy that bottom water TCO2 concentrations did not vary significantly throughout the region, based on the limited observations presented in Table 7.4. However, calcium (Ca) and carbonate (CO32-) ions are the crucial

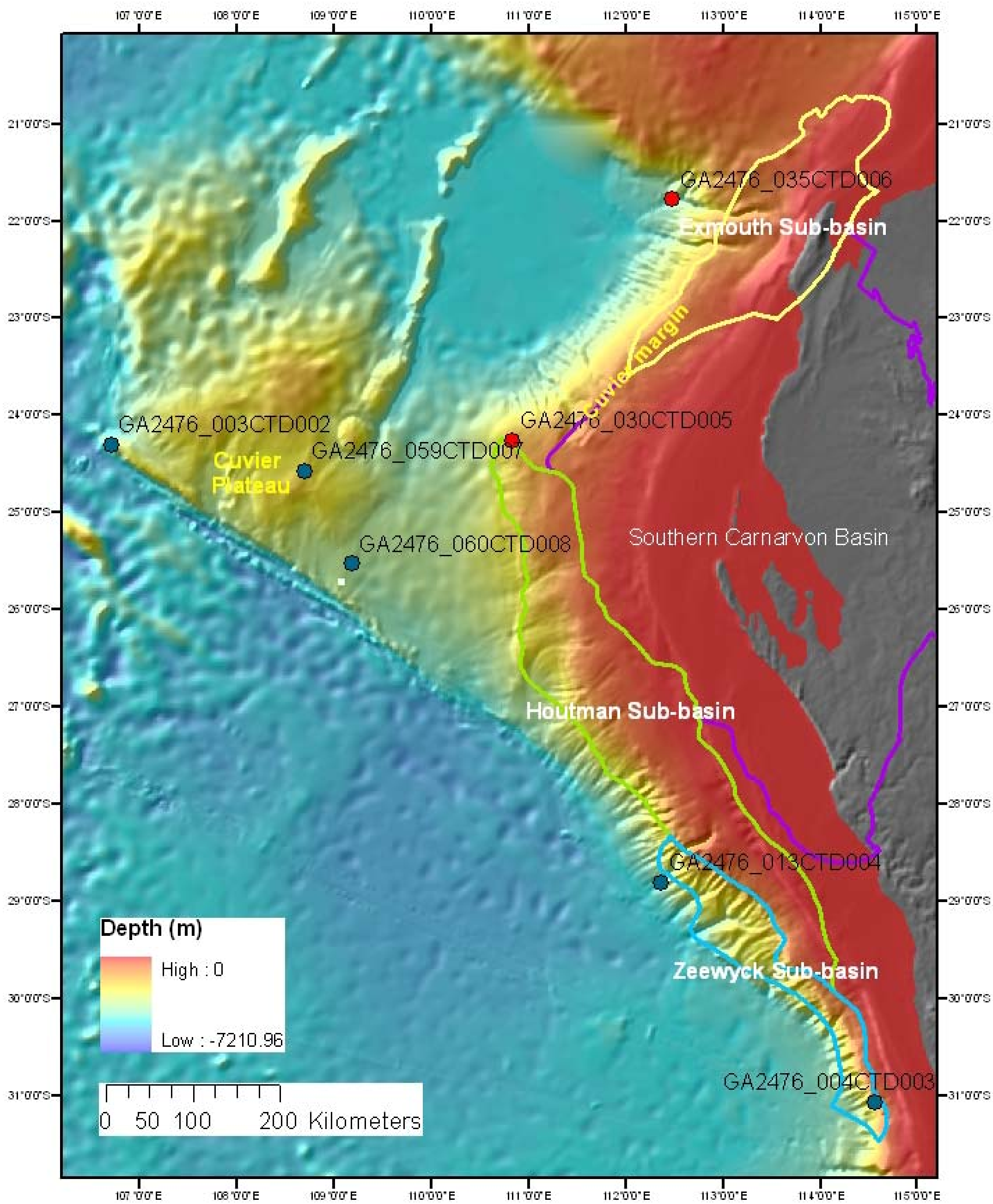



***Figure 7.2.*** *Location of CTD deployments over the west Australian margin. 030CTD005 and 035CTD006 (red dots) were processed for dissolved* $N_2$ *and* $O_2$.

elements in CaCO3 equilibria, and were not measured in this study. In the case of chemical inhibitors, phosphate is a product of organic matter breakdown, and is known to inhibit CaCO3 precipitation. The main point to be made concerning the TCO2 fluxes is that they cannot be used to infer the reactivity of organic matter in the sediments on the west Australian margin. To offset the potential interference caused by CaCO3 precipitation (or dissolution) on the benthic TCO2 flux, it would be advisable to measure pH and/or alkalinity contemporaneously with the TCO2 so that the separate influence of calcium carbonate equilibria can be directly quantified.

TOU shows more promise as an indicator of organic matter break down for the purposes of this study. In Figure 7.3, TOU from the west Australian margin is compared to a TOU dataset comprising 242 in situ observations compiled from over an extensive geographic range by Glud (2008). Ex situ observations from the studies of Glud et al. (1999) and Wenzhofer and Glud (2002) and from the Tangaroa survey of the Faust and Capel basins (Heap et al., 2009) are also included for comparison. It is well known, and evident in the data presented in Figure 7.3, that O2 uptake rates measured in the laboratory are generally higher than those measured in situ (Glud et al., 1994). There are many potential explanations for the higher ex situ O2 uptake rates, including the lysis of organisms under decreasing hydrostatic pressures leading to increases in the amount of labile material in the incubation receptacle (Glud et al., 1994). It is noteworthy that the TOU measurements from both the Faust and Capel basins and the west Australian margin are generally higher than those based on the ex situ datasets of Wenzhofer and Glud (2002) and Glud et al. (1999) collected from the central and south Atlantic Ocean and the central Chile up-welling regions, respectively. It is doubtful that these differences are due to higher organic matter fluxes to the sediment in the Australian Economic Exclusive Zone (EEZ) because wind-driven up-welling off central Chile gives rise to some of the highest primary production in the ocean (Fossing et al., 1995 cited in Glud et al., 1999). It is more likely that the higher TOU we observe is due to differences in experiment design. Some differences in experiment design in the Glud et al. (1999) study include: (i) the use of the iodometric Winkler method to determine dissolved oxygen concentrations; and (ii) the regulation of O2 concentrations of incubator waters at constant values using a digital gasmixer. Notwithstanding these potential difficulties in making global comparisons, worthwhile comparisons can be made between the TOU datasets from the west Australian margin and the Faust and Capel basins because they were collected using the same methods. TOU measurements from the west Australian margin (21.4 ± 10.2 mmol m-2 d-1) were about twice as high as those from the Faust and Capel basins (10.1 ± 2.1 mmol m-2 d-1), potentially signifying generally higher organic matter fluxes in the region of the west Australian margin.

**Table 7.3.** Results of the core incubation experiments on cores from box cores and one grab. With one exception (station 20) all experiments are based on sediment cores extracted from box cores. The core from station 20 was taken from a BODO.

| STATION | LOCALITY | LATITUDE | LONGITUDE | DEPTH (M) | DO (MMOL/$M^2$/D) | $CO_2$ (MMOL/$M^2$/D) |
|---|---|---|---|---|---|---|
| 006 | Houtman Canyon, Houtman Sub-basin | -28.3641 | 112.8804 | 1,200 | -21.5 | 29.7 |
| 020 | Zeewyck Sub-basin | -30.4543 | 114.1769 | 3,680 | -24.5 | 35.2 |
| 022 | Zeewyck Sub-basin | -30.9441 | 114.4500 | 2,355 | -21.4 | 19.5 |
| 023 | Zeewyck Sub-basin | -30.9612 | 114.2605 | 3,794 | -43.7 | -7.3 |
| 048 | Houtman Sub-basin | -26.5438 | 111.5020 | 1,525 | -9.7 | -17.9 |
| 054 | Cuvier Plateau | -24.6358 | 107.7552 | 3,467 | -12.9 | -22.4 |
| 059 | Cuvier Plateau | -24.5733 | 108.6956 | 2,608 | -19.6 | -11.1 |
| 060 | Cuvier Plateau | -25.5197 | 109.1815 | 3,828 | -18.1 | -10.3 |

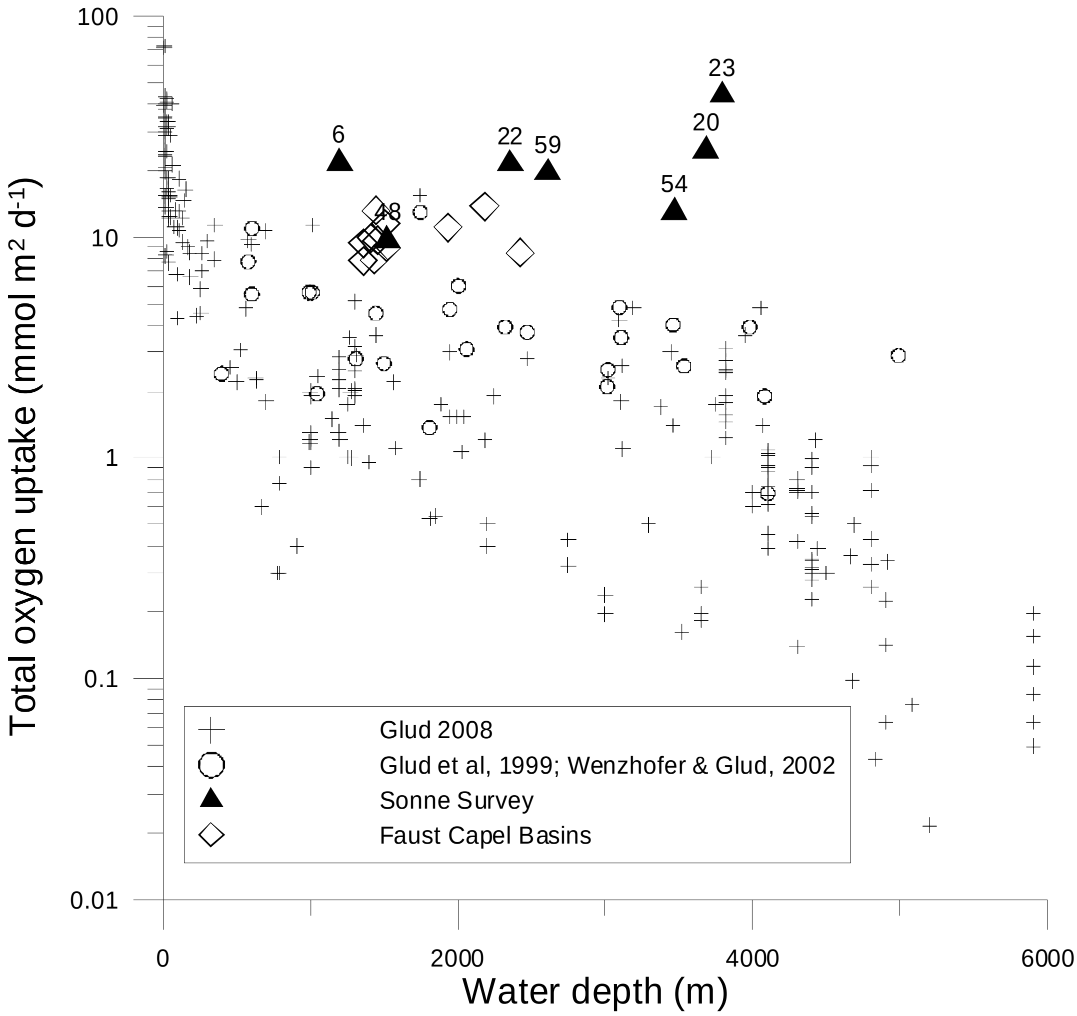



***Figure 7.3.*** *TOU versus water depth for data collected during GA2476, the Capel and Faust basins survey (TAN0713) and from published datasets of Glud et al. (1999), Wenzhofer and Glud (2002) and Glud (2008).*

### 7.3.2. Water Samples and CTD

The physical and chemical water column profiles from 030CTD005 and 035CTD006 are shown in Figure 7.4. Results of $TCO_2$ and $N_2$ on some bottom water samples are shown in Table 7.4 The influence of the Leeuwin Current at approximately 250 m can be seen in the salinity profiles at both sites. This current may also be responsible for anomalies in the $N_2$ and $O_2$ profiles. At both sites, there is more $N_2$ in the top 400 m than is predicted based on modelled data (calculated from dissolved gas ratios based on known temperature and salinity). The variance between measured and predicted $N_2$ is largest at a depth of 600 m at 030CTD005. The $O_2$ profiles from both sites are quite similar in that they increase from the surface to a depth of 400 – 600 m, before decreasing to their lowest concentrations at approximately 1,200 m. The $O_2$ maxima at around 400 m may be associated with the nitrogen fixing bacteria.

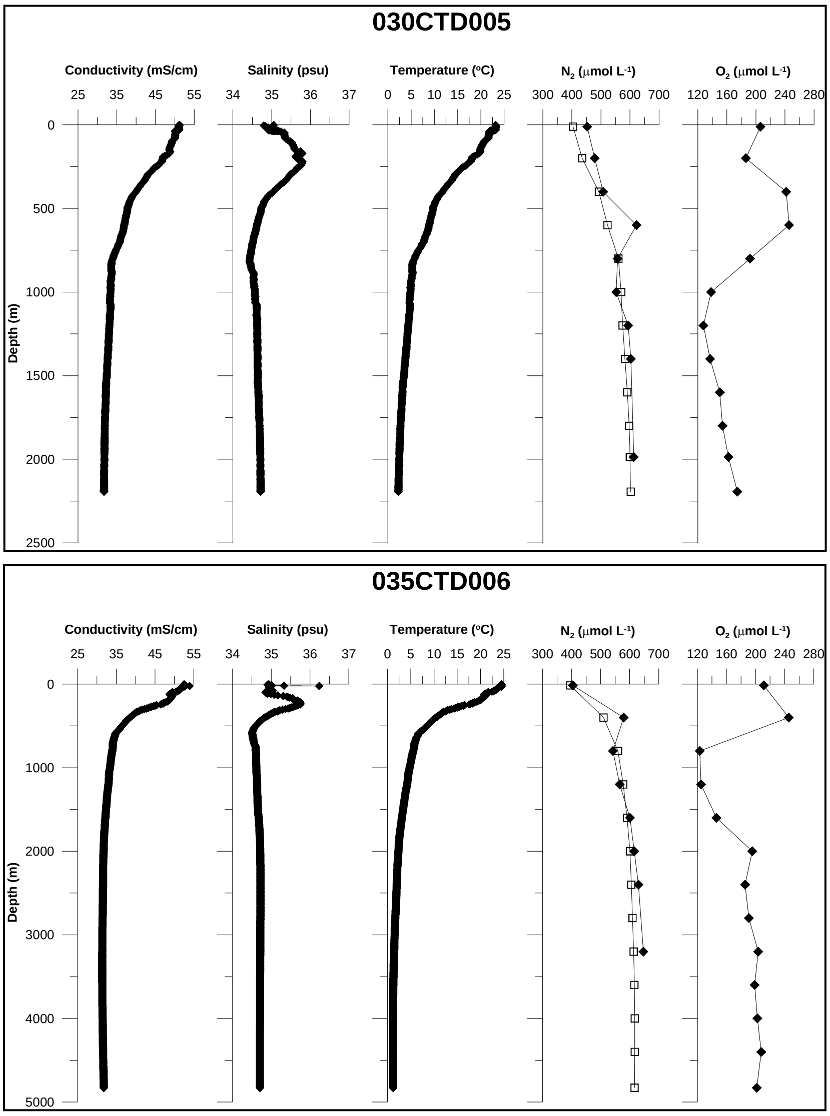



***Figure 7.4.*** *Water column profiles from CTDs: A) 030CTD005; and B) 035CTD006. The squares in the N2 profile represent modelled concentrations.*

**Table 7.4.** Results of $TCO_2$ and $N_2$ analyses on bottom waters from selected CTD locations.

| Station | Locality | Date | Latitude | Longitude | Water Depth (m) | $TCO_2$ (umol $L^{-1}$) | $N_2$ (umol $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| 001 | Indian Ocean | 25/10/2008 | -8.7553 | 105.0090 | 6,300 | N/A | |
| 003 | Indian Ocean | 29/10/2008 | -24.3038 | 106.7059 | 3,533 | N/A | |
| 004 | Indian Ocean | 31/10/2008 | -31.0665 | 114.5623 | 2,345 | 2,389.9 ± 3.6 | |
| 013 | Houtman Canyon, Zeeywck Sub-basin | 9/11/2008 | -28.8073 | 112.3634 | 4,525 | 2,346.4 ± 3 | 618.4 ± 1.4 |
| 030 | Houtman Sub-basin | 29/11/2008 | -24.2590 | 110.8348 | 2,200 | | 215.85 |
| 035 | Cuvier margin | 4/12/2008 | -21.7757 | 112.4783 | 4,848 | | 304.7 |
| 059 | Cuvier Plateau | 7/1/2009 | -24.5735 | 108.6950 | 2,612 | 2,345.7 ± 2 | |
| 060 | Cuvier Plateau | 9/1/2009 | -25.5225 | 109.1828 | 3,834 | 2,341.3 ± 2.4 | |

### 7.4. SUMMARY

This chapter presents some preliminary results from the biogeochemical analyses of seabed sediments and CTD samples from the Perth margin (Zeewyck and Houtman sub-basins), the Cuvier margin and the Cuvier Plateau. $TCO_2$ fluxes ranged from -22.4 to 35.2 mmol $m^{-2}$ $d^{-1}$ and were not found to be useful for inferring organic matter reactivity due to the confounding influence of $CaCO_3$ precipitation. To offset the potential interference caused by $CaCO_3$ precipitation (or dissolution) on the benthic $TCO_2$ flux, it is recommended that pH and/or alkalinity be measured contemporaneously with the $TCO_2$ in order to quantify the influence of calcium carbonate equilibria. Worthwhile comparisons can be made between the TOU datasets from the west Australian margin and the Faust and Capel basins because they were collected using the same methods. TOU measurements from the west Australian margin (21.4 ± 10.2 mmol $m^{-2}$ $d^{-1}$) were about twice as high as those from the Faust and Capel basins (10.1 ± 2.1 mmol $m^{-2}$ $d^{-1}$), signifying that organic matter fluxes were generally higher in the region of the west Australian margin. Further work is being undertaken to improve our understanding of the geochemistry of these sediments and to establish links with geomorphic, hydrodynamic and biological systems.

# 8. Benthic Ecology

This chapter presents a description of the benthic ecology component of the west Australian margin survey and provided the first observations of deep-water benthic habitats and biota from the west Australian margin, including the Cuvier Plateau survey area. Biological samples and observations were collected from water depths of 641 - 4,827 m. This broad depth range has rarely been surveyed for this purpose within Australia's marine jurisdiction. Consequently, the findings of this survey contribute substantially to our overall knowledge of deep-water (>1,500 m) marine assemblages in Australian waters.

Benthic assemblages were visually characterised from 41 towed-video stations sampled over the extent of the west Australian margin survey area: 21 stations were sampled on the Perth margin (13 stations in the Zeewyck Sub-basin and 8 stations in the Houtman Sub-basin); 12 stations were sampled on the Cuvier margin; and eight stations were sampled in the Cuvier Plateau area (see OFOS Camera and BODO columns in Table 3.2; Fig. 3.1). Seabed characterizations describing substrata, relief, bedform structure and the presence of biota, were recorded from 44 video-transects that covered approximately forty linear km's of the seabed. To describe the fine-scale structure of these deep-sea assemblages, a range of sampling methods were used to collect both epifaunal (animals found on the seabed) and infaunal (animals found in sediments) organisms. Epibenthic organisms were collected in 49 rock dredges and four epibenthic sleds at a total of 42 stations, while infaunal organisms were collected in 28 grabs, eight boxcores and 49 sub-samples of pipe-dredges attached to the rock dredges, at a total of 31 stations (Fig. 3.1, Table 3.2).

## 8.1. BACKGROUND

Few research surveys have been undertaken to examine the deep offshore environments of the west Australian margin and as a result the benthic ecology for these areas was largely unknown. Numerous oil exploration surveys have been undertaken on the upper continental slope and shelf regions of the west Australian margin, but only one of these surveys mentions the biology of the deeper region of the west Australian margin and Cuvier Plateau (Exon, 1979). In 1979, Geoscience Australia undertook a survey (GA0054) onboard the RV Sonne in which rock and sediment samples were collected from the region over depths of 100 to 5,200 m (Table 8.1, Exon, 1979). Although samples were not processed for biology, the survey report includes observational notes on the occurrence of bryozoans, brachiopods, molluscs, ostracods, pelecypods, solitary and colonial corals, crinoids and echinoids from the Exmouth Plateau (Exon, 1979).

More recently, national marine research surveys undertaken off WA, primarily by CSIRO, have focused on the upper continental slope and shelf regions of the west Australia margin in depths generally <1,000 m. However, a survey reported in Williams et al. (2001) sampled down to 1,500 m (Table 8.1). Importantly, even at a national-scale, video observations and biological specimens have rarely been collected from depths >1,500 m. Therefore, although biological samples were not intensively collected during this survey, they now provide some of the first observations and specimens collected from deep (> 1,500 m) offshore environments.

**Table 8.1.** Biological samples collected from previous surveys within the west Australian margin study area. Samples were collected between 1991 and 2005 on the *RV Southern Surveyor* by CSIRO (surveys SS01/91[1], SS07/05[2], and SS10/05[2]) and Geoscience Australia (SS08/05[3]), and on the *RV Sonne* by Geosciences Australia (GA0054[4]).

| SURVEY | YEAR | STATIONS | LATITUDE RANGE | LONGITUDE RANGE | DEPTH RANGE (M) | GEAR TYPE |
|---|---|---|---|---|---|---|
| SS01/91[1] | 1991 | n=95 +56 | 20°-35° S | 111° -115° E | 200-1500 | Demersal trawls (95);<br>* Commercial trawls (56)[1] |
| SS07/05[2] | 2005 | n=65 | 21°-35° S | 112°-118° E | 100-1000 | Video (64), sleds (2),<br>boxcores (2), grabs (107) |
| SS10/05[2] | 2005 | n=74 | 21°-35° S | 112°-118° E | 100-1500 | Trawl (69), sleds (63), grabs (13) |
| SS08/05[3] | 2005 | n=20 | 32°-33° S | 113°-115 °E | 30-2500 | Dredges (12) grabs (3) sleds (3)<br>boxcore (1) still photos (121) |
| GA0054[4] | 1979 | n = 57 | 16°-25° S | 108°-119° E | 100-5200 | Dredges (32), grabs (2)<br>boxcores (24) |

[1]SS01/91 (Williams et al., 1996), * Commercial trawls undertaken by commercial vessels 1989-1991.
[2]SS07/05 and SS10/05 (CSIRO Wealth from Oceans flagship Voyage of Discovery surveys; unpubl. report)
[3]SS08/05 (Heap et al., 2008)
[4]GA0054 (Exon, 1979)

## 8.2. SAMPLE PROCESSING AND ANALYSIS

To determine and describe both the physical structure of the seabed and the associated biota for each habitat type a towed-video transect was undertaken at a large number of stations throughout the survey area. Depending on the composition of the seabed, appropriate sampling gear was then deployed to collect epifaunal and infaunal organisms.

### 8.2.1 Towed-video Transects and Seabed Characterisations

To characterize the physical structure of the seabed and associated biota at each of the 44 towed-video stations, video footage of the seabed was acquired digitally along an approximately 1 hour long transect using the OFOS (video footage and still images) and/or BODO (video footage only) (Fig. 3.1, Table 3.2). A full description of the capabilities of the OFOS and BODO are presented in Section 3.

Real-time characterizations of the seabed were recorded approximately every 30 seconds along each video-transect or more frequently across transition zones (see Anderson et al., 2008). A 15-second moving window (i.e. five seconds prior to and ten seconds following a GPS fix) was used to evaluate and characterize the seabed for each data entry point, referred to as 'locations'. The seabed at each 30-second location was classified using C-BED (Characterisation of the Benthos and Ecological Diversity) a three-tiered characterization scheme of substratum composition, bedform-relief and biota presence described in Anderson et al. (2008) (classification attributes are listed in Appendix H). Substratum composition (i.e. rock, boulders [>25.5cm], cobbles [6.5-25.5 cm], sand and mud) was categorized by primary (>50% cover) and secondary (>20% cover) percent-cover following the protocol of Stein et al. (1992) and Yoklavich et al. (2000). For example, if the seabed comprised >50% sand and >20% mud (i.e. muddy sand) the substratum composition was classified as 'sand-mud' (SM); alternatively, if the seabed comprised >70% mud it was classified as 'mud-mud' (MM). Bedform-relief was defined as either a soft-sediment 'bedform' such as hummocky, sediment ripples, or sediment waves, or by the vertical 'relief' of hard substrata: where relief classes ranged from flat (0 m), slope (0 m relief and 50-80° incline), low (<1 m), moderate (1-3 m), to high relief (>3 m) or rock walls (high-relief with >80° incline). Relief was semi-quantitative (on an ordinal scale) with visual assessment of the seabed aided by the depth and altitude of the OFOS or BODO. Benthic composition was described by recording the presence of benthic macro-organisms identified to coarse taxonomic groups (e.g. starfish, brittlestars, holothurians, crinoids and fish), or broad functional categories (e.g. burrows, tracks and mounds) (Appendix L).

C-BED data entry required a two-person team (i.e. observer and data-enterer) using a rotation of three people, with data-entry for each location taking three to twelve seconds. For each data-entry location, observations were entered in 'GNav Real-time GIS Tracker' software (© Gerry Hatcher, 2002) using a 142 key Cherry programmable keyboard (© 2008 Cherry GmbH: http://www.cherry.de/english/products/keypads.htm). The position of the OFOS and BODO was tracked using IXSEA Posidonia long-range USBL (Ultra Short Baseline) tracking system. During each video-transect, one to two second USBL navigation was logged to two separate computers to provide navigational tracks for all video data. Date and time were also stamped onto each frame of the video footage for all tapes. USBL navigation (UTC date, time, latitude, longitude and depth) was also captured for each data-entry location to provide spatially referenced seabed characterisations. However, during three video-transects (e.g. 006CAM02, 021GR09, 023GR11) transmission of USBL data was intermittent and resulted in some seabed characterizations being recorded with UTC date and time but no latitude, longitude or depth. For these data points, USBL navigation was interpolated along track using the points prior to and after a missing navigation point. For one video-transect (005CAM01) no USBL data was received, consequently, the navigation source was quickly changed to ships navigation (UTC date, time, latitude, longitude) for this deployment. As the video system is towed at some distance behind the ship, all locations within this transect require a lag (or positional offset) to be calculated (lag = estimated distance of the towed-camera system behind the ship - based on cable length, wire angle, and seabed depth). Finally, four video-transects (027GR12, 028GR13,036GR19, 046GR25) were not characterized in real-time due to the complete loss of USBL navigation and GPS time into the field laptop. For these four transects, seabed characterizations were post-processed from video footage and then merged by UTC-date and time with the one to two second USBL navigation files.

Real-time C-BED characterizations were processed following the completion of the survey using a C-BED$_{SAS}$ macro-program (co-written by Dale Roberts and Tara Anderson using Statistic Analysis System, SAS Institute Inc., 2001,) that imported and parsed the variable-length characterization text files, checked and cleaned data entry errors, combined all video transect data, and exported the combined dataset to a MS-Access database (Son2476_Video.mdb) file (see Anderson et al., 2008 for more detailed methods). Video observations initially recorded to DVD (Chapter 3) were also copied to digital hard drives to enable further post-processing and data checking and validation of real-time characterizations against the original seabed footage.

### 8.2.2 Biological Collections

Epibenthic organisms were collected in 49 rock dredges and four epibenthic sleds, at a total of 42 stations (Table 3.2). Infaunal organisms were primarily sampled using 28 BODOs and eight boxcores at a total of 31 stations (Table 3.2). Pipe-dredges, which were attached by chains to both the epibenthic sled and rock dredge (Chapter 3; Fig. 3.3) filled with benthic sediment as they dragged over the seabed and potentially captured infaunal organisms. To examine the biology captured by pipe-dredges, the sediments collected from 40 stations were sub-sampled for infauna. Offshore zooplankton were also sampled from surface waters during Leg 3 of the survey. A full description of the methodological deployment of each gear type is presented in Chapter 3.

Upon completion of Leg 1 of the survey, all biological specimens were cleared through customs and transported to Geoscience Australia. The remaining biological specimens, collected during Legs 2 and 3, were transported to Geoscience Australia following the completion of the survey and held in Quarantine-approved premises – awaiting customs inspection. At the time of writing, all specimens preserved in ethanol and formalin had been released from Quarantine, while frozen material (e.g. sponge material) had not.

#### *Epifaunal Collections*

All biological material collected in the epibenthic sleds was carefully removed, sorted into taxonomically similar groups, photographed and then preserved based on CSIRO and Museum of Victoria requirements – 70% ethanol (most specimens), four percent formalin (e.g. polychaete worms), or frozen (e.g. sponges) (Appendix I). Taxonomically similar groups were then stored together (e.g. cnidarians, echinoderms, crustaceans, molluscs, etc.) in 20 L containers for storage and transport.

#### *Infaunal Collections*

Although numerous boxcores were attempted throughout the survey, extreme sampling depths and the logistical difficulty required to maintain the ship's position over the equipment during deployment meant that very few boxcores were successfully deployed. Consequently, only eight boxcores from seven stations were sampled. These included four boxcores at three stations on the Perth margin associated with the Zeewyck Sub-basin and one boxcore associated with the Houtman Sub-Basin; no boxcores on Cuvier margin; and three boxcores from the Cuvier Plateau area (Table 3.2). In conjunction with the boxcores, a total 28 BODO samples (12 BODO samples from 10 stations associated with the Zeewyck Sub-basin and four BODO samples associated with the Houtman Sub-Basin of the Perth margin; 10 BODO samples on the Cuvier margin; and two BODO samples in the Cuvier Plateau) area were successfully collected during the survey (Table 3.2). The BODO was more successful at collecting sediments in these depths due to its real-time video capability that enabled a more accurately timed release of the grab mechanism. Pipe-dredged sediments from the rock dredges were also sub-sampled for infauna.

*Boxcores*: For each boxcore, the elutriate from each of the three boxcore layers (supernatant, surface sediments, bottom sediments) was carefully sorted in the laboratory under a dissection microscope (6.3x magnification). Similarly, for the three stations where finer sieve sizes were used (054BC006, 059BC007, 060BC008), the elutriate from the 300 μm-sieved surface sediments and the 100 μm-sieved supernatants were also carefully sorted under a dissection microscope (20x magnification). All organisms found were recorded by boxcore station, boxcore layer and sieve-size and identified to the highest taxonomic resolution possible, photographed and preserved as part of the biological voucher collection. Specimens that could not be identified in the laboratory were sent to taxonomic specialists for identification. Due to the inability to differentiate recently living versus remnant specimens, shells, pteropods and foraminifera were not recorded.

Taxa from supernatant, surface and bottom sediments were combined for each boxcore to calculate two diversity indices: 1) species richness (i.e. number of species); and 2) abundance of key taxonomic groups (polychaetes and other worms, crustaceans, molluscs). Species richness was calculated conservatively such that biological signs that may represent a species were excluded (e.g. worm tubes, urchin spines, coral rubble, shell fragments). Although they were not able to be identified to phyla, several organisms were considered to be too different from other taxa to be included in species richness calculations. Worms were a key taxonomic group, but their abundance was possibly underestimated in four boxcores (006BC002, 022BC003, 023BC004, 060BC008) due to the difficulty in separating and counting the masses of interwoven worm tubes collected at these sites.

*BODO*: Each vertical section from the grab was passed through a 500 μm sieve, transferred to a barcode-labelled container, photographed and stored in preservatives as listed in Appendix I.

Pipe-dredges: The sieved sample from the pipe dredge was photographed, transferred to a barcode-labelled container and preserved in 70% ethanol, with the exception of macro-organisms which were removed, photographed and stored in preservatives as listed in Appendix I.

### *Zooplankton Collections (Leg 3 only)*

Zooplankton were examined onboard under a stereo microscope (6.3 – 50x magnification), and motile specimens were recorded. Samples were then fixed in four percent formalin for at least five days prior to preservation in 70% ethanol. Preserved specimens will be examined in the laboratory to determine proportion of animals intact, species richness and taxa (class and morphospecies). Due to the rolling of the ship, accurate volumes of surface water through the net were unable to be calculated, and comparisons between deckwater and surface sampling were standardized by using only proportional data.

## 8.3. RESULTS

### 8.3.1. Towed-video Transects and Seabed Characterisations

Forty-four video-transects from 41 stations were surveyed across the west Australian margin survey area. These included 16 video-transects from 13 stations within the Zeewick Sub-basin and eight video-transects from eight stations in the Houtman Sub-basin of the Perth margin; 12 video-transects from 12 stations in the Cuvier margin; and eight video-transects from eight stations in the Cuvier Plateau area (Table 3.2). A total of 49 hours of video footage, and 3,175 still photographs were collected during the three-month survey, and, collectively provide the first observations of deep-water (>1,500 m) benthic habitats on the west Australian margin.

A total of 4,184 seabed characterizations were recorded from 44 video transects, across a depth range of 641-4,827 m for the entire survey. These comprised 1,225 characterizations from the Zeewyck Sub-basin (854 - 4,811 m) and 937 characterizations from Houtman Sub-basin (depth range 968 – 3,260 m) of the Perth margin; 1,029 characterizations from Cuvier margin (641 - 4,827 m); and 993 characterizations from Cuvier Plateau area (1,685 - 4,581 m). Four video-transects (027GR12, 028GR13, 036GR19, 046GR25) were not characterized due to the loss of USBL navigation and GPS time into GNav.

The seabed across the entire survey area was comprised of homogeneous mud (63%), mixtures of rock and mud (24%), or homogeneous rock (13%), with only rare occurrences of sand, cobbles or boulders (<1%). In areas of homogeneous mud, seabed relief was flat (89% of all locations) or sloping (5%), with occasional occurrences of low (3%) or higher relief (<2%) outcrops. Conversely, in areas of homogeneous rock, seabed relief was characterized by rock walls (41%) or high (20%) to moderate (20%) relief outcrops, with few occurrences of low (6%) and flat (4%) relief areas. Rock outcrops were generally associated with volcanic cones, seamounts, plateau margins, steep canyon walls, or were at the base of canyons. In areas of mixed substrata, seabed relief was highly variable and included most relief types: moderate (27%) low (23%), and high (15%) relief areas, rock walls (11%), and flat or sloping ground (8% and 14%, respectively).

Deep-sea habitats along the west Australian margin survey area were extremely depauperate of biota (i.e. very few organisms recorded) with few visible organisms found either on mud or rocky substrata. Mud habitats, while extensive across the study areas, supported surprisingly few visible organisms. The most common signs of life in these habitats were bioturbation marks made by deposit-feeding infauna (Appendices L; Fig. 8.1, 8.2). Bioturbation marks were observed at almost all camera and BODO stations (93% of all stations, Fig. 8.2), but with only low to moderate incidence along transects (37% of all locations: tracks [25%], burrows [16%] and mounds [2%]). A common bioturbator in deep-sea sediments is the acorn worm (Hemicordata: Enteropneusta), which makes characteristic spiral and meandering trails (e.g. Fig. 8.2g). Acorn worms and their trails were patchily distributed across the study area (34% of all OFOS and BODO stations) (Appendices L), with most recorded between 2000-3000 m water depth (mean depth 2,432 m ± 7.6 SE, depth range 1,515-4,811 m). Motile species, typically shrimps/prawns and fishes, were ubiquitous throughout the survey area (89% and 82% of all stations respectively, Fig. 8.3), but were sparsely distributed (7% and 6% of all locations respectively) and were never abundant. In contrast to shrimp/prawns and fishes, jellyfish occurred less frequently (41% of all OFOS and BODO stations, 1.5% of all locations (mean of 1, range 0-14% per station)) (Appendices L).

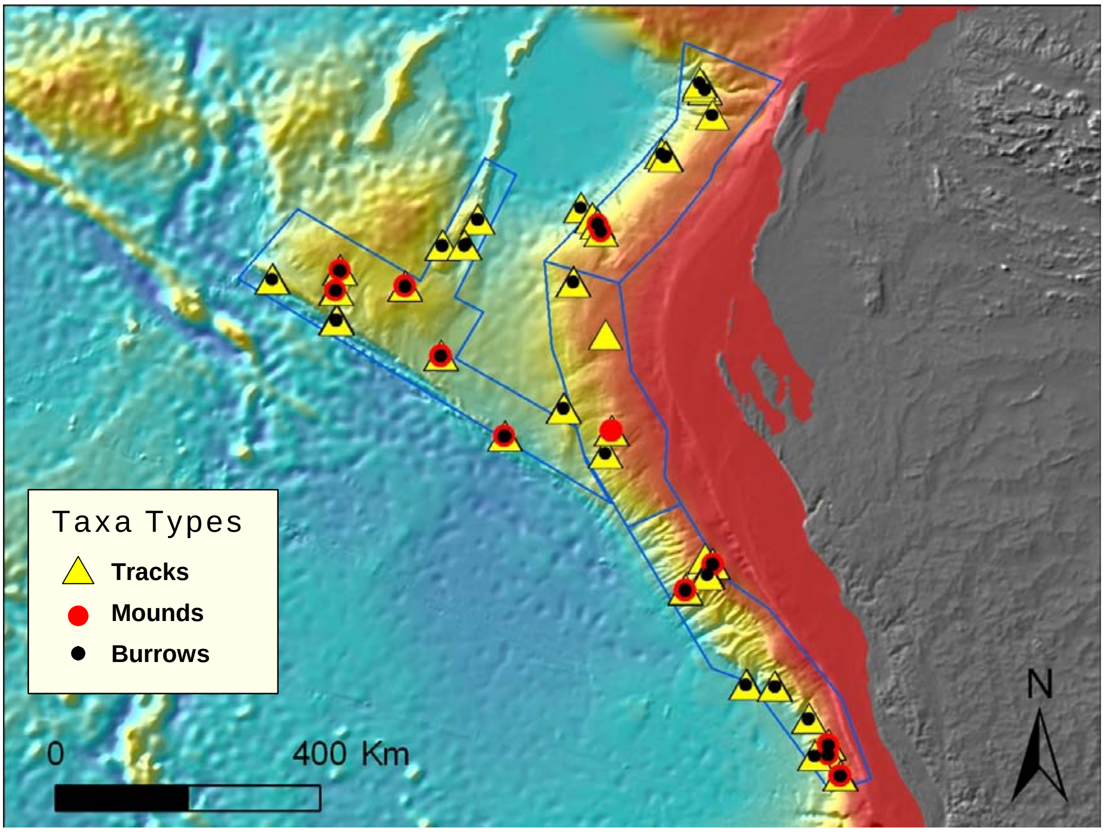



***Figure 8.1.*** *Presence of bioturbation marks (tracks, mounds and burrows) recorded per OFOS and BODO station from seabed video characterizations of the west Australian margin survey area.*

Deposit feeding holothurians (sea cucumbers) were one of the few organisms regularly observed throughout the west Australian margin survey area (Fig. 8.4, 8.5) on both mud and rock habitats. Although holothurians were ubiquitous throughout the survey area (86% of all OFOS/BODO stations; Fig. 8.4) and had locally high occurrences at some OFOS/BODO stations (e.g. 76% occurrence at 043CAM05), overall they were sparsely distributed (12% of all within-transect locations). Several types of holothurians were identified from video and still photographs (e.g. Fig. 8.5). Herds of a small pink elasipodid sea cucumbers (or sea piglets, Family: Elpidiidae) were recorded locally in high densities (up to nine individuals in a single still photograph) at the head of the Houtman Canyon (006CAM02, 1,886 – 1,975 m depth; Fig. 8.2g) and sporadically at other stations (e.g. 044CAM06, Fig. 8.5a). Elpidiidae feed on phytodetritus, with some species (Amperima roasea) known to colonize large areas quickly, possibly in response to ocean surface phytoplankton blooms (Wigham et al., 2003). The most unusual holothurians recorded during the survey were deep-sea swimming cucumbers (Family: Pelagothuriidae), found swimming immediately above the seabed at three stations (006CAM02, 047CAM08, and 057CAM13) (Fig. 8.5c,d). Usually sea cucumbers rest and feed on the seafloor, but a few species are able to swim for extended periods using mobile sail-like fins (Fig. 8.5b,c). No holothurians were captured during benthic sampling, so finer species-level identifications were not possible.

Hard substrata in the deep sea is often colonised by a variety of suspension feeders such as corals, sponges, gorgonians, hydroids and crinoids. Rocky habitats were moderately common in the west Australian margin survey area (37% of all OFOS/BODO locations), but these habitats were conspicuously barren or supported only a few suspension feeders (Appendices L; Fig. 8.6). Although suspension-feeders occurred in 75% of all stations (Fig. 8.7), they were very sparsely distributed (8% of all OFOS/BODO locations). The most frequently recorded suspension-feeders were cnidaria (e.g. corals, gorgonians and hydroids) found in 73% of all OFOS/BODO stations, but only in 7% of all locations. Higher occurrences of cnidarians were recorded along the upper slope margins, particularly around the three stations associated with volcanic pinnacles, while cnidarians were rare or absent on the Cuvier Plateau (Fig. 8.8). Similarly, sponges and crinoids were recorded in 43% and 30% of all OFOS/BODO stations (Appendices L), but were only recorded in 1% and 1.5% of all locations, respectively.

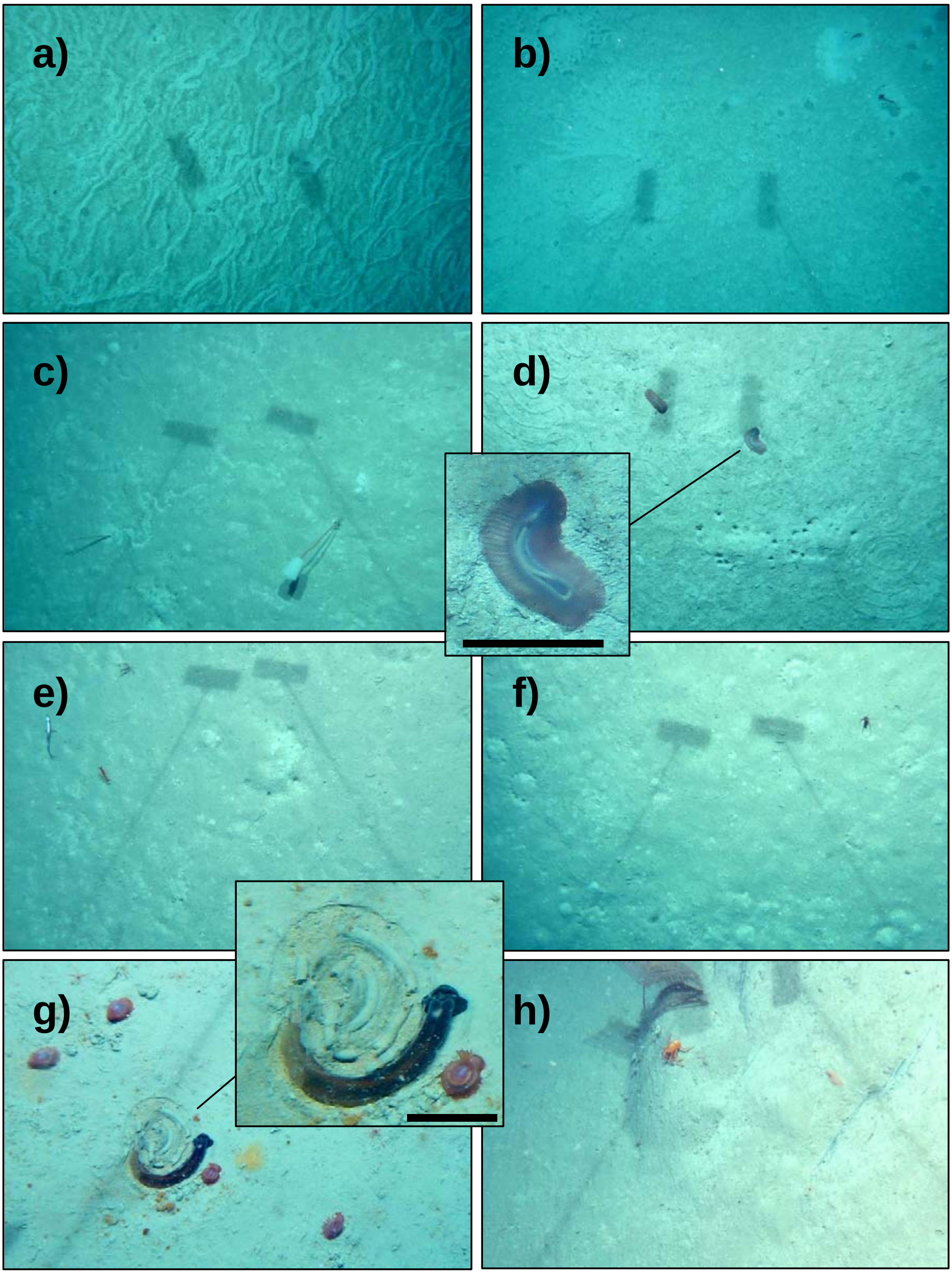



***Figure 8.2.*** *Still colour photographs of soft sediment habitats from the west Australian margin survey area collected during survey GA2476. a) Cuvier Plateau (051CAM11) 3,514 m – bioturbated sediments inundated with tracks, b) Cuvier margin (048CAM09) 1,514 m – bioturbated sediments with polychaete worm tracks, mounds,and burrows, c) Houtman Canyon (006CAM02) 1,819 m – bioturbated sediments with gorgonian whip and tulip-shaped glass sponge, d) Cuvier margin (047CAM08) 2,892 m–- bioturbated sediments with acorn worm tracks, burrows and two sea cucumbers (insert: sea cucumber enlarged), e) Houtman Canyon (006CAM02) 1,200 m – sediment with burrows, fish and shrimp, f) Houtman Canyon (006CAM02) 1,210m – bioturbated sediments with starburst tracks and bristleworm, g) Houtman Canyon (006CAM02) 1,969 m – sediments with  four Holothurian piglets and an acorn worm (insert: acorn worm and a piglet enlarged), h) Houtman Canyon (006CAM02) 1,954 m – sediment veneer over rock slope with hydroid and Galathaid lobster. Scale bar ˜10 cm.*

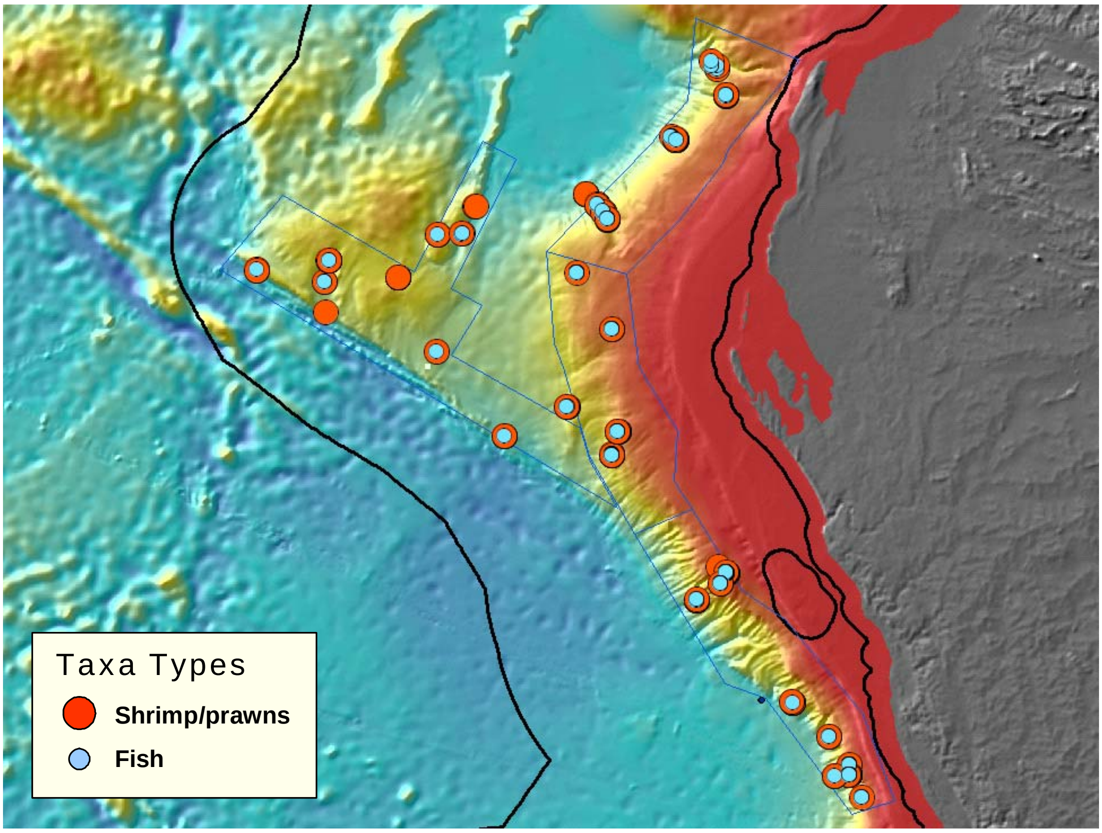



***Figure 8.3.*** *Presence of shrimp/prawns and fish recorded per OFOS/BODO station from seabed video characterizations of the west Australian margin survey area.*

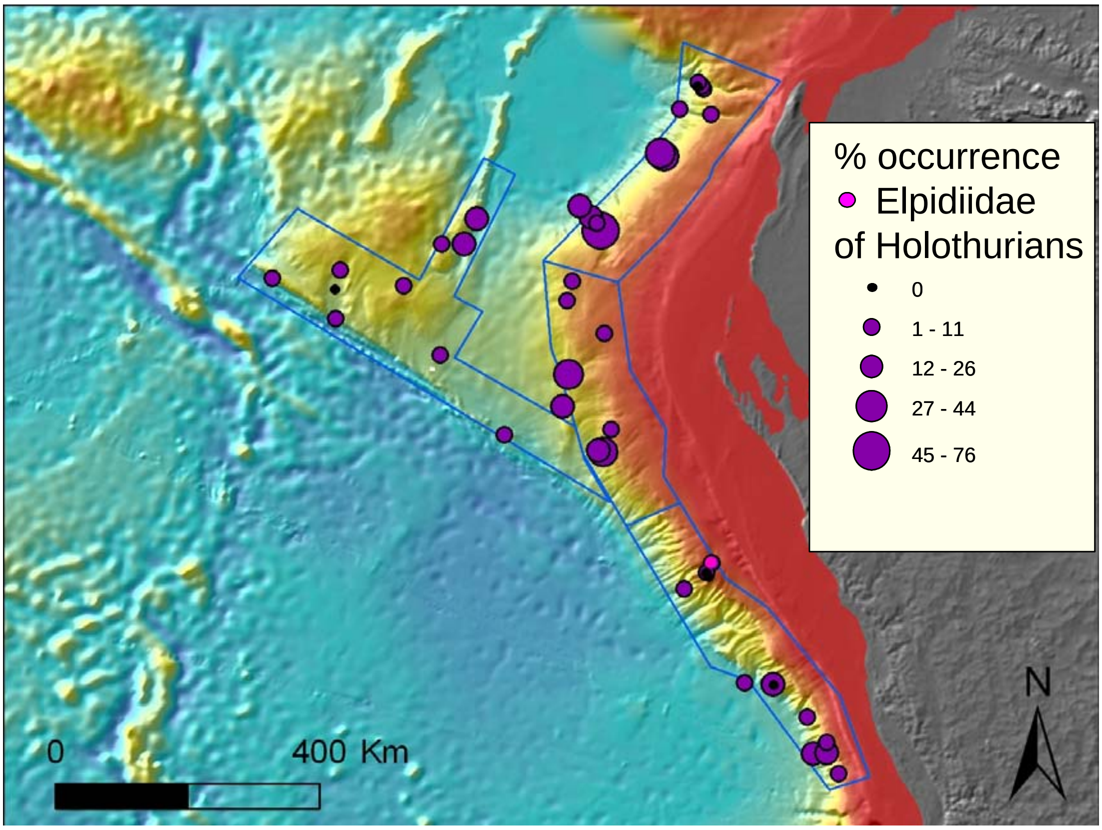



***Figure 8.4.*** *Presence and percent occurrence of holothurians recorded from seabed video characterizations of the west Australian margin survey area. Holothurians (in purple) are plotted as percentage occurrence within each OFOS/BODO station (values from Appendices L), Elipiidae (sea piglets) are plotted as presence per OFOS/BODO station.*

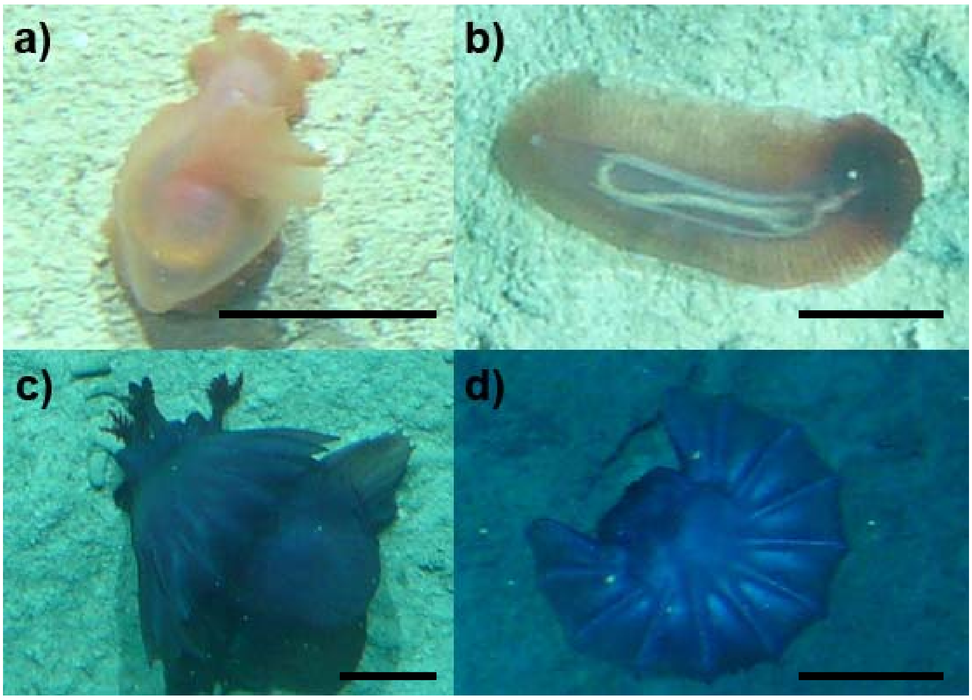



***Figure 8.5.*** *Holothurians were the most widespread taxa on video and photographs, representing numerous species and body shapes: a) sea piglet (Family: Elpidiidae) (044CAM06, 1,144 m), b) sea cucumber (Order: Elasipoda) (043CAM05, 3,034 m), c) swimming pelagothuriid with feeding tentacles extended (047CAM08, 2,609 m), and d) swimming pelagothuriid in water column immediately above the substratum (047CAM08, 2,696 m). Scale bars ~ 5 cm.*

Locally high occurrences of suspension-feeders were recorded on the three volcanic pinnacles that were surveyed (Fig 5.9; Appendix K). For example, suspension-feeders occurred at 38% of OFOS/BODO locations on the volcanic pinnacle located over the north Houtman Sub-basin(044CAM06). The seabed on this pinnacle was dominated by moderate to high relief (26% high, 55% moderate, 11% low and 5% flat relief) rocky habitat (81% rock, 16% sand and 3% mud) at depths of 968-1,145 m. Rocky areas here were characterized by often high-density patches of gorgonians (33% living and rubble combined), with crinoids (33%), echinoids (34%), soft corals (18%) and brittlestars (1%) (Appendix L; Fig. 8.9f,g).

The two volcanic pinnacles located immediately south of the Houtman Canyon (009CAM03, 009CAM01, 009CAM02, 011CAM03) were also characterized by suspension-feeders, which occurred at 75% of all locations (range of 36-100%) (Appendix L). The northwestern volcanic pinnacle was characterized by low-lying rock outcrops (Substrata: 69% rock, 29% mud, 1.5% boulders and sand 0.5%; relief: 66% flat, 24% low, 9% moderate and 1% high relief) at depths of 854-1,028 m, and finally, the southeastern volcanic pinnacle was characterized by mixed mud and rock habitats (66% mud and 33% rock) of low to moderate relief (66% low and 33% moderate relief), although only a small depth range was sampled (881-889 m). Although both volcanic pinnacles were characterized by large amounts of dead coral rubble (19-100% of locations) that densely covered the seabed (Fig. 8.9a), these habitats also supported living organisms from a range of taxa, including echinoids (≤29%), crinoids (≤21%), sponges (≤10%), gorgonians (≤7%) and brittlestars (≤2%) (Appendix L; Fig. 8.9b,f), as well as worms (recorded from BODO sediment samples). The physical BODO sample from the northwestern volcanic pinnacle (009GR01) collected large volumes of sediment littered with dead coral fragments and lots of dead molluscs, including gastropod and slipper limpet shells (Fig. 8.9c, e). Similarly, the physical BODO sample from the southeastern volcanic pinnacle (011GR03) collected sediments littered with dead coral fragments and rocks, with mollusc shells and living brittlestars (Fig. 8.9d,f). Dead coral fragments appear to represent a combination of long dead Solenosmilia variabilis, Desmophyllum dianthus and bamboo corals, although identification of these are yet to verified. Fragments were also retained for carbon dating to determine how old these remnant coral areas might be.

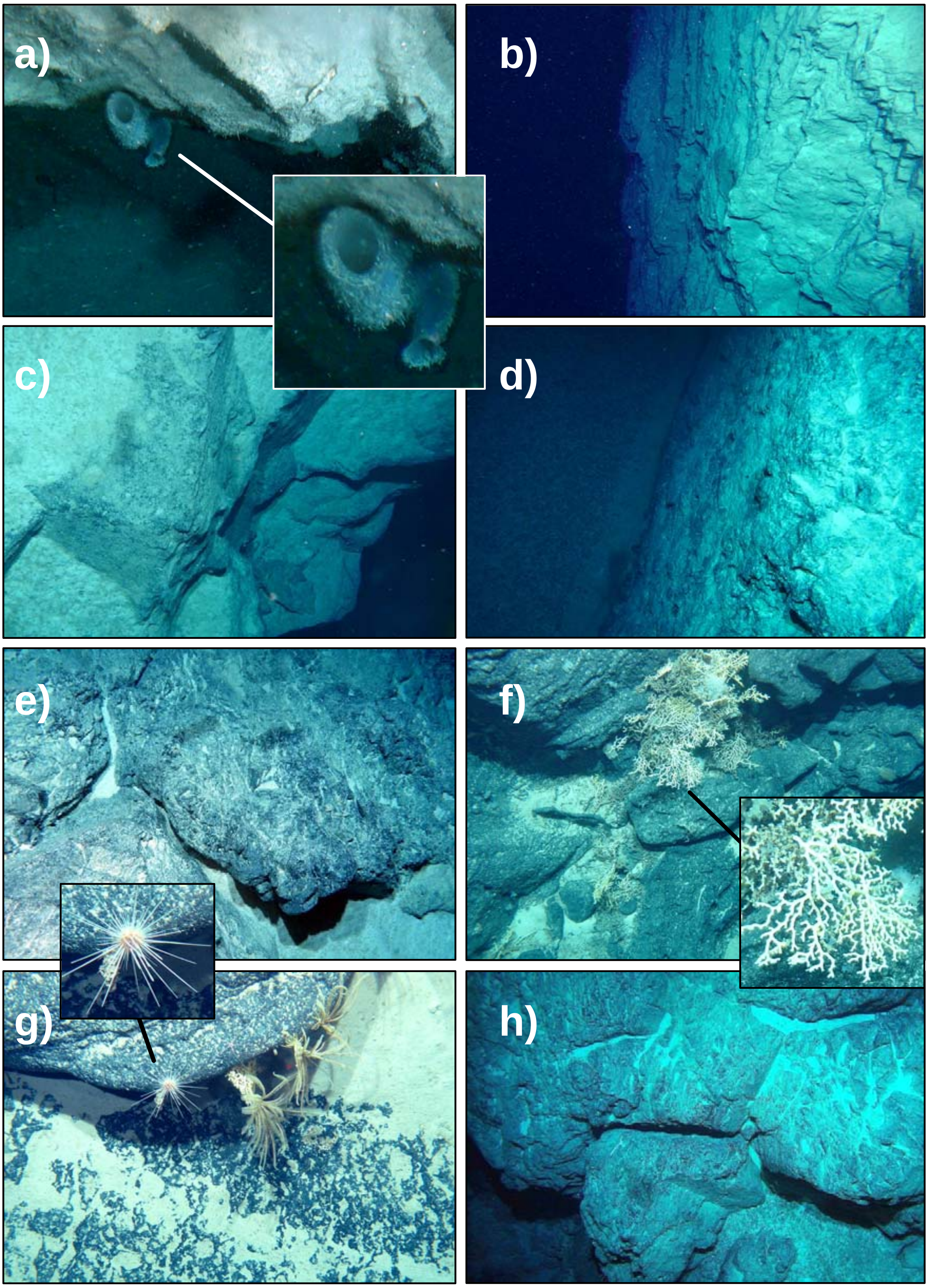



***Figure 8.6.*** *Still colour photographs of rocky outcrop habitats from the west Australian margin survey area collected during survey GA2476. a) Upper Houtman Canyon (006CAM02) 1,942 m – sedimentary rock with two vase sponges (Insert: sponges enlarged), b) Upper Houtman Canyon (006CAM02) 1,281 m – sedimentary rock exposed on canyon wall, c) Lower Houtman Canyon (005CAM01) ~3,700 m – sedimentary rock (conglomerate) exposed on-canyon wall, d) Cuvier Plateau (050CAM10) 4,041 m – sedimentary rock exposed on escarpment, e) Cuvier Plateau (051CAM11) 2,601 m – volcanic outcropping devoid of biota, f) volcanic peak in north Houtman Sub-basin (044CAM06) 970 m – volcanic outcrop with gorgonians, g) volcanic peak in north Houtman Sub-basin (044CAM06) 1,134 m – volcanic outcrop with urchin (Insert: urchin enlarged), crinoids and brittlestar, h) Cuvier Plateau (051CAM11) 3,410 m – volcanic outcropping devoid of biota.*

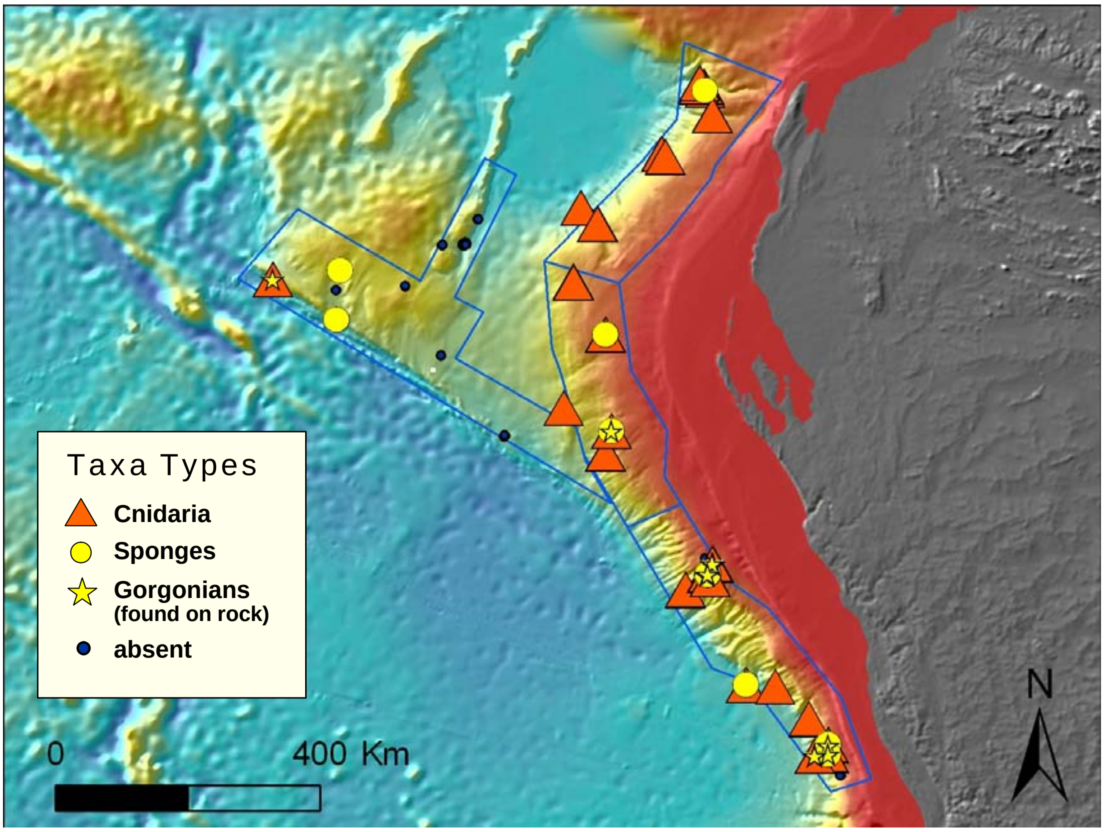



***Figure 8.7.*** *Presence of suspension-feeding organisms recorded per OFOS/BODO station from seabed video characterizations of the west Australian margin survey area.*

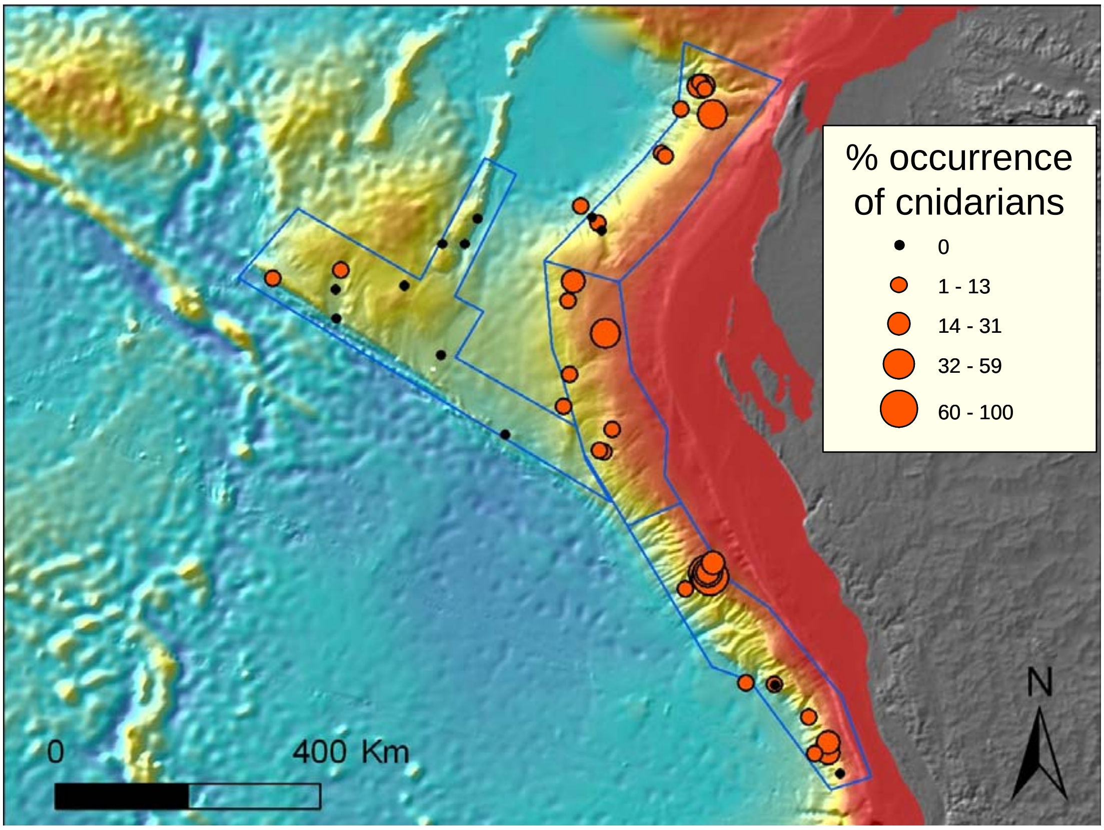



***Figure 8.8.*** *Percent occurrence of cnidarians recorded within each OFOS/BODO station from seabed video characterizations of the west Australian margin survey area (values from Appendices L).*

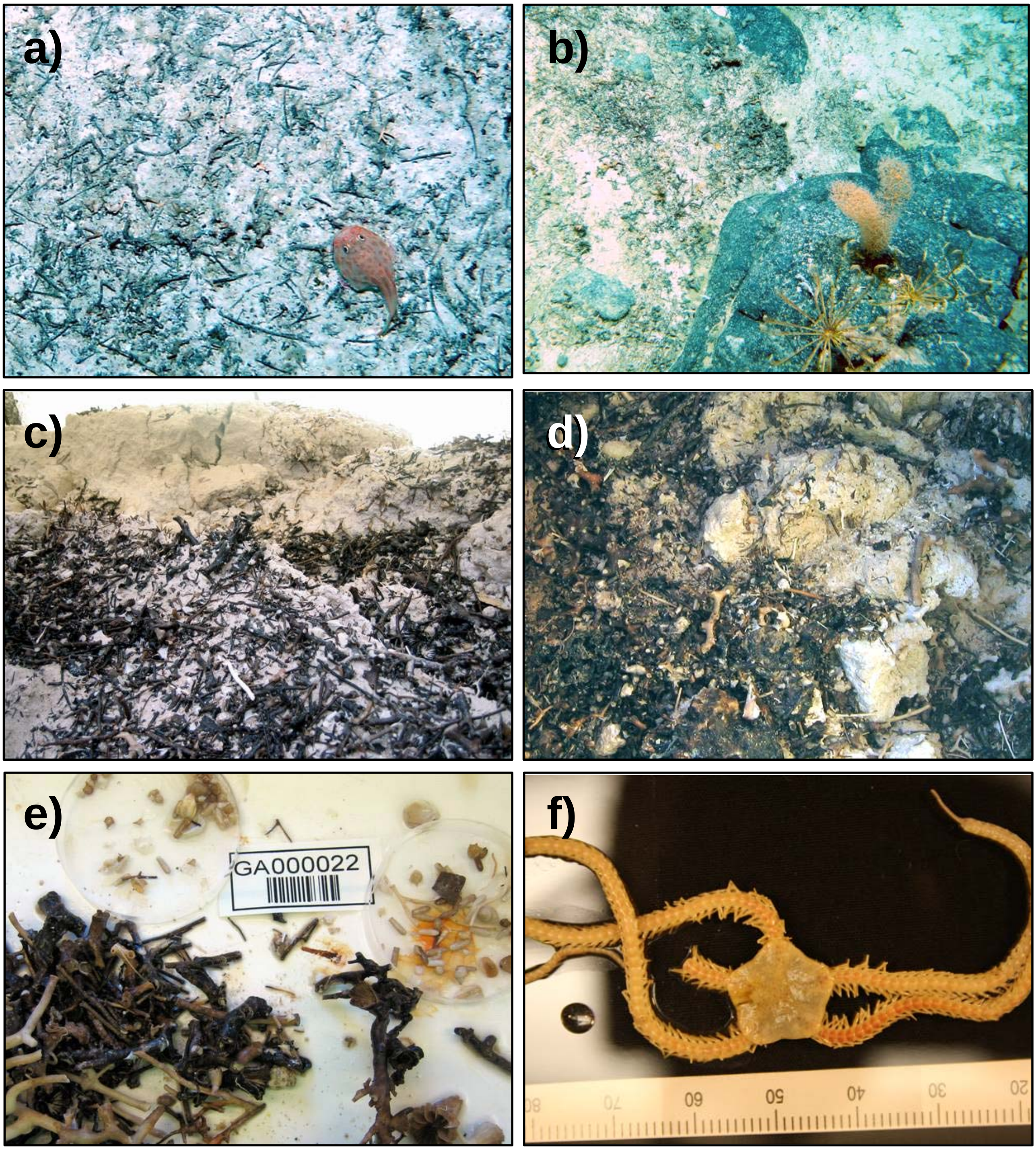



***Figure 8.9.*** *Still colour photographs of seabed habitats and associated physical BODO samples collected from the two volcanic peaks immediately south of the Houtman Canyon. a) northwest volcanic peak (station 9) ~856 m – flat-relief soft-sediments with coral rubble and frogmouth fish (Family Chaunacidae: Chaunax sp.), b) northwest volcanic peak (station 9) ~953 m rock outcrop with crinoid and hydroid, adjacent to sediment with coral rubble, c) surface view of TVgrab sediments collected from northwest volcanic peak (station 9) 910 m – sediment mixed with dead coral fragments, d) surface view of TVgrab sediments collected from Hardy Pinnacle (station 11) 906 m – sediment mixed with dead coral fragments, e) dead coral fragments, tube cases and mollusc shells collected from northwest volcanic peak (009GR01); f) brittlestar (Ophioplax lamellosa) collected from lower Houtman Canyon (011GR03).*

At the other end of the scale, rocky substrata on the Cuvier Plateau, although relatively common (21%: range 0-51%), showed little sign of life and contained very few suspension feeders (0.2% of all Cuvier Plateau locations; three out of the ten OFOS/BODO stations; and only 1-3% of locations within these three stations) (Appendix L; Fig. 8.6d,e,h). The only signs of life that occurred regularly on the Cuvier Plateau were bioturbation marks (51% of all Cuvier Plateau locations: burrows [37%], tracks [26%: e.g. Fig. 8.6a] and mounds [2%]); deposit-feeding sea cucumbers (7%), and sparsely distributed shrimp/prawns (6%), jellyfish (1.5%) and fish (1.2%) (Appendix L).

### 8.3.2 Biological Collections

***Epifaunal Collections***

Very few epifaunal specimens were collected from the seabed during survey GA2476. The few specimens collected in the epibenthic sleds and rock dredges included bamboo corals, goose barnacles, a gorgonian, hydroids, brittlestars, small sponges, cnidarian fragments, a galatheid lobster, a gastropod and polychaetes. Many of these taxonomic groups were collected only once during the survey. Other sampling equipment returned the occasional epibenthic specimen, including an anemone from a pipe dredge, and brachiopods and gorgonians from the BODO.

*Echinoderms*: Seven echinoderm species were collected during the survey, and all but one of these were ophiuroids (brittlestars) (Table 8.2). Although the number of echinoderms collected was very low, Ophiomyxa sp. seems to be an undescribed species (Fig. 8.10a), while Amphioplus (Unioplus) may be a new species (T. O'Hara, pers. comm.) (Fig. 8.10b). In addition, Ophioplinthaca plicata was collected deeper than previously recorded for this species (T. O'Hara, pers. comm.) (Fig. 8.10c).

**Table 8.2.** Echinoderms collected on GA2476, identified by Dr Tim O'Hara, Museum of Victoria (MoV). Only one specimen was collected for each species. Parentheses indicate the identification number previously assigned to matching unnamed specimens at the Museum of Victoria.

| STATION | DEPTH (M) | GEAR | CLASS | MOV REGISTRATION # | SPECIES |
|---|---|---|---|---|---|
| 11 | 888 | BODO Grab | Ophiuroidea | F165947 | *Ophiomyxa* sp (5486) |
| 11 | 888 | BODO Grab | Ophiuroidea | F165948 | *Ophioplax lamellosa* |
| 21 | 2380 | BODO Grab | Ophiuroidea | F165949 | *Amphioplus (Unioplus)* |
| 25 | 1700 | Rock Dredge | Ophiuroidea | F165950 | *Ophiomusium lymani* |
| 37 | 2732 | Rock Dredge | Ophiuroidea | F165951 | *Ophioplinthaca plicata* |
| 38 | 3808 | BODO Grab | Echinoidea | - | Heart urchin |
| 48 | 1626 | Boxcore | Ophiuroidea | F165952 | *Amphiura* |

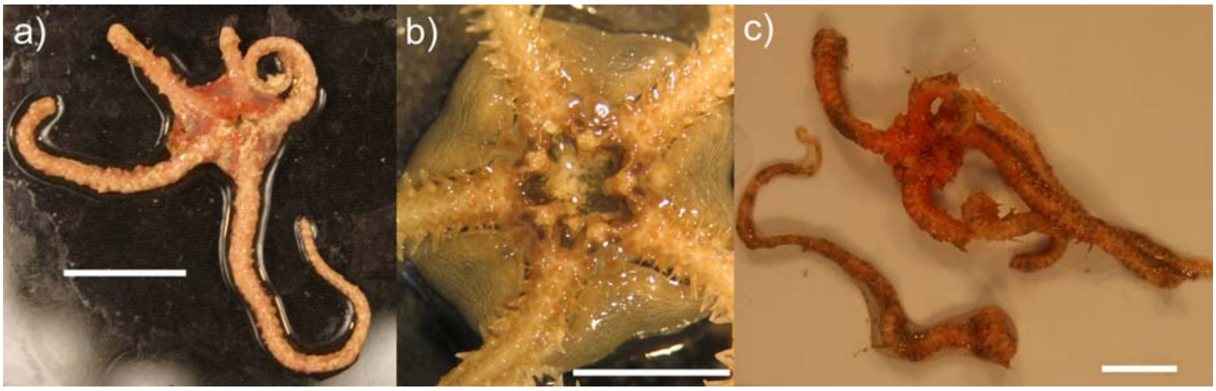



***Figure 8.10.*** *Echinoderms found in epifaunal samples from survey GA2476: a) Ophiomyxa sp. from 888 m, b) close-up of Amphioplus (Uniplus) from 2,380 m, and c) Ophioplnkthaca plicata from 2,732 m. Scale bars for a) and c) is 1 cm. Scale bar for b) is 0.5 cm.*

***Infaunal Collections***

During sample collection and elutriation all macro-organism observed were removed and preserved separately of the remaining elutriate. At the time of writing this report, only boxcore elutriate samples had been fully sorted. BODO elutriate samples are expected to be sorted and analysed in late 2009 in the manner presented below for boxcores. Here, we present the information on the specimens removed during shipboard elutriation for all types of sampling equipment, and for those specimens collected from boxcore samples.

*Polychaetes and Other Worms (removed during ship-board elutriation):* A total of 61 worm specimens were collected during shipboard elutriation for survey GA2476. These worms were identified to phylum (non-polychaetes) or family (polychaetes) by Robin Wilson at the Museum of Victoria (Appendix J). Ten specimens were only collected as fragments but were able to be identified to family and so are included in these results. Worms were represented by two phyla, Polychaeta and Sipuncula (Fig. 8.11). During the survey, 30 specimens were collected from BODO; 17 specimens were collected from rock or pipe dredges; and 14 specimens were collected from boxcores (Appendix J).

Infaunal worms removed during shipboard sorting included polychaetes (Fig. 8.11) and sipunculans, encompassing 17 families and 55 specimens (Appendix J). All polychaetes were represented by single specimens, with the exception of two ampharetids from 006BC02, two siboglinids from 029GR14, two spionids from 018GR06, two serpulids from 055BS04, and four serpulids from 033DR30. Cirratulidae was the most widely distributed and abundant polychaete family, occurring at eight stations (056GR28, 055GR27, 054BC06, 036GR19, 033GR17, 031DR28, 024DR25, 021GR09) (Figure 8.11b; Appendix J). Importantly, some of these specimens represent the deepest records in Australian waters for their respective families (R. Wilson, pers. comm.).

*Siboglinids*: Of potential interest to petroleum exploration is the presence of siboglinids, a family of polychaetes sometimes referred to as 'seep worms'. Siboglinids are generally long (up to 75 cm) and very thin (~ 1 mm diameter) and occur buried in sediment in association with cold seeps from a range of sources, including hydrothermal vents, and decomposition of whale carcasses (Lösekann et al., 2008). Siboglinid worms have previously been collected from depths between 400 and 3,820 m in Australian waters, with most samples recorded from eastern Australian waters (Fig. 8.12, Appendix G). Prior to this survey, siboglinids were known from only three locations in western Australian waters (1,440 – 1,660 m) (Fig.8.12, Appendix G). From the survey GA2476 samples sorted so far, siboglinids ('seep worms') have been identified from four locations: 049DR042 at 1,939 m, 029GR014 at 1,966 m, 022BC003 at 2,808 m, and 033DR030 at 3,820 m (Figure 8.11c). In addition, two empty siboglinid tubes were collected from 006BC02 at 1,200 m. Importantly, 033DR030 (3,820 m depth) represents the deepest location at which siboglinids have been collected in Australian waters to date (Appendix G).

*Taxonomic Groups*: The most widespread taxonomic groups found in the boxcore samples were worms (7.1 ± 4.8 species and 13.0 ± 7.8 individuals per boxcore, mean ± stdev) and crustaceans (2.3 ± 1.8 species and 3.4 ± 2.8 individuals per boxcore , mean ± stdev) (Fig. 8.13). These were found in all boxcores, although worms were generally more abundant and species-rich. Molluscs (006BC02, 022BC03, 048BC05), glass sponges (006BC02, 023BC04, 048BC05, 054BC06, 060BC08) and an echinoderm (048BC05) were also collected in boxcores (Fig. 8.14).

*Species Richness*: The number of species varied greatly among boxcore stations, with between three to 30 species recorded in each boxcore (supernatant, and top and bottom sediment layers combined). Surprisingly, the highest and lowest number of species were recorded from two boxcores collected approximately two km apart (006BC001 at 1,982 m; and 006BC002 at 1,200 m) (Fig. 8.15), indicating high variability at the scale of hundreds of metres. These two boxcores were collected on the upper flanks of the Houtman Canyon, and high levels of physical and biological heterogeneity and biodiversity are known to occur in canyon habitats. Furthermore, boxcore 006BC001 was filled with rust flakes and unknown diaphanous material and had an extremely low abundance of forams compared to all other boxcores samples. The low species richness observed in this boxcore may be due to associated anomalous geochemistry or sediment quality. Excluding this boxcore from the south Houtman Sub-basin part of the Perth margin, the Cuvier Plateau (054BC006, 059BC007 and 060BC008) had the lowest species richness (Fig. 8.15).


***Figure 8.11.*** *Worms found in samples from the survey GA2476: a) sipunculan from 1,966 m at b) cirratulid polychaete from 3,163 m at 055GR027; c) sibliognid polychaete tubes from 3,820 m at 033DR30; d) Paraprionospio sp. (spionid polychaete) from 2,732 m at 033DR030; and e) onuphid polychaete from 1,626 m at boxcore 048BC005. Scale bars are all 1 mm.*

Comparisons between supernatant, surface and deep sediments, identified that most species were found in the supernatant and top 5 cm of sediment (Fig. 8.16a). However, in the anomalous boxcore (006BC001), which contained rust flakes and diaphanous material, most species inhabited the bottom sediment layer (Fig. 8.16a). Specifically, several long, thin, white worms were detected in the bottom sediment layers of this boxcore. Similar worms were also detected in the bottom layer of boxcore 022BC003 implying that the deeper sediments at these stations had some special characteristics that facilitated these deeper burrowing animals. In contrast, no animals at all were detected in the bottom sediment layers from the Cuvier Plateau boxcores (054BC006, 059BC007 and 060BC008) (Fig. 8.16b). Grain size analyses in combination with geochemistry results may provide some insight into these patterns. Geochemical analyses may also shed some light on the anomalous rust-coloured sediments from boxcore 006BC001 and why infauna from this boxcore were mostly recorded in the deep (> 5 cm) sediment layer.

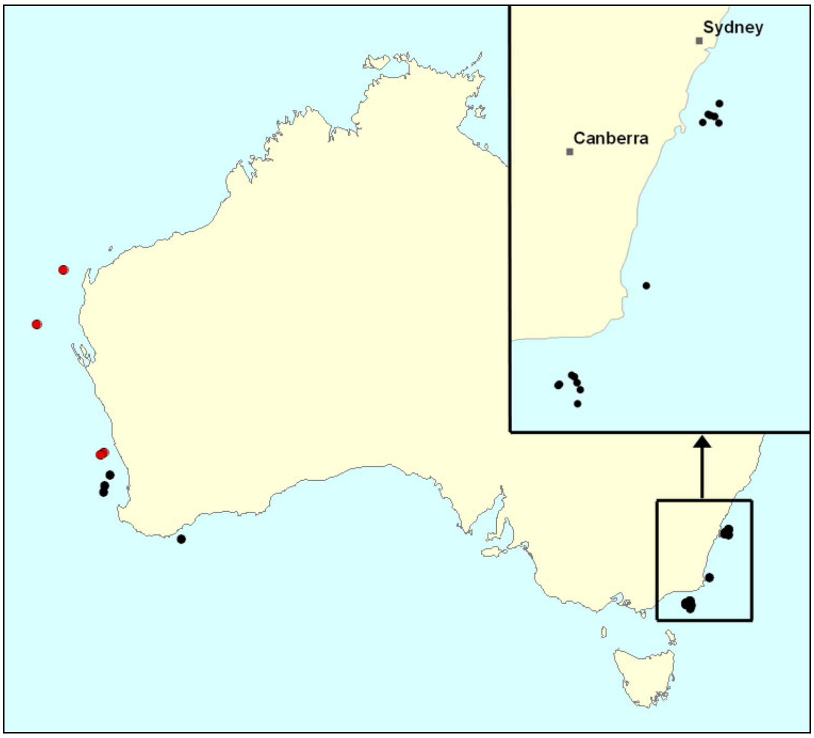



***Figure 8.12.*** *Locations of siboglinids collected from Australian waters. Black dots represent specimens from the Museum of Victoria collections (see Appendix G for specimen details). Red dots indicate specimens collected during survey GA2476.*

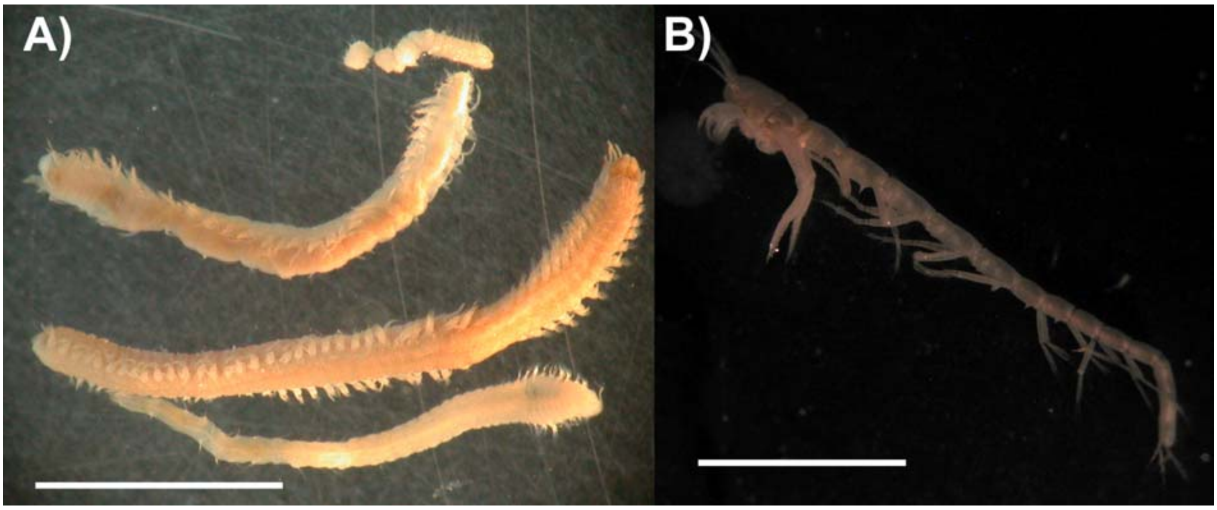



***Figure 8.13.*** *Two taxonomic groups were found in boxcores from all boxcore stations: A) Polychaetes and other worms (specimens shown here from 023BC04 were tentatively identified as eunicid and paranoid polychaetes); and B) crustaceans (specimen shown here from 060BC08 was identified as a tanaid). Scale bars are A) 500 µm and B) 1 cm.*

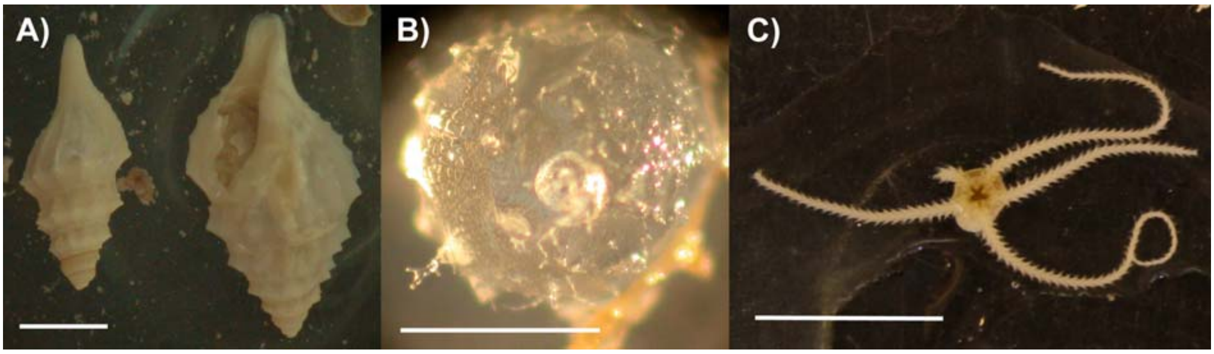



***Figure 8.14.*** *Other taxa recovered from boxcores: A) Molluscs (gastropods shown here from 006BC02); B) Glass sponges (specimen shown here from 023BC04); and C) an echinoderm (juvenile Amphiura sp. shown here from 048BC05). Scale bars are 200 µm for A and B and 1 cm for C.*

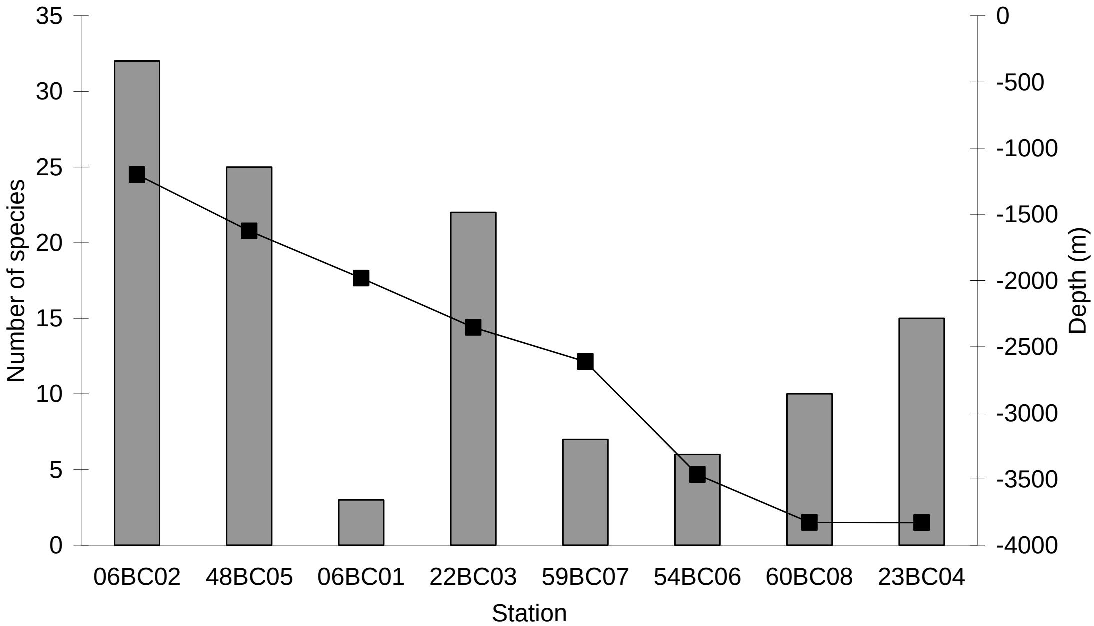



***Figure 8.15.*** *Number of species recovered from boxcores (combined supernatant and top and bottom sediment layers) and sieved through a 500 µm sieve. Grey-shaded bars represent species richness at each boxcore, while the line represents bathymetric depth with progressively deeper stations.*

For the three boxcores where the finer 300 µm and 100 µm sieves were used, the number of species recorded increased by 200% (from three to six species at boxcore 054BC012), 71% (from seven to 12 species at boxcore 059BC007), and 60% (from ten to 16 species at boxcore 060BC008), although total species richness at these boxcores was low so detection of a single additional species greatly affected these values. Worms, crustaceans and small glass sponges were collected from the top layers of sediment sieved through 300 µm sieve mesh size, as well as several unidentified taxa. The two species collected from the supernatant sieved through 100 µm sieve mesh size have not yet been identified. Using the finer 300 µm sieve mesh size required approximately four times longer to sort than the samples sieved through the 500 µm sieve mesh size so available time to sort samples must be taken into account if finer-sieve sizes are to be used in the future.

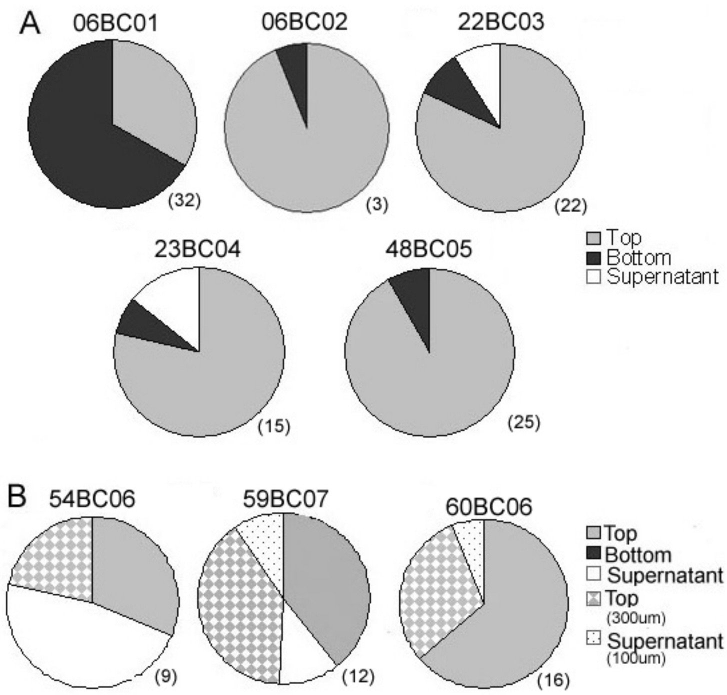



***Figure 8.16.*** *Percentage of species in different layers from boxcores: A) Samples from boxcores that were sieved with the 500 µm sieve mesh size ; and B) Samples from boxcores that were sieved with the 500 µm sieve mesh size as well as an additional 300 µm sieve mesh size for top sediment layer and a 100 µm sieve mesh size for the supernatant. Boxcores are listed above each pie chart. Total number of species for a boxcore is shown in parentheses at the lower right of each pie chart. NB: No supernatant was collected from 006BC001.*

*Species/taxa Abundances*: As expected for deep-sea sediment, polychaetes were the dominant taxa found in most boxcores. Sponges were the next most abundant taxa, and accounted for the majority of animals found in boxcores 006BC002 and 023BC004 (Fig. 8.17). There was no relationship between abundance and depth, with the possible exception of molluscs which decreased with increasing depth, due to the absence of molluscs at depths greater than 3,000 m (Fig. 8.17).

***Zooplankton Collections***

Laboratory analysis of zooplankton collected from sub-surface water samples is pending. However, shipboard observations of live copepods indicates that sampling from ship-pumped seawater is an appropriate method to reveal broad patterns in sub-surface zooplankton assemblages. From initial onboard examination, no obvious differences in zooplankton assemblages were recorded between water samples taken directly from the ocean surface and those from ship-pumped seawater. Sample composition was dominated by an unknown y-shaped animal with single 12-tentacled polyps, which may be fragments of colonial cnidarians fouling the ship pipes (Fig. 8.18). Copepods were also prevalent in all surface water samples, although comparative values with other animals have yet to be determined. Higher numbers of live copepods were collected during night sampling than during the day (Fig. 8.19) supporting the well-established fact that many zooplankton species nocturnally migrate to the surface (Lampert, 1989). Lower numbers of benthic organisms from all sampling gear and video transects on the Cuvier Plateau compared with the Perth and Cuvier margins were also mirrored by lower numbers of live copepods from surface water samples above the Cuvier Plateau compared with higher numbers above the Houtman Sub-basin part of the Perth margin (Fig. 8.19). However, higher spatial and temporal sampling intensity is required to examine these potential offshore patterns in zooplankton.

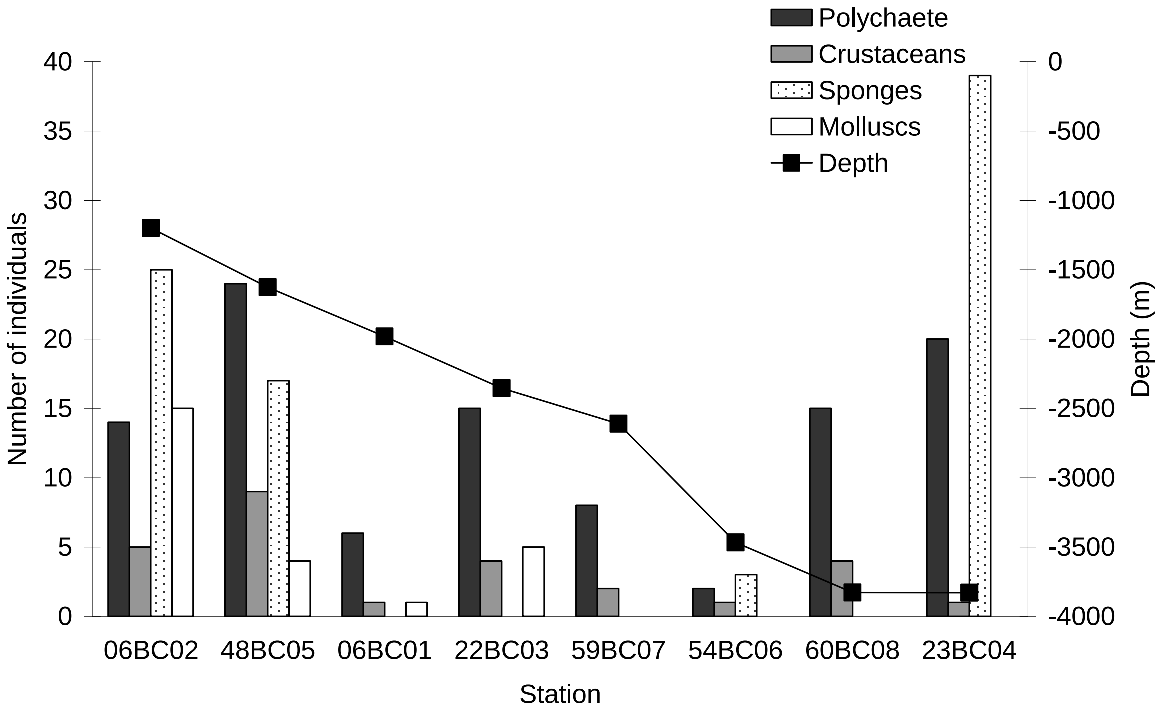



**Figure 8.17.** *Abundance of key taxa in samples from boxcores sieved through the 500 µm sieve mesh size (supernatant, top sediment layer and bottom sediment layer combined). Shaded bars represent key taxa richness at each boxcore, while the line represents bathymetric depth with progressively deeper stations.*

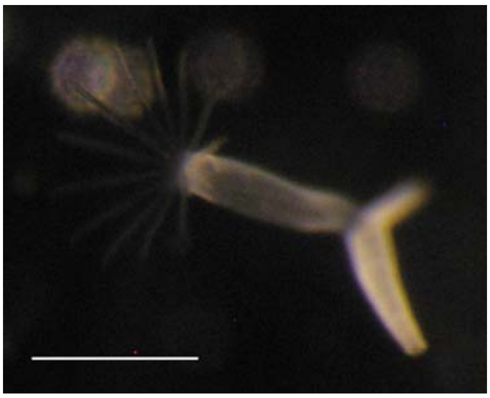


***Figure 8.18.*** *Zooplankton collected above the Cuvier Plateau from sub-surface ship-pumped seawater. The animal was the most abundant species collected, but its identify is unknown. Scale bar is 1 mm.*

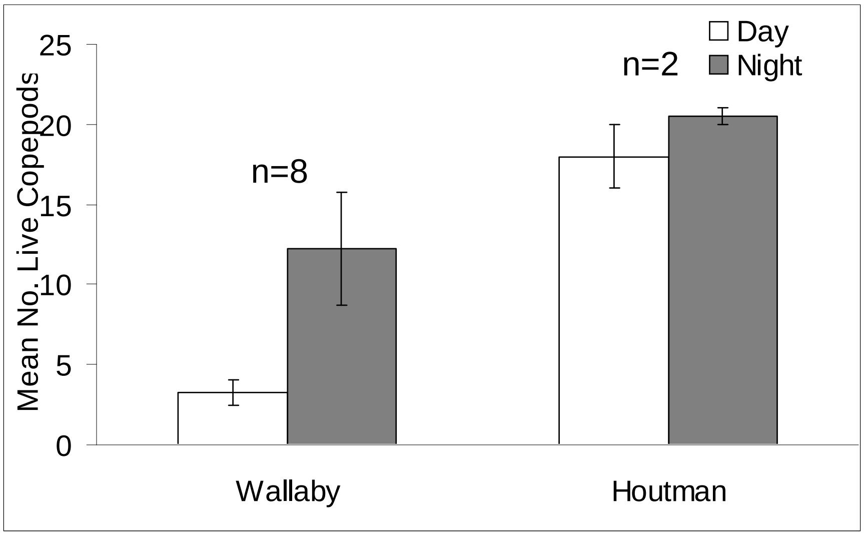



***Figure 8.19.*** *Live copepods collected from Zooplankton sampling of sub-surface waters above the Cuvier Plateau (labelled Wallaby) and the Houtman Sub-basin part of the Perth margin (labelled Houtman) from 11:30 am to12:30 pm (Day – not filled) and 11:30 pm to 12:30 am (Night – filled), Western Standard Time. Error bars are Standard Error Mean (SEM).*

## 8.4. SUMMARY

Few biological surveys have been undertaken in Australian water depths greater than 1,000 m. The biological collections and seabed descriptions for the west Australian margin survey area contribute greatly to our knowledge of Australian deepwater (water depths >1,000 m) environments. The most obvious finding from video characterizations and biological sampling was that seabed habitats across the west Australian margin were depauperate of marine organisms, and that habitats on the Cuvier Plateau area were even more depauperate than those of the inner west Australian margin. The most common signs of life were bioturbation marks (tracks, burrows and mounds) which, although only present in low levels, occurred at almost all OFOS/BODO stations. Deposit-feeding holothurians (sea cucumbers) were the most common taxa observed in OFOS/BODO camera tracks, with occurrences also higher along the inner west Australian margin than on the Cuvier Plateau. The sea piglet holothurian (Family: Elpidiidae) was absent or rare at all OFOS/BODO camera tracks except OFOS 006CAM002. This OFOS track was anomalous from other OFOS/BODO stations as sediments were intensely rust-red in colour, possibly from groundwater discharge. A more detailed examination of the composition of the sediments recovered from this area may in part explain the high numbers of sea piglets observed here. In contrast to deposit-feeders, suspension-feeding organisms, such as corals, sponges and hydroids were extremely rare throughout the survey area, with the exception of the three volcanic pinnacles where occurrences of suspension-feeders were much higher. While live suspension-feeders and other associated organisms were present on these volcanic pinnacles, large amounts of dead coral rubble (volcanic pinnacles immediately south of Houtman Canyon) and gorgonian rubble (volcanic pinnacle over the north Houtman Sub-basin) characterized these habitats. It is unclear how recent these coral rubble fields are, or whether they are relics from a previous time when living corals covered these features. All biological samples contained extremely low numbers and negligible biomass of marine organisms; however, some important specimens were collected. Several new taxa were identified, and several known taxa were collected from greater depths than previously recorded for Australian waters. The biological data collected during survey GA2476 will, as a consequence of these findings, make important contributions to the knowledge of Australia's deepwater (water depths > 1,000 m) environments.

# 9. Oceanography

## 9.1. BACKGROUND

Oceanographic data were obtained from both underway measurements and sample station measurements obtained from shipboard instruments. This chapter provides a description of the instrumentation used. It also provides an overview of the available underway and station data.

## 9.2. DATA PROCESSING AND RESULTS

### 9.2.1 Conductivity-Temperature-Depth Profiles

CTD data were collected from 22 stations (Table 3.5 and 3.11). For the purposes of presenting the CTD data, the survey area has been divided into three regions within which water mass properties are expected to be broadly similar. Region 1 encompasses the Zeewyck Sub-basin and southern Houtman Sub-basin that are associated with the Perth margin (from 31.5°S to 25°S and eastward of 110.2°E). Region 2 encompasses the Cuvier margin (from 25°S to 21°S and eastward of 110.2°). Region 3 encompasses the Wallaby Saddle and Cuvier Plateau (from 27°S to 23°S and west of 110.2°E). The sample stations included in each region are listed in Table 9.1.

**Table 9.1.** List of sample stations included in each region. Locations of the sample stations are shown in Fig. 3.1 and listed in Table 3.5 and 3.11.

| REGION | STATIONS |
|---|---|
| 1 | 4, 5, 6, 9, 13, 44, 45, 47, 48 |
| 2 | 30, 35, 42, 43 |
| 3 | 3, 50, 51, 54, 57, 58, 59, 60, 62 |

***Region 1 (Zeewyck and southern Houtman sub-basins)***

Depth-profiles of water temperature, salinity and density are shown in Fig. 9.1. The entire depth profiles are shown in the left column of the figure, and to clarify any structure of the surface water mass, the first 500 m of the depth profiles are plotted in the right column of the figure. There was a surface mixed layer evident in many of the temperature profiles, which extended from the surface down to between 30 and 80 m depth. Water temperatures within the mixed layer were 19-21.5°C. Beneath the surface mixed layer both a seasonal thermocline and the permanent thermocline were evident. The base of the latter being at about 800 m depth, where the water temperature was reduced to about 5°C. Below the permanent thermocline the water temperature decreased to about 1.2°C at 4595 m depth; the bottom of the deepest profile.

Depth-profiles of salinity showed a maximum at the base of the surface mixed layer (ca. 30-80 m depth) of about 35.8 (Fig. 9.1). Surface salinities were slightly less. Below the surface mixed layer there was a halocline over which salinity decreased to a minimum of about 34.4 at 800 m depth (also the base of the permanent thermocline). Over the remainder of the water column salinity was relatively uniform with depth at 34.7. In the surface water mass (ca. 0-800 m depth), which includes the surface mixed layer and seasonal and permanent thermoclines, the density increased from about 1025 to 1033 kg m-3 due to temperature and to a lesser extent salinity changes with depth (Fig. 9.1). In the deep water mass (ca. >800 m depth), the density increased linearly with depth due to increasing pressure. Density at the base of the deepest profile (ca. 4595) was 1048 kg m-3.

The data from Fig. 9.1 are shown on a temperature-salinity (T-S) plot in Fig. 9.2. Also shown are the extents of water masses previously identified on the southwest margin of west Australia (Table 9.2). Tropical surface water (TSW) was not present in this region, being restricted to latitudes south of 25°S. South Indian central water (SICW), Subantarctic mode water (SAMW) and Antarctic intermediate water (AAIW) were all present in the water column. There was no evidence for Northwest Indian intermediate water (NWIIW). The T-S combinations that did not match any of the water masses listed in Table 9.2, i.e. temperature range of 1 to 5°C and salinity range of 34.4 to 34.7, were possibly degraded Antarctic bottom water (AABW) or North Atlantic deep water (NADW).

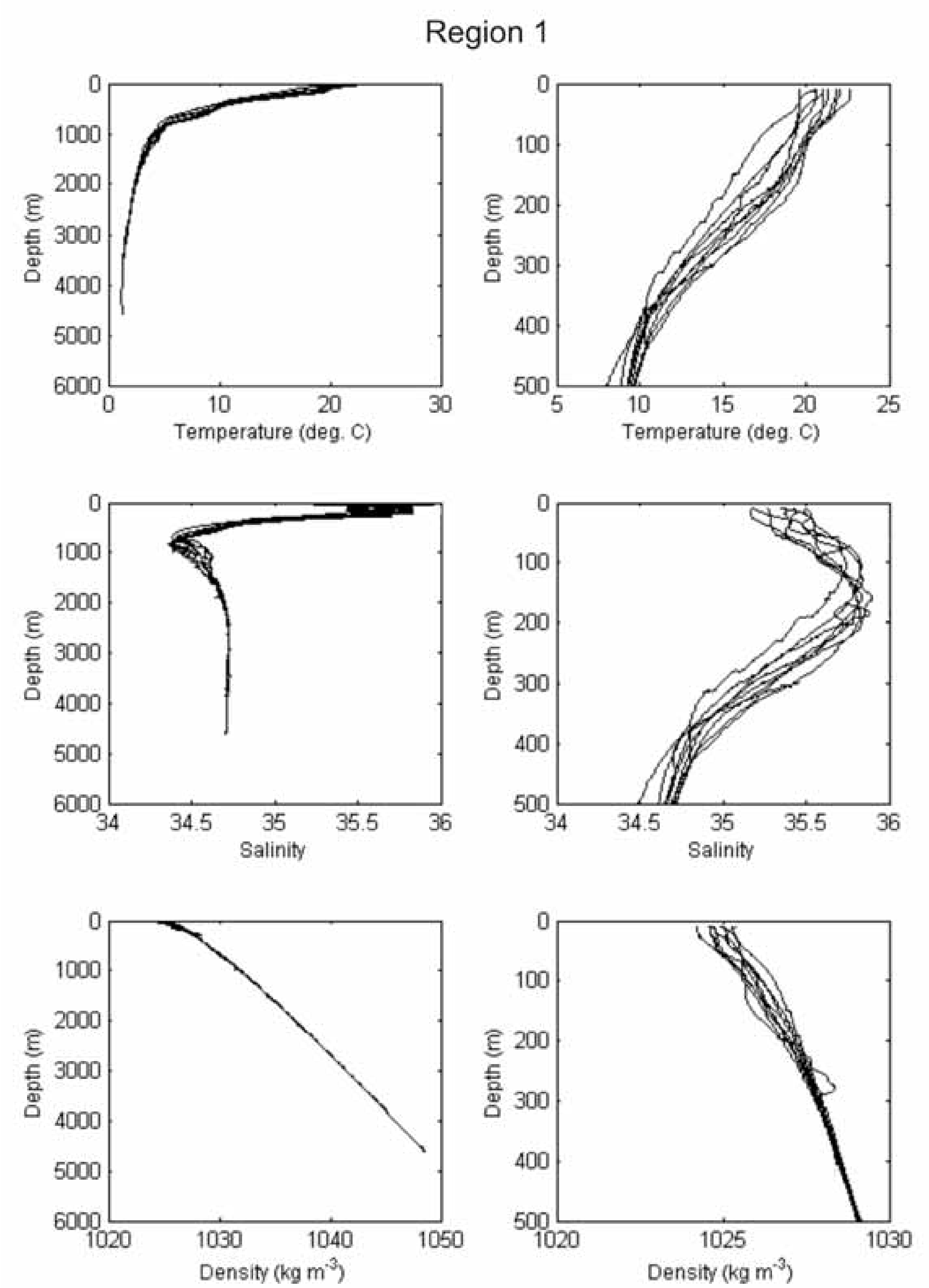



***Figure 9.1.*** *Depth-profiles of water temperature, salinity and density in Region 1 (Zeewyck and southern Houtman sub-basins). The left column shows the full depth-profile and the right column shows detail of the surface 500 m of the water column.*

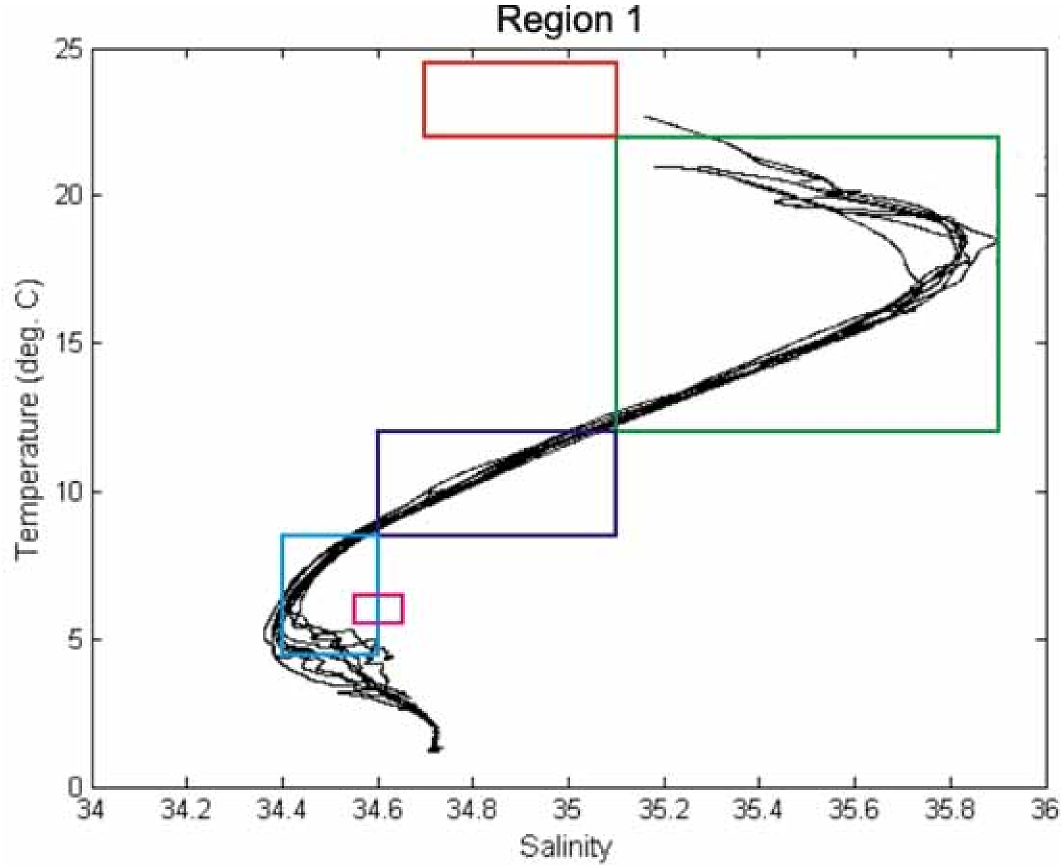



***Figure 9.2.*** *A T-S plot for the depth-profile data from Region 1 (Zeewyck and southern Houtman sub-basins). The coloured boxes show the extents of temperature and salinity for the water masses listed in Table 9.2: TSW (red), SICW (green), SAMW (blue), AAIW (cyan) and NWIIW (magenta).*

**Table 9.2.** List of characteristics for water masses off west Australia (after Woo and Pattiaratchi, 2008).

| WATER MASS | TEMPERATURE RANGE | SALINITY RANGE |
|---|---|---|
| Tropical surface water | 22-24.5 | 34.7-35.1 |
| South Indian central water | 12-22 | 35.1-35.9 |
| Subantarctic mode water | 8.5-12 | 34.6-35.1 |
| Antarctic intermediate water | 4.5-8.5 | 34.4-34.6 |
| Northwest Indian intermediate water | 5.5-6.5 | 34.55-34.65 |

***Region 2 (Cuvier margin)***

The few available profiles in Region 2 did not show the shallow mixed layer present in Region 1 (Fig. 9.3). Surface water temperatures were 23-24.5°C, somewhat warmer than those in Region 1, and consistent with the lower latitude of this region. The seasonal thermocline appeared to occupy the first 100 m of water depth and the permanent thermocline extended from there down to 800 m water depth, where temperatures decreased to 5.5°C. Below the permanent thermocline the water temperature decreased to about 1.2°C at 4920 m depth; the bottom of the deepest profile.

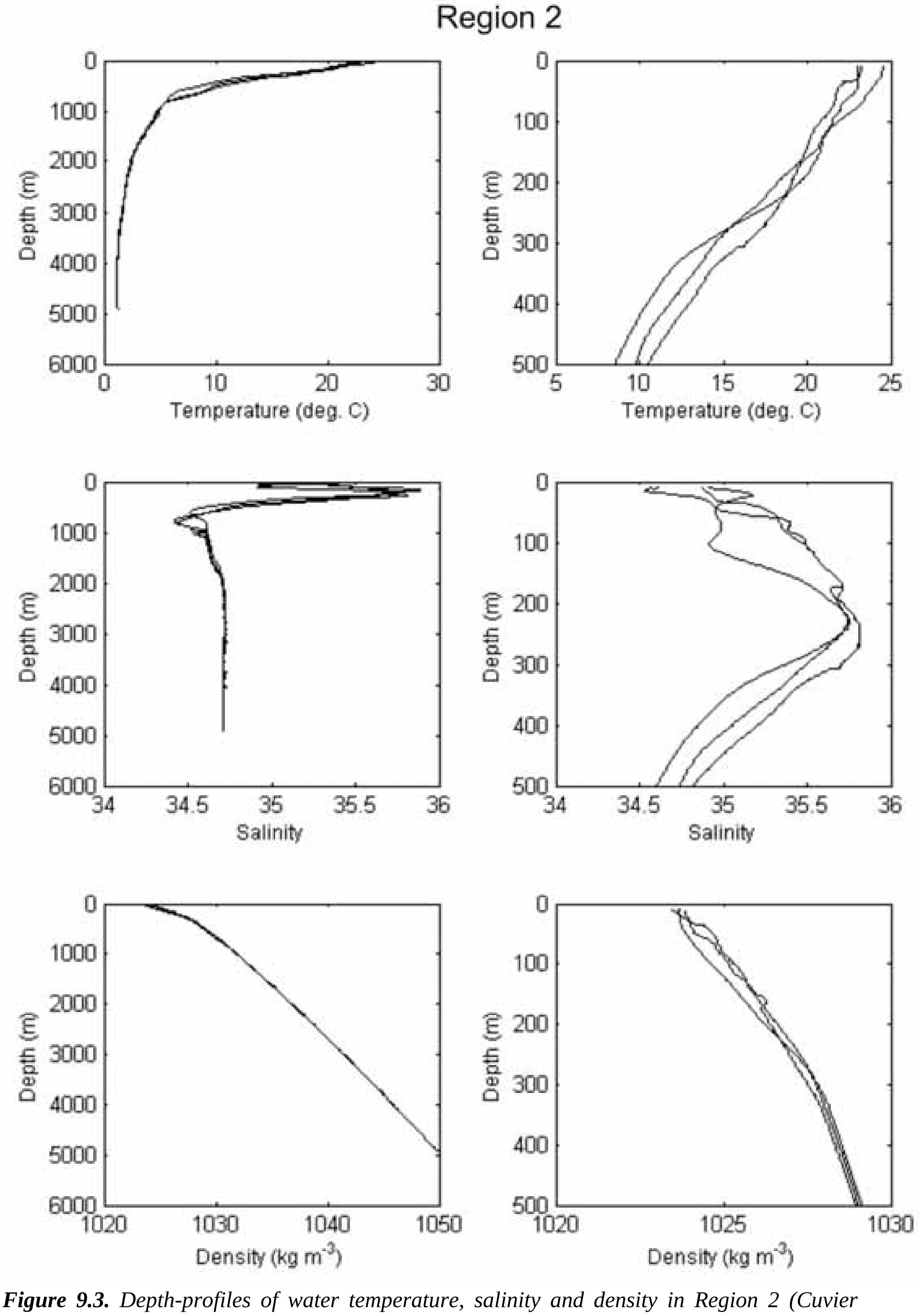



***Figure 9.3.*** *Depth-profiles of water temperature, salinity and density in Region 2 (Cuvier margin). The left column shows the full depth-profile and the right column shows detail of the surface 500 m of the water column.*

Depth-profiles of salinity showed a maximum at about 250 m depth of about 35.8 (Fig. 9.3). Below this maximum there was a halocline over which salinity decreased to a minimum of about 34.4 at 800 m depth (also the base of the permanent thermocline), and the remaining vertical structure was similar to that described for Region 1. The vertical structure for water density was also the same as that described for Region 1, except the density of the surface water mass was smaller (ca. 1023.4-1024 kg m-3), due to the warmer surface water temperatures in this region (Fig. 9.3). The water density at the base of the deepest profile (ca. 4917) was 1049.8 kg m-3.

The T-S plot for Region 2 is shown in Fig. 9.4. The same water masses were present in Region 2 as in Region 1, with the addition of TSW and perhaps a hint of NWIIW.

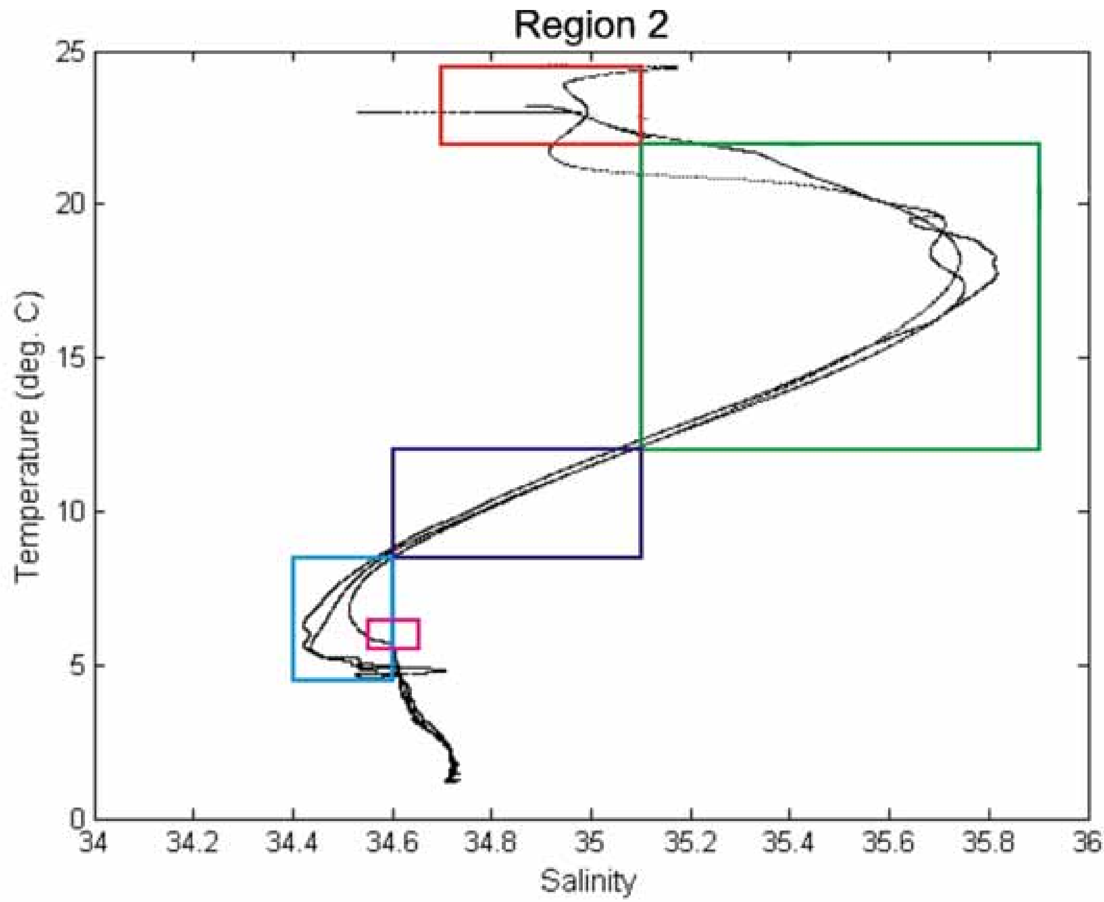



***Figure 9.4.*** *A T-S plot for the depth-profile data from Region 2 (Cuvier margin). The coloured boxes show the extents of temperature and salinity for the water masses listed in Table 9.2: TSW (red), SICW (green), SAMW (blue), AAIW (cyan) and NWIIW (magenta).*

***Region 3 (Wallaby Saddle and Cuvier Plateau)***

Similar to Region 1, Region 3 is exposed to the predominantly southwesterly swell-wave climate. Again there was a surface mixed layer evident in many of the temperature profiles, which extended from the surface down to between 30 and 80 m depth (Fig. 9.5). Water temperatures within the mixed layer were 21.5-24°C. Beneath the surface mixed layer both a seasonal thermocline and the permanent thermocline were evident. The base of the latter being at about 800 m depth, where the water temperature reduced to about 5°C. Below the permanent thermocline the water temperature decreased to about 1.2°C at 4670 m depth - the bottom of the deepest profile.

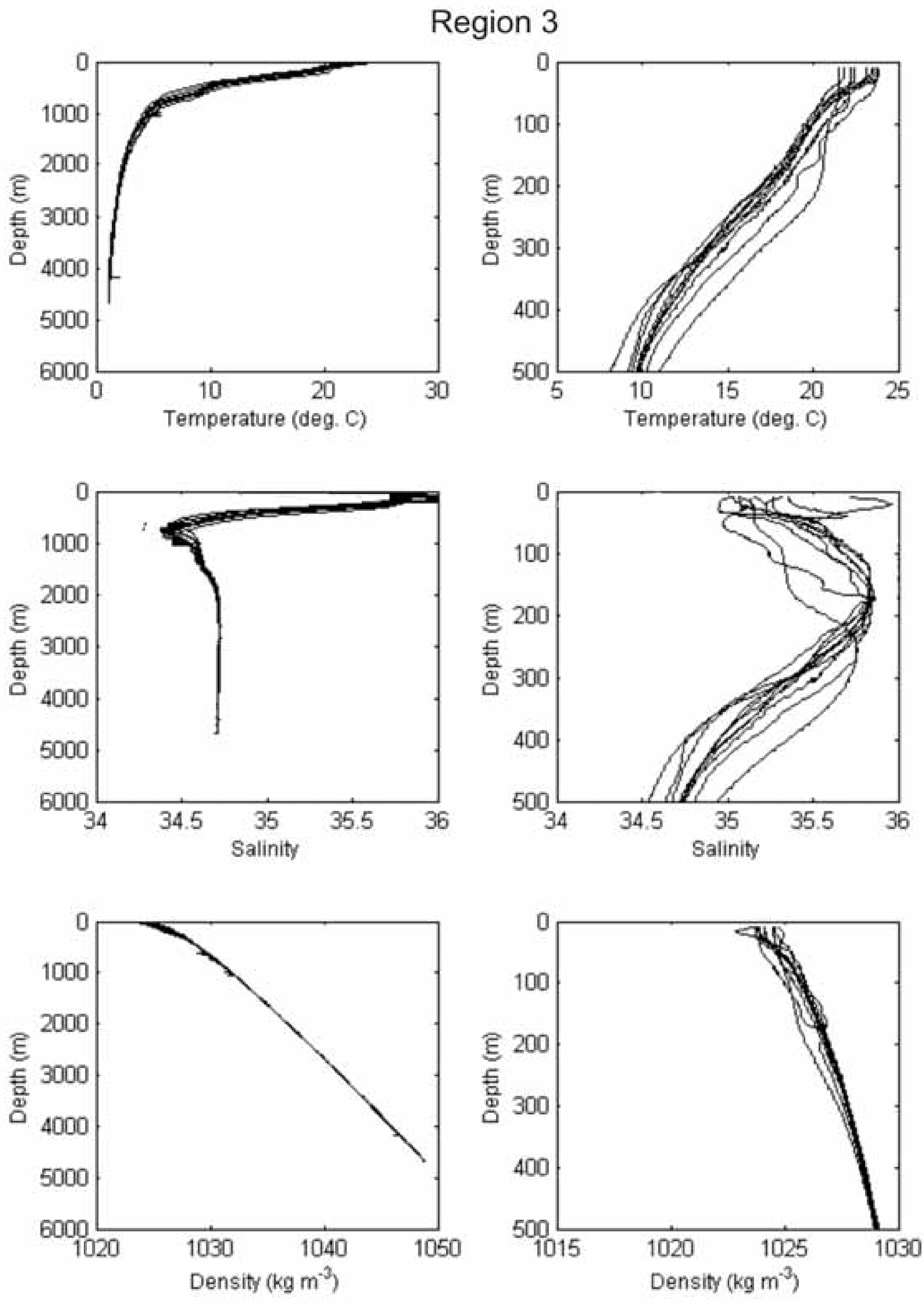



***Figure 9.5.*** *Depth-profiles of water temperature, salinity and density in Region 3 (Wallaby Saddle and Cuvier Plateau). The left column shows the full depth-profile and the right column shows detail of the surface 500 m of the water column.*

Depth-profiles of salinity showed a maximum at about 180 m depth of about 35.8 (Fig. 9.5). Below this maximum there was a halocline over which salinity decreased to a minimum of about 34.4 at 800 m depth (also the base of the permanent thermocline), and the remaining vertical structure was similar to that described for Regions 1 and 2. The surface water density was 1024-1025 kg m-3, which was intermediate between that observed for surface water in Regions 1 and 2 (Fig. 9.5). The vertical structure for water density was the same as that described for Region 2. The water density at the base of the deepest profile (ca. 4670) was 1048.9 kg m-3.

The T-S plot for Region 3 is shown in Fig. 9.6. The same water masses were present in Region 3 as in Region 2.

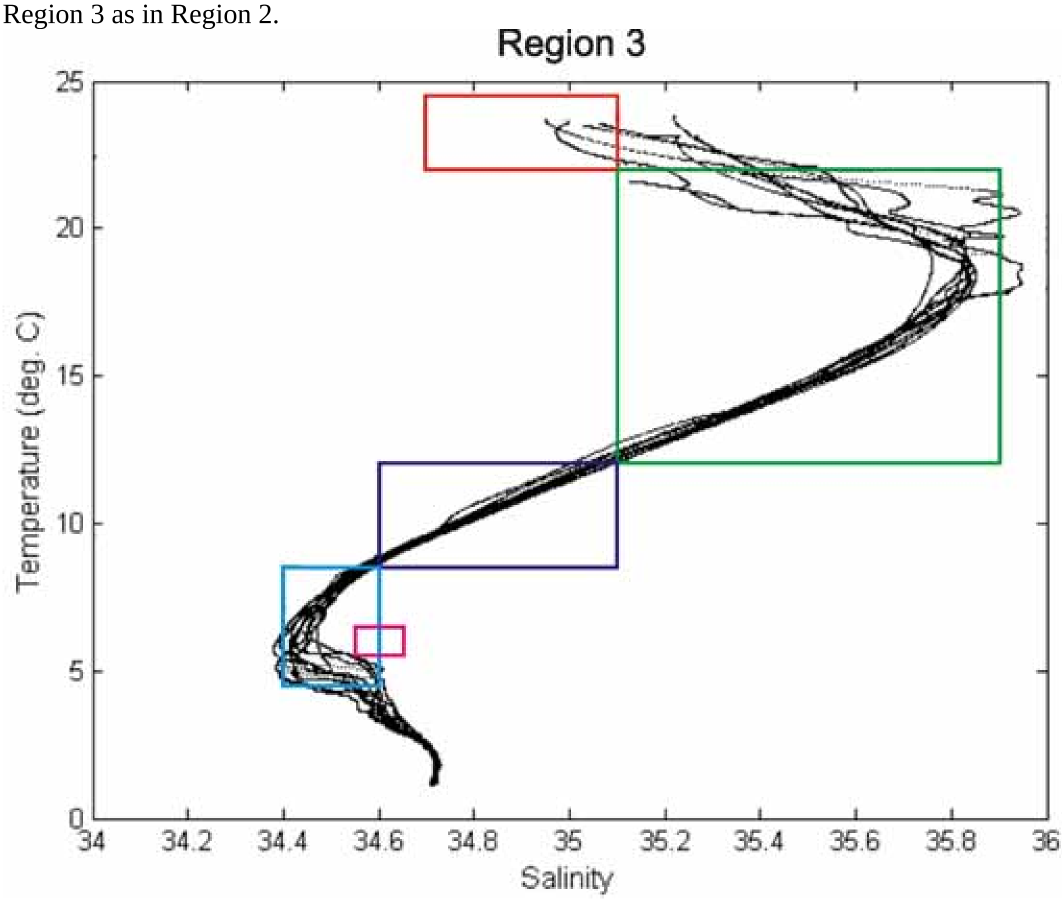



***Figure 9.6.*** *A T-S plot for the depth-profile data from Region 3 (Wallaby Saddle and Cuvier Plateau). The coloured boxes show the extents of temperature and salinity for the water masses listed in Table 9.2: TSW (red), SICW (green), SAMW (blue), AAIW (cyan) and NWIIW (magenta).*

### 9.2.2. Underway Acoustic Doppler Current Profiler

Underway ADCP data were collected throughout the survey. Ship-tracks for this data are shown in Fig. 1.1. Although 50 depth-bins were sampled only the first 35 bins, down to a water depth of about 900 m, provided reliable data. Only a sample of the underway data is presented for two reasons: 1) the data could not be fully processed in the time available; 2) the underway data must be analysed and interpreted over regions of limited extent to ensure temporal uniformity with respect to the time-scales of the processes. A sample of the data over the Cuvier Plateau is shown in Fig. 9.7. The data shown were collected over a 3.5 week period. The ship started in the south and made its way progressively north over that period. The vectors shown are the horizontal component of the current velocity measured in the first depth-bin representing the depth interval of 41 to 66 m. For clarity only every 4th vector along the ship-track is shown.

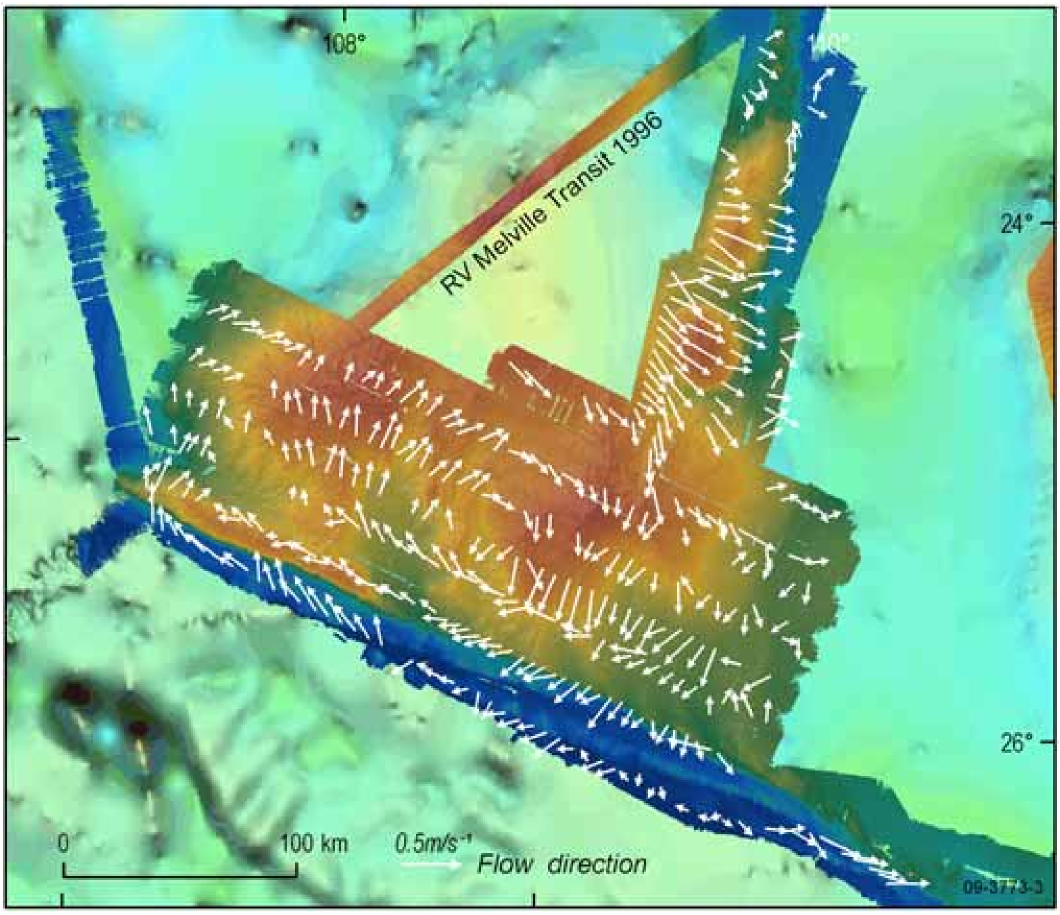



***Figure 9.7.*** *Near-surface horizontal current velocity vectors along the ship-track plotted over the seabed bathymetry collected during the period 21 December 2008 to 14 January 2009. The ship began in the southeast corner of the survey area, and made its way progressively north over this time period.*

In as much as the 3.5 week sampling period can be considered short with respect to the oceanographic processes involved, there is a clear pattern in the data. A clockwise rotating eddy is evident, apparently centred at roughly 25°S 109°E, with the largest velocities on the northern side of the eddy (ca. 0.5 m s-1). This eddy is also partially evident in the regional circulation forecast for the 1 January 2009 obtained from NOAA's Ocean Surface Current Analysis – Realtime (OSCAR) (Fig. 9.8). OSCAR assimilates satellite-derived sea-surface elevation, sea-surface temperature and wind data with a numerical model to forecast surface water circulation (Bonjean and Lagerloef, 2002). The eastward-directed flow over the northern part of the survey area and westward-directed flow over the southern part is correctly forecast by OSCAR. The dimension and detail of the eddy is not evident in the OSCAR forecast, due to its coarse resolution, which probably also explains the underestimation of the current speeds measured by the ADCP (cf. Fig. 9.7 and 9.8).

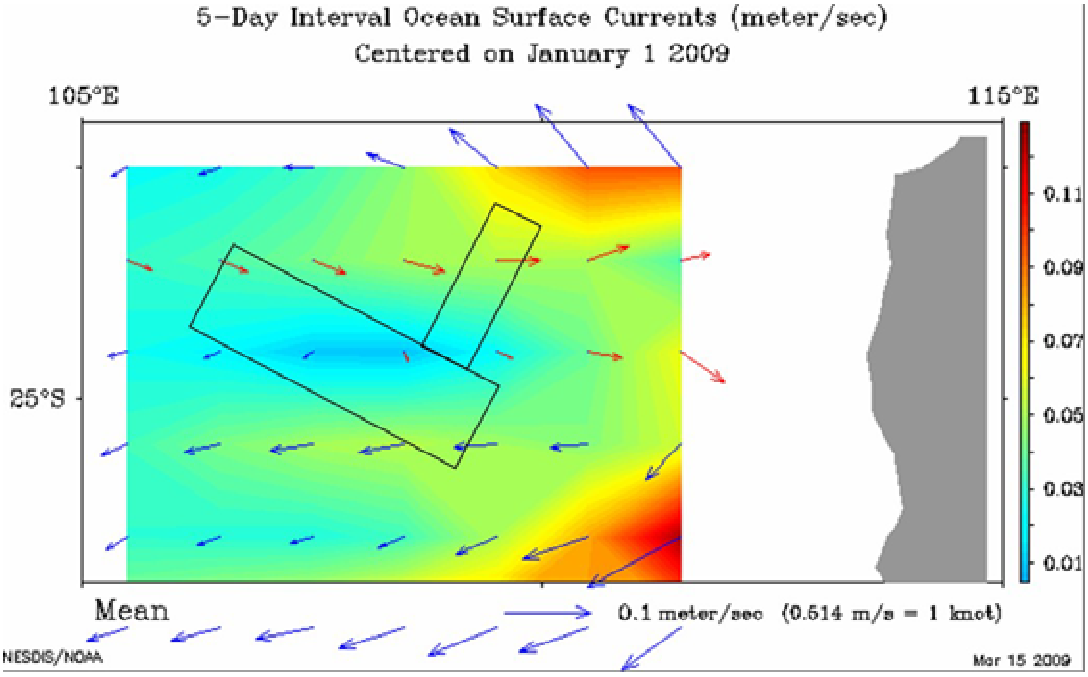



***Figure 9.8.*** *A data-model assimilation forecast of surface water circulation for the 1 January 2009. The forecast is from the National Ocean and Atmospheric Administration's Ocean Surface Current Analysis – Realtime model (see Bonjean and Lagerloef, 2002 for details). The Cuvier Plateau survey region is indicated by the black boxes (cf. Fig. 9.7).*

### 9.2.3. Underway Oceanographic, Meteorological and Hydrographic Data

An initial quality check of the data based on acceptable ranges for each parameter showed that the conductivity and salinity data was unreliable. All other parameters are shown in Figs. 9.9.

The Beaufort scale is an empirical measure for describing wind speed based mainly on observed sea conditions (Beer, 1997). It is also related to wind velocity using empirical formula:

$$v = 0.836B^{2/3}$$

Where wind velocity (v) is measured in m s-1.

"High winds" and "Fresh Gale" conditions (Beaufort scale 7-8) were often experienced during the survey and equivalent to wind speeds of 14-20 m s-1 (50-75 km hr-1) typically from the north and northwest (Fig. 9.10), with wind gusts occasionally exceeding 75 m s-1. Relative humidity, air temperature and water temperature are strongly correlated with latitude and the Sonne moving between tropical and temperate conditions in the north and south of the survey region.

## 9.3. SUMMARY

Oceanographic data from 22 sample stations extending across 10° of latitude were collected during survey GA2476. In addition, underway meteorological and hydrographic data along 21,000 km of ship-track were also collected. The data, when fully analysed, will provide a detailed picture of the oceanography and hydrography of the southwest margin during an Austral summer.

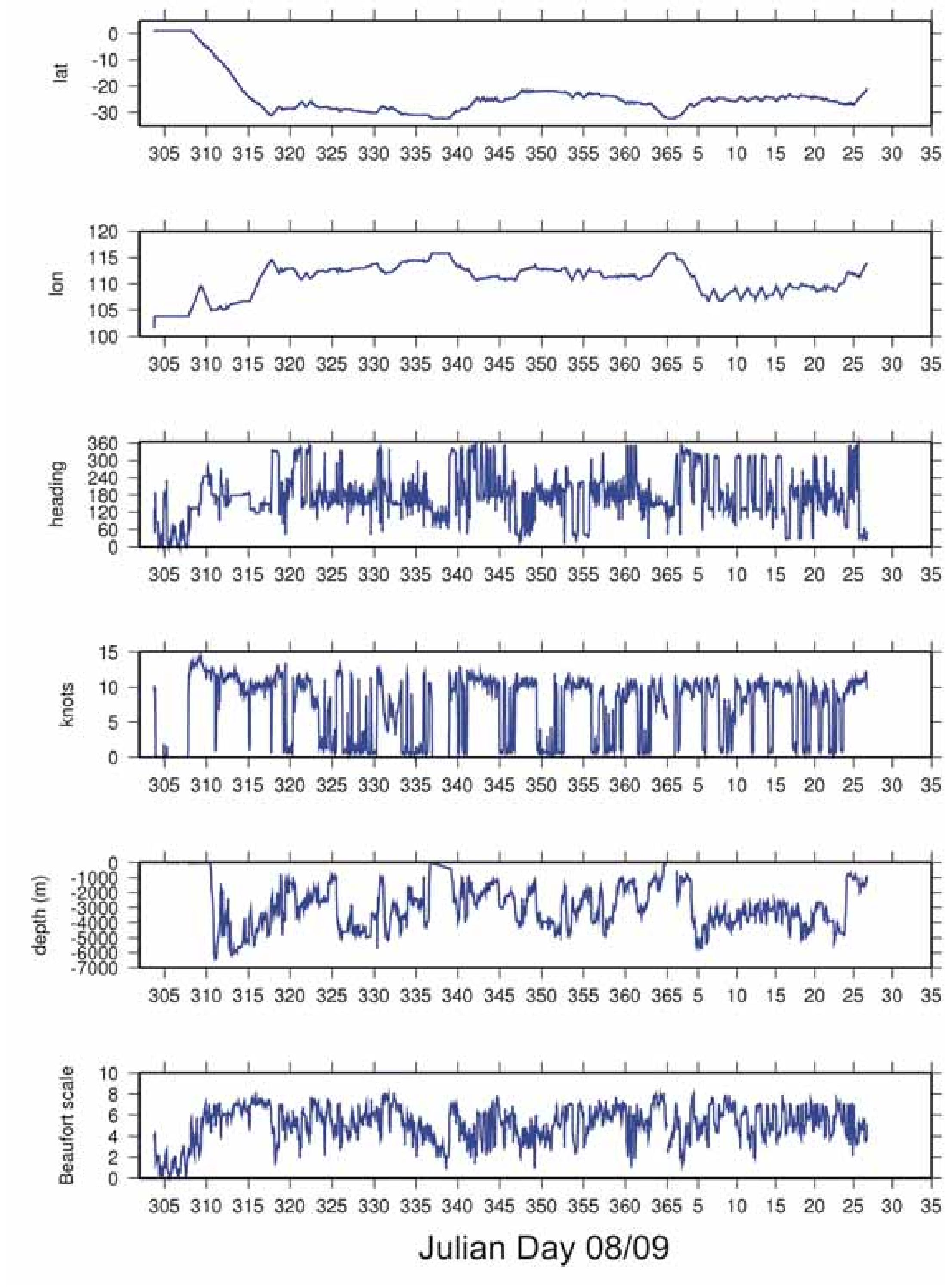



***Figure 9.9.*** *Underway data for the duration of survey GA2476. Hourly averages for latitude, longitude, heading, velocity, depth and Beaufort scale are shown.*

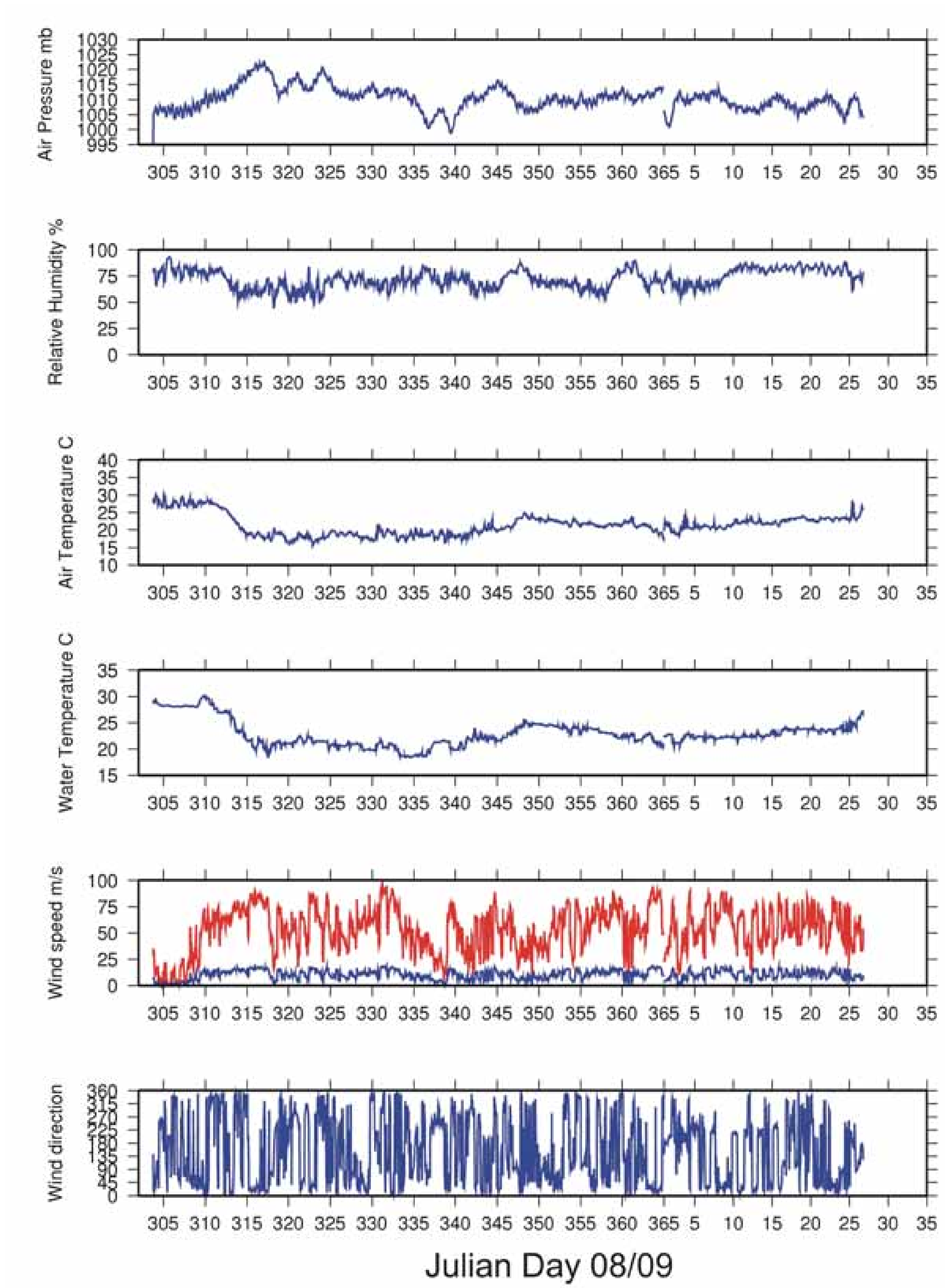



***Figure 9.9 (continued).*** *Underway data for the duration of survey GA2476. Hourly averages for air pressure, relative humidity, air temperatu70*
*re, water temperature, wind speed (average = blue, gust = red) and direction are shown.*

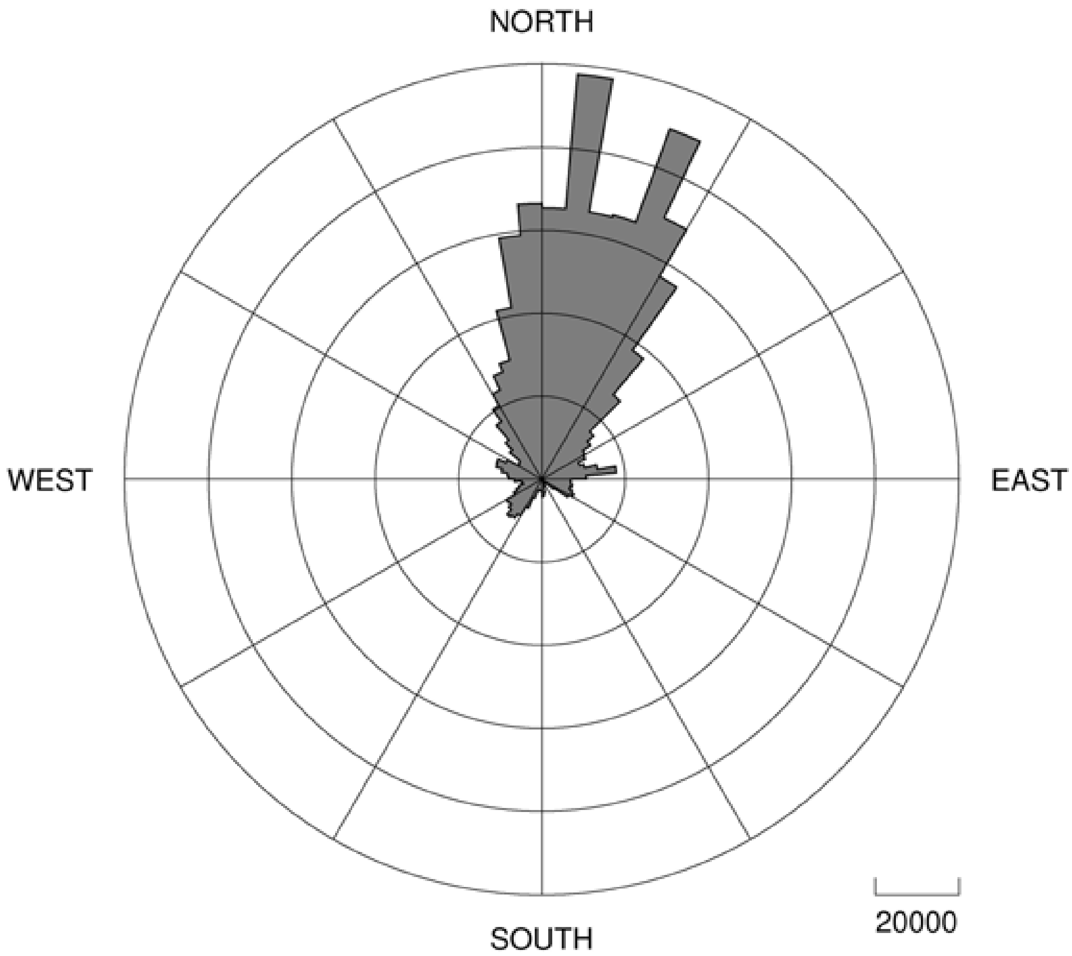



***Figure 9.10.*** *Histogram of underway wind direction data that records the direction to which wind is going to (i.e. not wind source direction). Each circular increment in the histogram represents 20000 counts of wind direction data.*

# 10. Summary

### 10.1. SURVEY GA2476 RESULTS

The marine reconnaissance survey GA2476 was designed to increase our understanding of the regional geology, petroleum prospectivity and environmental significance of the west Australian continental margin. In order to assist in this understanding, the survey collected extensive geological, geophysical, biological and oceanographic datasets. The 90-day marine reconnaissance survey focused on the under-explored areas of the west Australian margin – more specifically four areas of interest: the Zeewyck and Houtman sub-basins (Perth Basin, also associated with the Perth margin); the Cuvier margin (associated with the nearby Carnarvon Basin); and the Cuvier Plateau (a sub-feature of the Wallaby Plateau) (Fig. 1.1 and see Section 1). The survey, which took place as three legs between 25 October 2008 and 19 January 2009, successfully mapped and sampled all four areas of interest.

The survey collected 230,000 $km^2$ of multi-beam sonar data, almost 25,000 line kilometres of gravity, magnetic and sub-bottom profiler data and underway oceanographic, meteorological and hydrographic data. Sampling program included 53 dredge hauls, 28 BODO hauls with accompanying camera footage, 17 OFOS camera tracks, eight boxcores, eight CTD profiles with accompanying water samples, four epibenthic sled hauls, 47 surface water samples, two XBTs and one beam trawl haul. A total of 62 stations were occupied throughout the survey, including 16 over the Houtman Sub-basin and 16 over the Zeewyck Sub-basin on the Perth margin, 13 on the Cuvier margin, 13 on the Cuvier Plateau, and four in the Indian Ocean.

The on-board results of marine reconnaissance survey GA2476 and the preliminary results from analysis of collected datasets are summarized below.

#### 10.1.1. Potential Field Data and Sub-bottom Profiler

Almost 25,000 line kilometers of gravity, magnetic and sub-bottom profiler data were acquired over the duration of the survey. Sub-bottom penetration and overall quality of the data was variable but generally poor due to rough seas combined with variable seabed morphologies and water depths of up to 6,000 m. The newly acquired magnetic and gravity data are being processed by Gravionic. Later it will be merged with the existing datasets to produce new gravity and magnetic images of the west Australian margin. Along with the new seismic data acquired on the concurrent seismic acquisition survey (GA310), the newly acquired potential field data will be critical in determining the extent and depth to basement of the main sediment depocentres as well the nature of the crust underlying the depocentres.

#### 10.1.2. Multibeam Sonar Bathymetry

Almost 230,000 $km^2$ of multibeam bathymetry was acquired over the duration of the survey including all transits. Seafloor features revealed by the backscatter and swath-bathymetry have shown that geomorphology of the study areas is diverse. The continental slope of the west Australian margin study areas is characterised by large areas with numerous deeply incised canyons and areas with low-angle slumps and scarps mostly on the upper part of the slope. Other geomorphic features on the continental slope include short escarpments of local extent and small volcanic peaks over the Houtman Sub-basin part of the Perth margin. New bathymetry from the Cuvier Plateau has mapped large volcanic domes, some of them with terraces, ridges, a large previously unmapped valley and two large seamounts (newly named the Cuvier Seamount and Wallaby Seamount). Bathymetric data acquired onboard proved to be critical for successful dredge, grab, camera and boxcore operations – in particular, to select the steepest canyon slopes and identify accessible rock outcrops. Accurate maps of the seafloor may be a useful for evaluation of the possible risks of trap and seal breach in the Zeewyck and southern Houtman sub-basins and for characterisation of the physical properties of the seabed in each study area.

### 10.1.3. Rock Sampling

Fifty-one dredge, 13 grab and three benthic sled hauls as well as one box core recovered several hundred individual rock samples and a diverse range of rock types. These rock samples represent the first successful recovery of rock dredges from the Houtman Sub-basin and a further successful recovery of rock dredges from the frontier areas of the Zeewyck Sub-basin, the Cuvier margin and the Cuvier Plateau. The samples recovered during the survey will provide useful information to establish a tectonostratigraphic framework and assess petroleum systems elements in the frontier depocentres of the region. Several sampling stations were outside the previously mapped boundaries of the Zeewyck, Houtman and Exmouth sub-basins. Preliminary analysis of the available seismic data together with the first results on the age of the samples suggests that basinal succession extends further seaward than previously mapped and has the potential to extend areas of the west Australian margin suitable for oil exploration.

The sampling program mainly targeted pre-breakup successions aiming at the oldest rocks exposed in canyons, scarps and ridges. Initial micropalaeontological analyses (foraminifera, nannofossils and palynology) of rock samples from the Houtman and Zeewyck sub-basins and the Cuvier margin have shown that most samples fall within two broad stratigraphic intervals: early Cretaceous strata (predominately siliciclastic rocks) and middle Paleocene to late Eocene strata (predominately calcareous rocks). Depositional environments derived from these analyses indicate a progression from terrestrial to restricted marine palaeoenvironments (Berriasian-Valanginian samples) to proximal shallow marine palaeoenvironments (late Valanginian-Barremian) to open marine palaeoenvironments (Aptian-Albian) continuing through to distal open marine facies in all the Paleogene samples. The sampling program also targeted peak-shaped bathymetric features in the Houtman Sub-basin. Basaltic rocks recovered from these features indicate that volcanism took place on this part of the Perth margin in the recent geological past.

The bulk of dredge samples recovered across the Cuvier Plateau contain volcanic rocks that are consistent with the known extensive volcanism across this area at the time of continental breakup. However importantly, for the first time, sedimentary rocks composed of clastics weathered from terrigenous environments into the marine realm have been recovered in several locations on the Cuvier Plateau. These rocks deposited in relatively shallow water environments include fossiliferous claystones, quartz-dominated sandstones and siltstones. Preliminary palaeontological analyses have shown at least one sample is likely to be Upper Jurassic, making it the oldest known sedimentary sample from the Cuvier Plateau.

### 10.1.4. Biological Sampling

Biota were sampled from 53 pipes that were attached to the rock dredge, 49 dredges, 28 BODO grabs, eight boxcores and four epibenthic sleds. Deep-water benthic habitats were characterised from observations from 44 video transects and 17 still-photo transects. These biota samples and benthic habitat observations were collected in water depths greater than 1,000 m, which have rarely been surveyed within Australian waters. Zooplankton was also sampled from surface waters over the Zeewyck Sub-basin of the Perth margin and the Cuvier Plateau. The most obvious finding from the benthic habitat characterisations and biota sampling was that seabed habitats in the study areas were depauperate of marine organisms, particularly over the Cuvier Plateau. While biological samples generally contained extremely low numbers of marine organisms, several important specimens were collected. Several new taxa were identified, and several known taxa were collected from water depths greater than previously recorded for Australian waters. The samples and observations from the survey will characterise the relationship between biotic and abiotic factors on a variety of ecologically significant features (e.g. canyons, ridges, etc) and will substantially contribute to the overall knowledge of deepwater marine (water depths >1,000 m) assemblages in Australian waters.

The most common signs of life were bioturbation marks (tracks, burrows and mounds) that, although only present in low levels, occurred in all video and still-photo transects. Deposit-feeding holothurians (sea cucumbers) were the most common epifauna observed in video transects, and polychaetes and crustaceans were the most common infauna in boxcore samples. Suspension-feeding organisms, such as corals, sponges and hydroids were extremely rare across the study areas, with the exception of the three volcanic peaks over the Houtman Sub-basin in the Perth margin, where occurrences of suspension-feeders were much higher. While live suspension-feeders and other associated organisms were present on these volcanic peaks, large amounts of dead coral rubble (volcanic peaks immediately south of Houtman Canyon) and gorgonian rubble (volcanic peak in north Houtman Sub-basin) characterized these habitats.

### 10.1.5. Seabed Sediments and the Water Column Profiles (Physical and Chemical)

A total of 73 seabed sediment samples were collected from 43 pipes that were attached to the dredge, 22 BODO grabs and eight boxcores, which were collected in water depths between 900 and 5,200 m. Textural and compositional analyses show that the sediment is largely fine-grained calcareous mud and calcareous sandy mud. This is consistent with the largely pelagic sedimentation occurring on the west Australian margin survey area.

Eight CTD and 17 OFOS stations recorded depth-profiles of water temperature, salinity, conductivity and density. Vertical structures of temperature, salinity and density were similar in all study areas. In many of the temperature profiles, a mixed layer at the surface, a seasonal thermocline and a permanent thermocline is evident. Combination plots of temperature-salinity show that the same water masses were present in all study areas.

Water samples were collected throughout the water column during the deployment of two CTDs, which reached depths of 2,000 and 4,830 m, and only TCO2, O2 and N2 analyses have been completed. Surface and shallow sub-surface sediments were collected on eight boxcores and 17 BODOs and underwent bulk sediment chemistry, porosity and bulk density, grain size/carbonate and vial incubation experiments. Biochemical analyses of seabed sediments and water samples from the two CTD water samples will improve the understanding of the geochemistry of these samples and assist in establishing surrogacy links with geomorphic, hydrodynamic and biological systems.

### 10.1.6. Other Complementary Datasets

Reliable underway ADCP data was collected throughout the survey down to a water depth of about 900 m. Other oceanographic, meterological and hydrographic parameters were measured while the ship was underway and resulted in approximately 126,000 records. This data is currently being processed, analysed and interpreted over limited regions.

## 10.2. FUTURE WORK PROGRAM

Survey GA2476 collected extensive geophysical, geological and biological datasets over poorly known areas of the west Australian margin. At the time of this publication, a number of datasets and physical samples acquired on the survey are still undergoing processing and analyses (see relevant chapters). Briefly:

- The newly acquired magnetic and gravity data is currently being processed by Gravionic;
- Selected rock samples are undergoing geochemical, petrographic and biostratigraphic analyses;
- Some frozen biological samples (e.g. sponge material) are awaiting customs inspection and subsequent processing;
- Coral rubble samples have been sent to CSIRO and are undergoing analyses for aging;
- Elutriate samples recovered from BODO are undergoing sorting and analysis for infaunal collections and are expected to be done by August 2009;
- Zooplankton recovered from surface water is undergoing laboratory analysis and is expected to be done by December 2009;
- Seabed surface and shallow sub-surface sediments and water samples collected from CTD are undergoing biogeochemical analyses; and
- Oceanographic, meterological and hydrographic data is currently being processed and analysed over limited regions.

To achieve the principal scientific objectives of survey GA2476, the fully processed and analysed datasets will be integrated and interpreted. Specifically:

- Gravity and magnetic data collected on survey GA2476 and the concurrent seismic acquisition survey (s310) will be integrated to create a calibrated magnetic and gravity dataset;

- Calibrated magnetic and gravity dataset will be used to model sediment thickness and nature of the basement underlying major depocentres;
- The calibrated magnetic and gravity dataset will be integrated with the satellite and other ship track data to produce new high-resolution images. These images will be used in conjunction with the seismic data to map the extent and depth-to-basement of the main depocentres and to update basin boundaries in the Zeewyck, Houtman and Exmouth sub-basins;
- The rock sample results (age, lithology and geochemical character of rock samples) will be tied into the regional tectono-stratigraphic framework. Analyses of the sedimentary rock samples from the Cuvier Plateau may provide evidence to support the presence of continental depocentres beneath parts of the Cuvier Plateau, whereas analysis of the various volcanic rocks may yield further insights into its the volcanic history and the breakup, thermal and subsidence history of the west Australian margin;
- The physical properties of the seabed will be characterised by the integration of analysed seabed sediment samples, real-time characterisations of the seabed (OFOS and BODO) and backscatter- and swath-mapping data;
- The abiotic and biotic relationships on a variety of ecologically significant features (e.g. canyons, ridges, etc) will be characterised by establishing surrogacy links with analysed seabed sediment samples (biochemical, textural and compositional analyses), biochemically analysed water samples, biological samples and seabed video characterisations.

This work program will provide a basis to further understand the regional geology and petroleum potential of frontier depocentres, as well as the environmental significance of the west Australian margin. Data from the survey will be used to improve resource management and underpin decisions in regards to future acreage release and marine zone management of offshore Western Australia.

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# 13. Appendices

## 13.1. APPENDIX A – SURVEY LEADERS' LOGS

Geoscience Australia Survey 2476 – Western Australian Margin
25/10/2008 – 19/01/2009
Survey Leaders Log
RV *Sonne*
Kriton Glenn (Leg 1), Andrew Heap (Leg 2), Michael Hughes (Leg 3)

Leg 1.

**Thursday 23 October 2008:** RV Sonne departed Port of Singapore this morning at 05:15 hrs. 14 hours later, Location 0° 9.02'N 106° 6.96'E on JD 296 travelling at 12.8 knots, on transit to the north of Christmas Island to begin the swath, sub- bottom profiler, gravity and magnetic survey. Received word from the Captain of the vessel that we are now in known Pirate Waters and therefore the vessel is in complete lock down from 8pm to sun rise until we are into the Indian Ocean. All staff have heeded warnings. All the labs are set up and University of the Sea (UoS) people are settling in to vessel life. It was found that the Mercuric Chloride was incorrectly delivered as pure mercury, this is an important part of the Geochemistry processing. Options on how to acquire some out of Christmas island are being investigated. Weather and sea state are fine, next 60 hours will put us in Australian Waters

**Friday 24 October 2008:** On transit to Christmas Island on route to the survey area of the Zeewyck Sub-basin**.** Presently located at 2°47 600'S 109° 22 112'E. Speed 12.4 knots**.** Pirate precautions (evening lock down) are still in force. The work areas (Swath, data bases, geolab, geochem, photographic) are set up across the vessel is completed. The extensive set up of the Biology area has just been completed with comprehensive assistance from all the FES Staff. The Captain has agreed to take the vessel to the northern side of Christmas Island to send in the work boat to pick up the chemicals. This also allows a a slightly extended swath program of the island that will assist other areas of GA. This may take two extra hours. The weather and sea state are fine. Next 40 hours will be transiting to Australian waters.

**Saturday 25 October 2008:** On transit to Christmas Island on route to the survey area of the Zeewyck Sub-basin**.** Presently located at 10.1.694 S 105.17.735E approaching the north of Christmas Island**.** Speed 11.8 knots**.** Pirate precautions are no longer in force. Calibration of the swath, magnetometer, and the portable USBL completed. Swath and cetacean watches are now underway. Weather and sea state are fine 1.5 k swell

**Sunday 26 October 2008:** On transit to the survey area of the Zeewyck Sub-basin.Presently located at 13.17.510S 05.21.463E Speed 11.8 knots. The Swath is stunning around Christmas Island it has been a good test place. GA staff and UoS people are working well.

**Monday 27 October 2008:** On transit to the survey area of the Zeewyck Sub-basin**.** Presently located at 20 50 907S 106 35 625E on a heading of 173, Speed of 10.4 knots. Multiple 'sea mounts' observed in vicinity of Christmas Island, ~9958 $km^2$ mapped to date. The cetacean watches are underway. Weather and sea state are fine 2m swell and increasing. Awaiting input from GA regarding contingency plans should the magnetic program be reduced. Trials suggest that the fish can be towed at 11 knots and produce good data. Sub bottom is producing better results yet still intermittently. The safety drills have been completed and safety talks from the Doctor. The site selection workshops have been well attended by the GA and invitees. XBT seminar conducted by Andrew Hislop

**Tuesday 28 October 2008:** On transit to the survey area of the Zeewyck Sub-basin**.** Presently located at 27.46.66S 111.42.838E on a heading of 149 degrees**.** Speed over ground of 10.4 knots. Good swath acquisition with around 38 000 square kilometres mapped so far. New and exciting data along the southwest edge of the Cuvier Plateau has been acquired in the past 24 hours. Weather and sea state is 6 Beaufort and increasing. Continuing swath, gravity and magnetic and sub-bottom profiler data acquisition on route to the work area and anticipated plane drop. Arthur Mory (GSWA) and UOS students have been introduced to seismic data and sample site selection workflow and are working the data to assist insite selection.

**Wednesday 29 October 2008:** On transit to the survey area of the Zeewyck Sub-basin. Presently located at 24 18 863 S 106 43 162 on a heading of 127 Speed, SOG of 9.8 knots, air temp 18C. The seas did not get to 7 m last night but was certainly lumpy at times. The bridge informs us that as we approach the WA coast line, a heavier sea state anticipated. Generally good swath acquisition, some loss of signal as air gets under the hull of the vessel in large seas. XBT deployed last night all went smoothly. CTD cast #2 deployed at the edge of the Wallaby. Water samples being processed to ensure all protocols are set up and ready. Magnetometer in the water and acquiring.

**Saturday 01 November 2008:** On transit to the first sampling area (Murchison Canyon, Zeewyck and Houtman sub-basins). Presently located at 27.46.580S 111.51.215E on a heading of 85 degrees, speed over ground (SOG) of 10 knots. Good swath acquisition with over 45,000 square kilometres mapped so far. CTD 003 was successfully completed yesterday in the south of the mapping area. Magnetic data acquisition continues to be successful at mapping speeds of between 10 and 12 knots. Transit to the first sampling area (ETA 1200 02/11/2008) in the Murchison Canyon where sample sites target pre-rift rocks in both the Zeewyck and Houtman sub-basins as well as deep and shallower benthic habitats and environments. Planned sampling procedure will start with OFOS (video). Subsequent sampling equipment will be selected based on data obtained from the video and may include benthic trawl, Sherman sled, TV Grab, box core, gravity core. Several rock dredge sites have been pre-selected and will be sampled after other sampling is complete.

**Sunday 02 November 2008:** Presently located at 28.28.209S 112.46.876N**,** speed SOG of 10.6 knots. Good swath acquisition of 51 384 $km^2$. The video camera deployed down the side of Murchison Canyon to select a good dredging site and see what other operations could be undertaken at this site. This precipitous edged canyon was unsuitable for dredging. The Chief Scientist agreed with the Boson that it was to dangerous to risk one of the two dredges at the first site. The canyon cliff face has overhangs and abrupt escarpment profiles. This site may be selected after seeing others and if suitable will be sampled on the return to Freemantle section of this survey. Weather and sea state are fine 1.5m swell and steady

**Monday 03 November 2008:** Presently located at 26 24 564 S 111 7 818 E with a heading of 168, Speed (SOG) 10.6 knots. Weather and sea state are fine 2 – 4 m swell and steady. Swath acquisition to follow the previous days sampling effort. Continue in the northern area mapping over the Houtman Sub-basin. Then using new bathymetry data, progress the site selection using the new data and then return for the second phase of the physical sampling. Await update from GA on the proposed air drop from Geraldton. To ensure safety, due to the rough sea state, the speed was dropped to 6 knots last night for several hours. Then as the seas got better speed was increased back up to 10.5 we will return to 12.5 knots as soon as it is safe to do so.

**Tuesday 4 November 2008:** Presently located at -28 28.897 S 112 46.906, Speed (SOG) of 11.6 knots. Weather and sea state are fine 2m swell and steady. Deployed the video camera down the side of Murchison Canyon (x2). Second Video Transect revealed a better sample location as the first was precipitous some overhangs and little sediment accumulation noted. 2 box cores, 1 benthic trawl, and 2 dredges were taken at the second transect in the (shallower) eastern Murchison canyon. Dredge samples include fine grained muddy sandstones and minor coal bearing sandstone from the Houtman Sub-basin. Acorn worms along with a wide variety of other benthos has identified in video footage. After mapping the sea floor anomalies (pinnacles ?? vents ??) to the south of Murchinson Canyon (as seen on the seismic) we will head north for 2-3 days to continue the mapping over the Houtman Sub-basin. Then using new bathymetry data, progress the site selection using the new data and then return for the second phase of the physical sampling.

**Wednesday 05 November 2008:** Speed (SOG) 8.3 knots Weather and sea state deteriorating 2 – 4 m swell and steady. 58,000 $km^2$ swathed so far. The new bathymetry data being processed so progress on the site selection continues. Conduct the second phase of the physical sampling starting around midday

**Thursday 06 November 2008:** As the Sea state again deteriorates, to ensure safety, the vessel speed has been dropped to 8 knots for several hours. Then as the situation gets better (we hope) speed will be increased back up as soon as it is safe to do so. Confirming the proposed air drop from Geraldton with the pilot. Awaiting email from him tomorrow and will then phone for arrangements.

**Friday 07 November 2008:** Presently located 28 6 863 S 112 23.930E, on a high graded dredge site, Speed (SOG) Stationary, Weather and sea state are fine 2 – 4 m swell and steady Third dredge no rocks yet significant sediment. Second dredge attempt at this site underway. For the next 48 hours the second phase of the physical sampling. Confirming the proposed air drop from Geraldton with the pilot.

**Saturday 08 November 2008:** Presently located, 28 20.32 S 112 24.09 E, on high graded dredge sites. The second phase of the physical sampling well underway. A number of dredges were successful and produced a range of lithotypes. Including a dark shale possibly of pre rift age. For the next 48 hours the next phase of the physical sampling at the submarine conical features (volcanic, carbonate, mud?) We will be using most of the equipment here including the camera dredge sled gravity core and TV Grab. Air drop from Geraldton confirmed with the pilot for 2 pm Saturday.

**Sunday 09 November 2008:** Presently leaving the deep water site west of the Murchison Canyon. Speed (SOG) 0 knots as we are sampling**.** Location 28 48.408 S 112 21.770 E. CTD and Box core underway in Deep water site off Murchison Canyon. The chemicals received via air drop and have been used with several sediment and water samples. Greater than 64,000 $km^2$ swath mapped so far. Swath mapping on way to next site (1 hr) in mid Murchison Canyon.

**Monday 10 November 2008:** Presently at 29 17.536S 112 50.098E, on route to a high graded dredge site, Speed (SOG) 12.5 knots. 2 dredges were moderately successful and produced a range of litho types. Swath imagery is being cleaned and then gridded producing striking large scale canyon imagery. Swathing on way to next site (9 hrs). This site is one of the canyons south of the Murchison Canyon and has a northern facing dredge site. CTD, OFOS and box core are planned. Following this, the vessel heads for a site further up the canyon targeting pre-rift rocks.

**Tuesday 11 November 2008:** 29 34.933 S, 112 58.333 E, speed (SOG) 0 knots, as we are currently sampling. 2 dredges were moderately successful and produced a range of lithotypes. Most of the sample arriving up in the pipe dredges behind the dredge. Continue to sample the sites to the south of the work area. May have to head north in the next day or so to escape un-favourable weather. Assessing further environmental sites for the report.

**Wednesday 12 November 2008:** Presently located at 29 51 394 S 113 27 284 E, Speed (SOG) 11.5 knots. Deep sea sample collection in 4799 m water depth - a range of Biota was collected. Presently working on the mid southern section of survey area one. Mapped an additional 1421 $km^2$ today in between sampling

**Thursday 13 November 2008:** Located at 28 44.763 S 112 6.735 E , Speed (SOG) 4.0 knots, sea state 7. After the most successful dredge of the survey so far we are now swathing the outside northern area of area 1, deep water. Upon completion of this we will head south down the same track used by the French vessel L'Atalante (which currently has no magnetic or gravity data and inferior quality swath data). This is a scheduled mapping time and it is fortunate that we are doing so as the sea state is again unfavourable for anything else. The sea state will continue to deteriorate over the next 2 days and will hopefully improve for the planned final sampling. 70 080 $km^2$ swath mapped to date. Presently mapping the northern part of area 1 before returning to the south for final sampling efforts;

**Friday 14 and Saturday 15 November 2008:** Geological sampling to date (summary). Numerous pale green-white claystones (commonly calcareous), limestones, and interbedded limestone and chert were recovered from the Houtman Sub-basin and probably represent Cretaceous-Cenozoic (Post-rift) deposits. A variety of mudstones (including some black, organic-rich mudstones), siltstones, and sandstones (commonly with carbonaceous fragments) cannot be reliably dated in the field and will likely prove to be a mix of pre- and post-rift rocks. Vesicular, olivine basalts and volcaniclastic breccias were recovered from the Burke and Hearty seamounts (Gorter, 2008 unpub.) located immediately south of the Murchison Canyon. The Ocean Floor Observation System (OFOS) also recorded video images of large areas of apparent volcanic rocks (including possible pillow structures) and a thin veneer of cemented coralline rubble.

The Zeewyck Sub-basin dredge sites have successfully targeted several pre-rift sites with common recoveries including sandstones, interbedded sand- and siltstone, and claystones. The coarser lithologies commonly contained carbonaceous fragments. Again, it would be premature to ascribe any age to these rocks but there must be a chance that some of these represent the thick Middle-Upper Jurassic Yarragadee Formation.

The most recent dredge and TV grab site targeted rocks underlying the obvious pre-rift sedimentary packages in the southern Zeewyck Sub-basin. The seismic resolution in these sections is poor and it was not clear if sedimentary rocks, basement, or even volcanic would be recovered. Large volumes of sandstone, clayey siltstone, and mudstone (commonly interbedded and containing carbonaceous debris) were obtained. Some of these lithologies were more lithified than previous samples, but again only dating back at GA will provide any answers to the age of this material.

Many of the siliceous sedimentary rocks recovered from both the Houtman and Zeewyck sub-basins are very alike, particularly the moderately well-sorted sandstones with abundant carbonaceous debris. This is to be expected though, as many of the fluvial to shallow marine sequences through the Triassic-Jurassic of the Perth Basin are remarkably similar.

**Monday 17 and Tuesday 18 November 2008:** Located at 30 57 369 S 114. 15.299E, Speed 0 knots, weather and seastate are fine. While dredge sampling has been largely successful on leg 1, geologist are currently assessing dredge target success (to the extent this can be achieved on board) and preparing a shortlist of high graded missed targets or failed attempts that can be attempted by legs 2 and three if time permits. The key remaining targets include pre-rift Houtman rocks from the north of area 1 and some pre-rift targets in the south of the Zeewyck. In the past 24 hr an additional dredge failed due to hook up (5 T shear pin failed will go for 7T next time)

University of the sea students have commenced presentations on their areas of scientific focus over the course of the survey. The first of these were presented today on key biological and geological observations from underwater video footage, biological sampling techniques and dredge targeting practices used during the survey.

Next 12 hours will see us dock-side in Fremantle. Transit onto the channel

**Thursday 20 November 2008:** Arrival into Fremantle. Customs are now on board and going through the formalities. Immigration customs and providores on board assisting with the victualling for leg 2. Hand over to Leg 2 Chief Dr Andrew Heap for most of the day and spend the day orientating the new staff on board.

Leg 2.

**Saturday 22 November 2008.** RV Sonne departed Fremantle at 00:15 UTC (09:15 LT) to commence Leg 2 of the West Australian Margin survey. Weather: fine, 25° C, seas smooth, wind 10 knots from 265. Hand over went smoothly with Leg 1 and 2 crew working very hard to cover all issues. All GA, GSWA, AIMS and UoS crew are aboard and settling in well. We are currently en route to a way-point to begin mapping the in-board section of the Zeewyck Sub-basin and pick up three high-grade dredge sites that were prioritised by the Leg 1 crew. Next 48 hours: sampling and mapping of inboard section of Zeewyck Sub-basin.

**Sunday 23 November 2008.** Ship position at 00:00 UTC 29°37.884S, 113°06.016N. Winds 11.19 m/s from 208° and seas moderate; 1004 mb and steady. Over the past 24 hours we have continued mapping the inboard section of the Zeewyck Sub-basin. Multi-beam data show spectacular 'scalloping' of the upper to mid slope all the way along the margin. This is evidence for slumping and general mass wasting on the slope and in the numerous submarine canyons. Unfortunately, with the rugged seabed, the sub-bottom profiler is only producing marginal data - it does not perform well in deep environments with rugged seabed. Currently, we are dredging the first of the priority sites identified by Leg 1 for Zeewyck basin sediments. Next 24 hours: continue mapping and sampling inboard section of Zeewyck Sub-basin en route to Houtman Sub-basin.

**Monday 24 November 2008.** Ship position at 00:00 UTC 28°42.155S, 112°30.064E. Winds 6.25 m/s from 172° and seas slight. Over the past 24 hours we have completed three dredges on priority sites in the Zeewyck Sub-basin. The first dredge recovered about 100 kg of (organic-rich shales and sandstones, as well as about 50 kg of the ubiquitous nanno-fossil ooze. The second dredge in the upper Murchison Canyon recovered ~100 kg of interbedded mudstones (shales), sandstones, and claystones + 25 kg of ooze. The third dredge in 4,000 m on the lower Murchison Canyon recovered ~80 kg of abundant basalt (range of types), organic-rich mudstone, limestone, sandstone, chert, and 20 kg of ooze. All in all, a very good haul of terrigenous, volcanic and marine lithologies from the three dredges.

In the next 24 hours we will complete mapping the in-board section of the northern Zeewyck Sub-basin and then begin mapping the out-board section (lower to mid slope) of the northern Houtman Basin.

**Tuesday 25 November 2008.** Ship's position at 00:00 UTC 25°36.717S, 110°51.364E. Weather fine, slight swell 1.5 m from SW, winds 5.48 m/s from 214°. Over the past 24 hours we have completed our northerly run to the Houtman Sub-basin and are now mapping the lower slope up to the base of the Exmouth Sub-basin. During the night we passed the position of the HSK Kormoran but did not see it on the multi-beam or backscatter. The multi-beam data show the region to characterised by undulating topography, with shallow valleys, and evidence of mass wasting on the mid slope. The excellent sea conditions, and shallower gradients and water depths mean that the sub-bottom profiler data have improved considerably, with numerous sub-bottom reflectors being imaged. I'm assured also that the magnetic and gravity data are of excellent quality. In the next 24 hours we will continue to map the northern Houtman sub-basin and begin picking sites for sampling. So far the survey (Legs 1 + 2) has culminated in 76,000 $km^2$ of multi-beam data and >10,000 line-km of SBP and potential field data.

**Wednesday 26 November 2008.** Ship's position at 00:00 UTC 24°26.644S, 110°58.321E. Seas slight; swell 1.5 m from S; wind = 8.81 m/s from 198°. Over the past 24 hours we continued to map the northern Houtman Basin. The seabed is characterised by gently undulating slopes and numerous slump features (similar in size and character to those seen on the NSW margin). Also present are down-slope lineations that could be surface expressions of underlying faults. These are potentially good targets for gravity coring. In the next 24 hours we will continue to map the northern Houtman sub-basin and begin picking sites for sampling. Sampling is likely to begin on Friday.

**Thursday 27 November 2008**. Ship's position at 00:00 UTC -24°52.455, 111°13.154. Seas slight-moderate; swell 1.5 m from SW; wind = 9.35 m/s from 170°. Over the past 24 hours we continued to map the northern Houtman Basin. The seabed is characterised by gently undulating slopes and numerous slump features on the low gradient sea floor. Some of the slumps are quite distinct with very clear scarps, run outs and hummocky sections with presumed fault blocks; they have a 'fresh' appearance.

In the next 24 hours we will continue to map the northern Houtman sub-basin and then begin sampling. We have selected three sites, including the a slump feature, cross-slope lineations, and a shallow gradient valley in the south. We probably have time for 4-5 stations in total and will select 1-2 more environments based on the multi-beam and SBP data received in the next 12-18 hours.

**Friday 28 November 2008.** Ship's position at 00:00 UTC 28/11/2008 -24°47.471, 110°55.816. Seas slight-moderate; swell 1.5 m from SW; wind = 10.99 m/s from 152°. Over the past 24 hours we finished mapping the northern Houtman Sub-basin. The inboard section was relatively flat and featureless, save for a 200 m high (volcanic?) cone in 1,000 m water depth. We are now sampling the region. We have just completed a tv grab in 2,950 m water depth, which showed a relatively flat seafloor of pelagic ooze. Three large boulders (basalts?) were seen over the 1.8 km transect. Benthic organisms included Holothurians, sea pens, shrimp, and a fish. Tracks and burrows were also quite numerous. We will now complete a box core and benthic sled at this site.

In the next 24 hours we will continue to sample the northern part of the Houtman Basin. We will come back and visit the possible volcanic cone in this region after mapping and sampling the Carnarvon Basin (most probably Exmouth Sub-basin) on our way back to Fremantle.

**Sunday 30 November 2008.** Ship's position at 00:00 UTC 30/11/2008 = -23°46.570, 111°06.338; Seas moderate; swell 2.5 m from S, wind = 9.74 m/s from 176°. Over the past 24 hours we completed the initial sampling program of the northern Houtman Sub-basin. We attempted a gravity core on the lineaments but was unsuccessful due to the ship's wire parting just above the coring bomb. It appears that the corer got stuck fast and Davy Jones just didn't want to give up his secrets. Thankfully, we have a second coring bomb on board. We have arranged for another to shipped to Fremantle for Leg 3. We then collected a tv grab on the scarp of one of the largest slumps on the margin. The video showed a spectacular 100 m high vertical cliff that exposed nicely the interbedded partially lithified sediments along the scarp. We collected a sample and confirmed it was partially lithified carbonate ooze. We also completed a benthic sled at this location that recovered two small pieces of sulphide precipitate. Incidently, on retrieving the sled the ship was surrounded by a school of sharks and accompanying fish. We then completed a CTD at the northernmost part of the Houtman

Sub-basin. We now have commenced mapping the outboard part (mid to lower slope) of the Exmounth Sub-basin.

In the next 24 hours we will continue mapping the outboard part of the Carnarvon Basin (most probably Exmouth Sub-basin).

**Monday 01 December 2008.** Ship's position at 00:00 UTC 01/12/2008 -22°18.741, 112°03.386. Seas slight; swell 1.5 m from the S; wind = 3.55 m/s from 140°. Over the past 24 hours we have completed one line along the outboard (lower slope) of the Carnarvon Basin (most probably Exmouth Sub-basin). The seabed is extremely rugged and dissected with numerous submarine canyons. Although not as steep or deeply incised as the canyons in the Zeewyck Sub-basin, the data show a couple of nice slumps on the canyon flanks. They also appear to head on the mid to upper slope. We are now concentrating on mapping the most northern part of the Sub-basin focusing on the large, deeply-incised Cape Range Canyon (which is a tropical equivalent to the Perth Canyon in the south) as we believe some nice rock exposures will be present for sampling the basin sediments. The students will complete their talks on their research today.

In the next 24 hours we will continue mapping the canyons of the Carnarvon Basin (most probably Exmouth Sub-basin).

**Tuesday 02 December 2008.** Ship's position at 00:00 UTC 02/12/2008 = -21°40.053, 113°04.645. Seas smooth; swell 1 m from the S; wind = 5.53 m/s from 255°. Over the past 24 hours we have continued mapping the northern section of the Carnarvon Basin (most probably Exmouth Sub-basin), concentrating on the deeply incised Montebello and Cape Range Canyons. We have had to amend our mapping plan slightly to accommodate a seismic vessel (Pacific Sword) that is operating in the area. As a result we will not be able to map all of the northern section of the sub-basin and will concentrate on completing mapping of Montebello Canyon before heading west to begin sampling. Sampling will focus of obtaining tv grabs and rock dredges in the deeper parts of the sequence.

In the next 24 hours we will sample the deep sections of the canyons in the Northern Carnarvon Basin (most probably Exmouth Sub-basin).

**Wednesday 03 December 2008.** Ship's position at 00:00 UTC 03/12/2008 = -21°51.614, 112°44.438; Seas smooth; swell 1 m from the S; wind = 5.26 m/s from 228°.Over the past 24 hours we have completed mapping of the northern Carnarvon Basin (most probably Exmouth Sub-basin). Multi-beam data shows the Montebello Canyon migrating up slope via slope failure at its head (extensive failures are also present on the northern flank) and a smaller tributary canyon extends up-slope from the present knickpoint. We could not tell from the data, but it is probable that this tributary canyon connects with smaller gullies (feeder canyons) seen in multi-beam data on the upper slope/outer shelf. We have amended our plan to avoid the seismic vessel and thus have commenced sampling in the western region of the sub-basin. We have completed two tv grabs and a rock dredge. Both the TV grabs on the southern margin show precipitous slopes with well-bedded rocks interspersed with near vertical massive blocks. the one completed dredge contained friable greenish-brown siltstones as well as the ubiquitous pelagic ooze.

In the next 24 hours we will continue to sample the deep sections of the canyons in the Northern Carnarvon Basin (most probably Exmouth Sub-basin).

**Thursday 04 December 2008.** Ship's position at 00:00 UTC 04/12/2008 = -21°52.125, 112°41.187; Seas smooth; swell 1 m from the S; wind = 4.94 m/s from 196°. Over the past 24 hours we have completed two tv grabs and a rock dredge in Cape Range Canyon. Both the tv grabs showed very rugged slopes with bedded sediments separated by near vertical massive blocks. Very little biota was observed. The grabs contained black shales and organic-rich mudstones. We are dredging deeper in the section in water depths of >4,000 m now. Last night DR16 became fixed to the seabed. Generally, this is a regular occurrence and not a problem. In the process of getting the dredge free the winch lost power. The engineers and captain worked tirelessly for 9 hours straight (not stopping for lunch or dinner) to find the problem in what is a very complex system. Including 8 phone calls to the winch manufacturer in Germany, the problem was found and the winch is now back in complete working order. It was a faulty card in one of the controller boxes although the outward signs gave no indications that it was faulty. I commend the ship's crew and officers in their tireless efforts to get the winch working again. We retrieved the dredge, and despite the chain bag being relatively worse for wear after being stuck to the seabed for 9.5 hours the pipe dredges contained the following: black shale, felsic igneous rocks, weathered limestone, dolerite(?), mudstone, and ooze. Not a bad haul for one of the lengthiest dredges in GA history.

In the next 24 hours we will continue to sample the deep sections of the canyons in the Northern Carnarvon Basin (most probably Exmouth Sub-basin).

**Friday 05 December 2008.** Ship's position at 00:00 UTC 05/12/2008 = -22°10.531, 112°26.596; Seas smooth; swell 1 m from the S; wind = 8.86 m/s from 170°. Over the past 24 hours we have completed two tv grabs and two rock dredges in the lower Cape Range Canyon. The grabs continue to show very rugged slopes with bedded sediments (mudstones, shales) separated by vertical massive blocks (sandstones, igneous rocks(?)). Very little biota has been observed. The dredges contained friable sandstones and carbonaceous mudstones. We are not completely sure, but we think the shales may be the Locker Shale (has all the right elements) and the sandstones part of the Mungaroo Formation. We will continue to seek an interpretation of the rocks as more samples come on board. We also completed a CTD in 4,900 m water depth in the lower Cape Range Canyon. The data will be used to correct the multi-beam sonar data as well for geochem. Transit between the canyons now means that we have collected >100,000 km$^2$ of new multi-beam sonar data. I believe this is an area nearly half the size of the state of Victoria and the largest area of spatially continuous swath data collected on the Australian margin.

We are currently sampling a station in 4,700 m water depth in the lower Cloates Canyon to sample rocks lower in the sequence. In the next 24 hours we will complete sampling in Cloates Canyon and begin mapping again by filling in two gaps in coverage (as a result of our interaction with the Pacific Sword) before running a tie line for the mag and gravity. We will then commencing mapping of the outboard section of the central and southern regions of the Carnarvon Basin (most probably Exmouth Sub-basin).

**Saturday 06 December 2008.** Ship's position at 00:00 UTC -22°17.559, 112°50.099. Seas moderate; swell 1.5 m from the S; wind = 9.37 m/s from 183°.Over the past 24 hours we have completed two tv grabs and two rock dredges in Cloates Canyon. The first station in the lower canyon in 4,700 m water depth was selected to sample basement rocks. The tv grab showed a very rugged seabed with 100 m high vertical sections. The dredge recovered more of the friable sandstones. Interestingly, some of the fragments were concretions characterised by doloritic cement. The station in the upper part of the Canyon was characterised by highly fractured and well bedded mudstones covered with abundant benthic biota. Overhangs and vertical drop offs of >100 m were common. The dredge recovered friable mudstones and biota seen in the video, including bamboo corals, brittle stars, hydroids, sea whips, gorgonians, and goose barnacles. Although not sampled, weird tadpole-like fish were also seen in the video.

We are currently completing the E-W tie line across the northern Carnarvon Basin (most probably Exmouth Sub-basin) for the magnetic and gravity data. In the next 24 hours we will continue mapping the outboard sections of the central and southern Carnarvon Basin (maybe Exmouth Sub-basin).

**Sunday 07 December 2008.** Ship's position at 00:00 UTC -23°16.104, 111°46.399; Seas slight; swell 1 m from the S; wind = 6.00 m/s from 193°. Over the past 24 hours we have continued mapping the outboard section of the central and southern Carnarvon Basin (maybe Exmouth Sub-basin). The multi-beam data show an extensively incised slope characterised by numerous submarine canyons. The canyons cut the slope by up to 1,500 m in their lower reaches, and extend into water depths of >5,000 m. From the multi-beam data and the rocks in the dredges we obtained from the northern Carnarvon Basin (most probably Exmouth Sub-basin) it would appear that this sub-basin extends much further offshore than presently shown on maps. Gravity and magnetic data are of excellent quality and imply relatively deep depocentres.

In the next 24 hours we will continue mapping the outboard sections of the central and southern Carnarvon Basin (maybe Exmouth Sub-basin).

**Monday 08 December 2008.** Ship's position at 00:00 UTC 07/12/2008 is -24°09.508, 111°03.508; Seas slight; swell 1 m from the S; wind = 7.31 m/s from 171°. Over the past 24 hours we have continued mapping the outboard section of the central and southern Carnarvon Basin (maybe Exmouth Sub-basin). The canyons appear to head in about 1500-2000 m water depth and we are beginning to map the mid slope which is characterised by slump features, similar to those seen in the Houtman Sub-basin.

In the next 24 hours we will finish mapping the outboard sections of the central and southern Carnarvon Basin (maybe Exmouth Sub-basin) and begin sampling in the canyons.

**Tuesday 09 December 2008.** Ship's position at 00:00 UTC 09/12/2008 = -22°50.563, 112°15.144; Seas slight; swell 1 m from the S; wind = 9.74 m/s from 175°. Over the past 24 hours we have completed mapping the outboard central and southern Carnarvon Basin (maybe Exmouth Sub-basin). The numerous canyons head on the mid slope in about 1500-2000 m water depth. We have selected two of the deepest canyons to sample over the next 3.5 days and commenced sampling.

In the next 24 hours we will continue sampling the central and southern Carnarvon Basin (maybe Exmouth Sub-basin).

**Wednesday 10 December 2008**. Ship's position at 00:00 UTC -23°16.119, 112°09.875; Fine; Seas moderate; swell 2.0 m from the S; wind = 10.72 m/s from 176°. Over the past 24 hours we have completed two sites in an unnamed canyon in the central Carnarvon Basin (maybe Exmouth Sub-basin). TV Grabs showed more gentle slopes than in the larger Cape Range and Cloates Canyons further north, but with some rock exposure. In the TV Grab we recovered carbonate muddy sand and gravel, and numerous rock fragments including: calcilutite, sandy mudstone, sandy claystone, claystone, argillaceous limestone, and partially lithified limestone. Given the very coarse grain size of the surface sediment and the variety of rocks we believe we sampled a slump or a turbidity deposit. The dredge from this site contained different rocks again, including: muddy sandstone interbedded with mudstone, calcilutite, and a carbonate concretion. Further inboard we only sampled argillaceous limestones in both the TV grab and dredge.

Although yet to be confirmed, our initial interpretation is that these rocks represent syn-rift sediments seen below the break-up unconformity in the seismic sections. We have yet to sample basement, but have a deep site in 4,900 m water depth in the next canyon where we hope to recover these rocks.

In the next 24 hours we will continue sampling the southern Carnarvon Basin (maybe Exmouth Sub-basin). We have had to slow our speed to 9.5 knots due to the increased sea and swell.

**Thursday 11 December 2008.** Ship's position at 00:00 UTC 11/12/2008 = -23°39.685, 111°13.603; fine; seas moderate; swell 2.0 m from the S; wind = 10.29 m/s from 168°. Over the past 24 hours we have completed two sites in an unnamed canyon in the southern Carnarvon Basin (maybe Exmouth Sub-basin). The TV Grab at the deepest site yet (4,900 m) showed the sea floor to be covered in pelagic ooze (and abundant sea cucumbers) but unfortunately with no suitable dredge sites. A sample of the ooze was recovered. The next deepest site (4,100 m) also showed similar environments, with a similar sample recovered. Again a dredge was not attempted at this site due to the lack of suitable outcrop. Currently, we are unable to open the jaws on the TV Grab and the electronic engineers are on to it. We sincerely hope they fix it, because no-one on board fancies digging a ton of pelagic ooze out of it by hand. They have a spare on board but still need to move the one we have been using (empty).

On the upside, the latest high resolution magnetics and gravity data just delivered confirms what we have been finding with the samples, that the sub-basin extends further offshore than presently shown on regional magnetic and gravity maps.

In the next 24 hours we will continue sampling the southern Carnarvon Basin (maybe Exmouth Sub-basin).

**Friday 12 December 2008.** Ship's position at 00:00 UTC -24°01.903, 111°25.617; fine; seas moderate to heavy; swell 3-4 m from the S; wind = 15.49 m/s from 132°. In the last 24 hours we have completed sampling in the unnamed canyon of the southern Carnarvon Basin (maybe Exmouth Sub-basin). The two sites we completed overnight showed stark differences. The first, in 4,000 m water depth was characterised by an extremely rugged seabed with vertical cliffs and overhangs of >100 m height and enormous angular blocks strewn about the base of the cliffs. The dredge got hooked up numerous times on this section (no wonder) but recovered: a very hard silicified mudstone containing a layer of forams and/or radiolarians; and several fragments of a fossiliferous sandstone containing ammonite impressions, bivalves, wood, angular quartzite clasts, and rounded siltstone pebbles. The quartzite clasts possibly suggest the sandstone was deposited close to basement and perhaps the basin sediments pinch out in this area, with a condensed section. The second site was characterised by overall shallower slopes with some steeper sections of exposed outcrop. The dredge contained fragments of muddy sandstone and sandy mudstone.

At present the TV Grab is out of action due to an electric motor burning out, which will take two days to fix. We are using the OFOS camera system in its place.

In the next 24 hours we will transit to the Houtman Sub-basin and pick up a site of a (volcanic?) pinncale to sample before mapping the inboard section of the southern Houtman Sub-basin. We have had to slow our speed to 9 knots due to the heavy sea and swell.

**Saturday 13 December 2008.** Ship's position at 00:00 UTC -26°08.446, 111°24.116; fine; seas moderate to heavy; swell 3-4 m from the S; wind = 11.01 m/s from 149°. In the last 24 hours we have continued mapping the Houtman Sub-basin. We have also completed an OFOS camera and rock dredge on a 300 m high now confirmed volcanic pinnacle in the northern Houtman Sub-basin. The camera showed basalt outcrops, with pillow structures and chilled fractures in the jointing. There was also abundant biota on the 1,000 m deep summit flanks, including: fish, corals, sponges, shrimp, brittlestars and crinoids. We also captured a beer can on the still images - Milwalkee Best brand (consensus on board is that it's not a bad drop for an American beer). The rock dredge contained fragments of highly weathered hayloclastic breccia with a glass rind and phenocrysts. One small piece of basalt and carbonate foraminiferal sand was also recovered. A large piece of coral was recovered from the pipe dredge.

Unfortunately, the adverse sea conditions continue to compromise the multi-beam data, with the system losing data due to cavitation under the hull. We are attempting to alleviate this problem by reducing the ship's speed to 8 knots. We are getting full coverage with a following sea and beam on to the swell. At present the TV Grab is out of action due to an electric motor burning out, which will take two days to fix. We are using the OFOS camera system in its place.

In the next 24 hours we will monitor the quality of the multi-beam data and if ok will continue mapping the southern Houtman Sub-basin.

**Sunday 14 December 2008.** Ship's position at 00:00 UTC -26°04.849, 111°35.784; fine; seas slight; swell 1-1.5 m from the S; wind = 7.35 m/s from 194°. In the last 24 hours we have continued mapping the central Houtman Sub-basin. The data show the seabed to slope gently to the west, which is characterised by numerous slump features with 100 m high scarps. The whole of this part of the margin is characterised by these slump features. Also, several broad, shallow canyons incise the slope to 100 m depth. Interestingly, these canyons show distinct curved profiles, possibly related to underlying structures. Sea conditions are perfect now and we are getting excellent data. However, yesterday during the heavy going the data were not recorded by the gravity meter for about 10 hours. We have decided to re-run the line on which the data are missing. This will avoid having a gap in the coverage and allow us to collect 'clean' swath data over that area, thus filling gaps resulting from the rough conditions.

The TV Grab remains out of action due to an electric motor burning out. The engineers continue fixing it. Latest news is that it will be ready for the last two stations on Tuesday morning.

In the next 24 hours we will finish mapping the central Houtman Sub-basin and then commence sampling. We have three stations identified to target basin rocks.

**Monday 15 December 2008.** Ship's position at 00:00 UTC -26°49.053, 111°05.307; fine; seas slight; swell 1-1.5 m from the S; wind = 8.28 m/s from 174°. In the last 24 hours we completed mapping the central Houtman Sub-basin. We also completed a station on a 200 m high linear scarp in 3,200 m water depth on the outboard section of the basin, adjacent to the Wallaby Saddle. The video showed large up-turned and rotated blocks of chalk containing rounded and angular cobbles of darker mudstones and mafic rocks. Limestone conglomerates containing smaller pebbles of these darker rocks were also seen. These could be blocks that have tumbled down the slope, or perhaps part of the toe of the slumps that characterise the margin. The dredge contained chalk blocks. No large non-marine rocks were recovered, but small scoria fragments were sieved from the pipe dredges. The TV Grab has been fixed by the engineers and is being used at the next two stations.

In the next 24 hours we will finish sampling the central Houtman Sub-basin and begin our transit back to Fremantle.

**Tuesday 16 December 2008.** Ship's position at 00:00 UTC -26°32.601, 111°30.132; fine; seas slight; swell 1-1.5 m from the S; wind = 11.80 m/s from 173°. In the last 24 hours we completed two stations in unnamed canyons in the central Houtman Sub-basin. Both sites showed very steep slopes characterised by well-bedded vertical sections interspersed with shallower-gradients of chalky conglomerate containing pebbles and cobbles of different types of rocks. These conglomerates may be debris flow or turbidite deposits. The dredges from each site recovered chalk and fine-grained organic-rich friable sandstones and organic-rich siltstones and mudstones.

We are currently completing a camera and boxcore on the headwall of a large slump on the inboard section of the Houtman Sub-basin. Once the station is completed we will begin our transit back to Fremantle for hand-over.

The TV Grab has stopped working again and the engineers will try to fix it before the next leg.

**Wednesday 17 December 2008.** Ship's position at 00:00 UTC -29°19.419, 113°38.212; fine; seas slight; swell 1.5-2.0 m from the S; wind = 11.39 m/s from 169°. In the last 24 hours we completed a box core and camera station on the headwall of a slump deposit in the central Houtman Sub-basin. The camera showed gentle slopes and steep sections of finely bedded limestone/chalk. The boxcore contained interbedded pelagic carbonate sand and mud. Dominant constituent are forams. We then began our transit back to Fremantle, mapping the inboard sections of the Houtman and Zeewyck sub-basins. The swath data reveal the upper part of the slope to be characterised by slump deposits also. The SBP is giving excellent results with numerous reflectors being imaged.

Today, the UoS students will give their final presentations of their projects and the chief scientist will give a presentation of the results of the survey. In the next 24 hours we will continue our transit back to Fremantle.

**Thursday 18 December 2008.** Ship's position at 00:00 UTC -32°02.973, 115°44.709; fine; seas slight; swell nil; wind = 5.66 m/s from 99°.In the last 24 hours we completed our transit to Fremantle. RV Sonne arrived in Fremantle at 00:15 UTC on a mild, still, and cloudless morning. Yesterday, the students gave their final presentations on their projects. They did a fantastic job of summarising the sub-bottom profiler and video data collected on survey. Their motivation is outstanding. They provide a real energy and enthusiasm on the marine surveys. I congratulate them. I then gave a summary of the main achievements of leg 2, which are as follows:

1. identification of >40 new "blind" canyons on the Cuvier margin;
2. probable Cenozoic volcanism on the Bernier Platform (previously unknown);
3. identification of extensive mass wasting on the mid to lower slopes of Carnarvon Terrace;
4. collection of first-ever samples of syn- and post-rift sediments for Houtman Sub-basin and possibly an unknown segment of the Carnarvon Basin; and
5. recovery of indirect evidence of basement from quartzite xenoliths and felsic rocks.

We have increased our knowledge of the geology of the three sub-basins, provided evidence for the western boundary of the Carnarvon Basin to be moved 60 km to the west, and collected rocks that are likely to upgrade their petroleum prospectivity.

Data summary for Leg 2:
Multi-beam = >54,286 $km^2$
SBP and potential field = >7,986 line-km
Samples: DR = 17; GR(TV) = 14; CAM = 6; BS = 3; CTD = 2; BC = 1

Data summary for Legs 1+2:
Multi-beam = >128,256 $km^2$
SBP and potential field = 17,246 line-km
Samples: DR = 41; GR(TV) = 25; CAM = 9; CTD = 6; BC = 5; BS = 3; XBT = 2;
BT = 1

In the next 24 hours we will complete the change-over with Leg 3 personnel.

Leg 3.

**Sunday 21 December 2008.** Zeewyck Sub-basin (Study Area A). Position at 0000 UTC 30 14.377S 114 21.982E. Winds: 5 m/s from south. Seas: Slight on a low swell. The ship departed Fremantle on time at 0830 (local time) on the 20th December with all crew on board. Following a pilot escort from the port we transited to Stn 049 (Locality: Zeewyck-14; 31 13.962S 114 36.3041E), and successfully completed a TV Grab (BODO) and dredge sample.

Visual observation of the seabed at Stn 049 indicated minor rock outcrop at top of slope and mud down slope. Biota included sea cucumbers and acorn worms, with tracks and burrows being common. The grab from BODO return unlithified sandy-mud (biogenic ooze) of varying water content. The dredge recovered consolidated cool-water carbonate ooze with manganese-coating on exposed surfaces. The next 24 hours will consist of a transit north, along the inboard margin of the Zeewyck Sub-basin, toward the Cuvier Plateau to begin mapping Study Area D.

A couple are still finding their sea legs, but otherwise all crew are healthy and enjoying settling into their work programs.

**Monday 22 December 2008.** Houtman Sub-basin (Study Area B). Position at 0130 UTC 26 38.994S 111 40.646E. Winds: 10 m/s from south-southeast. Seas: Moderate on a low swell. The transit north along the inboard side of the Zeewyck and Houtman sub-basins continued over the past 24 hours, as we head to the Cuvier Plateau (Study Area D). The multi-beam bathymetry data shows the landward extent of some of the canyons identified on previous legs. We reached the end of the north-directed transit at approximately 0200 hrs 22/12/2008 UTC, and began transiting southwest to begin a survey line to the south of the line from Leg 1 coming in from Singapore. We hope to complete the mapping of the southern slope of the Cuvier Plateau with this line.

The next 24 hours will consist of swath, sub-bottom profiler, gravity and mag acquisition along the southern margin of the Cuvier Plateau.

**Tuesday 23 December 2008**. Cuvier Plateau (Study Area D). Position at 0030 UTC 26 22.962S 109 30.082E. Winds: 12.5 m/s from southeast. Seas: Slight-moderate on a low swell. The survey line along the southern margin of the Cuvier Plateau continued over the last 24 hours. At times the swath width reached 22 km. The data continues to be of excellent quality. The data collected along the inboard margin of Study Area B (Houtman Sub-basin) was in approximately 1000 m water depth and shows that we now have coverage of the heads of most of the canyons in this area. Over the next 24 hours we will continue to acquire swath, sub-bottom profiler, gravity and mag along the southern margin of the Cuvier Plateau. We also expect to reach Stn 050 at approximately 1200 hrs 23/12/2008 UTC where we will undertake a video tow and dredge operation. The swath bathymetry for the site, collected on the Leg 1 transit from Singapore, indicates a good quality dredge target.

**Wednesday 24 December 2008.** Cuvier Plateau (Study Area D). Position at 0600 UTC 24 32.231S 106 54.974E. Winds: 9.7 m/s from south-southeast. Seas: Slight-moderate on a low swell. Mapping of the southern margin of the Cuvier Plateau continued for the first part of the day. The ship arrived at Stn 050 (31 13.962S 114 36.3041E) at approximately 1330 hrs 23/12/2008 UTC. Visual observation of the seabed at Stn 050 indicated relatively low abundance of biota. Rocks at the surface appeared to be tabular in a few places, but overwhelmingly appeared to be pillow basalts, becoming more broken up toward the lower end of the transect. Approximately 250 kg of material was recovered in the dredge, most of which appears to be either highly weathered basalt or a mudstone in hand specimen. The sampling operations at Stn 050 were completed at approximately 0030 hrs 24/12/2008 UTC, and the magnetometer was redeployed.

Mapping of the Cuvier Plateau will now resume for the next couple of days. We are continuing to monitor the development of TC Billy, but at present it poses no threat as its course is tending west-northwest.

**Thursday 25 December 2008.** Cuvier Plateau (Study Area D). Position at 0530 UTC 25 16.661S 108 24.164E. Winds: 13.3 m/s from southeast Seas: Moderate on a low-moderate swell. Mapping of the southern margin of the Cuvier Plateau continues. Three survey lines in Study Area D are now completed. Most of the southern extent of the plateau was successfully mapped with our first survey line. The second survey line was completed by Leg 1 on the transit from Singapore. The third survey line indicates a largely flat and featureless plateau surface. The bottom appears to be very soft in places with poor acoustic return.

The fourth survey line began at approximately 0200 hrs 25/12/2008 UTC. At the completion of this survey line we will be at its northwestern end, and will make a short transit to Stn 051, located at 24 29.139S 106 53.642E. We expect to arrive at approximately 1600 hrs 25/12/2008 UTC to begin a camera (OFOS) transect and dredge sampling.

TC Billy has intensified to Category 4, but remains 500-600 nm north of us and tracking westward, so is currently posing no threat.

**Friday 26 December 2008.** Cuvier Plateau (Study Area D). Position at 0700 UTC 24 26.904S 106 57.072E. Winds: 13.3 m/s from southeast. Seas: Moderate on a low swell. We arrived at Stn 051 (24 29.139S 106 53.642E) at approximately 1600 hrs 25/12/2008 UTC and began sampling operations with a video (OFOS) transect. The first part of the transect (top of slope) consisted of a flat, muddy seabed, which gave way to rocky outcrop toward the end of the transect (further down-slope). Crinoids, possible sea urchins, shrimps and sea cucumbers were also observed. The dredge operation began well, but tension on the wire towards the end of the dredge reached 12 T and the shear pin gave way. The dredge was recovered, but most of the material was lost except for a few small pieces of weathered volcanics. A second dredge was attempted, but there were no significant bites and the chain bag came up empty. The pipe dredges contained unconsolidated, carbonate ooze and several rock fragments with a similar lithology to those recovered in the first attempt. We have now resumed mapping along a line to fill the gaps between two previous survey lines as we head towards Stn 052 (25 09.520S 107 58.485E) in 3900 m water depth. We expect to arrive on station at 1330 hrs 26/12/2008 UTC, and in the interest of saving time (and the fact that the station is close to Stn 051), we will only attempt a dredge sample at this location.

TC Billy has turned a little south from its westerly track, and will probably intensify again, but continues to pose no immediate threat.

**Saturday 27 December 2008.** Cuvier Plateau (Study Area D). Position at 0500 UTC 25 27.803S 108 33.852E. Winds: 13.6 m/s from south-southeast. Seas: Moderate on a moderate swell (rising). We arrived at Stn 052 (25 09.828S 107 58.135E) at approximately 1800 hrs 26/12/2008 UTC. A dredge was successfully completed in 4264 m water depth, although, the dredge was hooked on the bottom and the ship had to be maneuvered directly overhead in order to recover it. The lithologies recovered in the dredge included igneous (probably volcanic) rocks with secondary veining, as well as a well-sorted mudstone. The pipe dredge contained unconsolidated carbonate ooze.

After completing Stn 052 we undertook a 45 nm transit, at reduced speed due to sea conditions, to Stn 053 (25 31.966S 108 32.362E). Our initial intention was to perform a camera (OFOS) transect and dredge operation, but the swell is about 4 m thus precluding the camera operation. We will proceed with the dredge and then over the next 24-48 hours we will continue mapping the Cuvier Plateau (Study Area D). The increasing swell from the south-southeast, due to steady winds from that sector for the past 5 days, is slowing progress. At present, however, forward planning indicates we should still complete priority sampling sites in Study Area D and achieve close to 100% coverage with the multi-beam.

TC Billy is decreasing in intensity (now about 980 mb) and has dropped to Category 1 with winds easing. It remains no immediate threat.

**Sunday 28 December 2008.** Cuvier Plateau (Study Area D) Position at 0530 24 43.962S 107 46.650E. Winds: 13.0 m/s from southeast. Seas: Moderate on a moderate swell. We arrived at Stn 053 (25 31.970S 108 32.348E) at about 0600 27/12/2008 UTC, which is in about 4440 m water depth. The dredge was back on deck at about 1045 UTC, with approximately 45 kg of material in the chain bag. The lithologies recovered include (1) a volcaniclastic breccia interpreted as reworked mafic volcanics proximal to site and time of eruption; (2) vesicular basalt; and (3) a shell-rich sandstone interpreted as shallow marine reworking of biogenic and clastic sediments. The pipe dredge contained unconsolidated gravely, sandy ooze.

We will continue mapping the central Cuvier Plateau (Study Area D) over the next 24 hours, and then select suitable sampling sites to characterize some of the geomorphic features and habitats present.

**Monday 29 December 2008.** Cuvier Plateau (Study Area D). Position at 1330 UTC 25 08.112S 108 37.849E. Winds: 11.0 m/s from south-southeast. Seas: Slight on a moderate swell. We have completed another survey line on the Cuvier Plateau in the past 24 hours and have begun the fifth. The surface of the plateau includes broad, low relief 'valleys', which appear to be related to normal faulting (evident from existing seismic lines). The sub-bottom profiler is working particularly well in this area; revealing considerable near-surface structure, including some apparent lithological boundaries. A site has been selected for the next round of sampling: Stn 054 (24 38.150S 107 45.283E). We should arrive at Stn 054 at about 2000 hrs 29/12/2008 UTC, where we will complete a camera (OFOS) transect, box core, and potentially a benthic sled. After completing this station we will resume mapping the central Cuvier Plateau (Study Area D).

Sea conditions remain generally conducive for both mapping and sampling, although, ship speed must be reduced when heading southeast at present in order to ensure good multi-beam data. All on board remain healthy and in good spirits.

**Tuesday 30 December 2008.** Cuvier Plateau. Position at 1400 UTC 24 11.659S 107 27.307E. Winds: 9.0 m/s from southeast Seas: Slight on a low swell. We arrived at Stn 054 (24 37.889S 107 45.249E) at about 2100 hrs 29/12/2008 UTC, and completed a successful camera tow and box core. The site was located on the floor of a broad, low relief valley apparently related to a sub-surface graben structure. Observations of the seabed in the video did not warrant the possible benthic sled. The seabed was largely flat and muddy, with tracks, burrows and the occasional fish observed. The box core recovered fine-sandy carbonate ooze. We have resumed mapping the central Cuvier Plateau. We completed the $6^{th}$ survey line this evening and have started the 7th. Over the next 24 hours we will continue mapping our way towards potential dredge sites B, E, and J.

**Wednesday 31 December 2008.** Cuvier Plateau. Position at 1330 UTC 24 22.561S 107 51.688E. Winds: 11.0 m/s from southeast Seas: Slight-moderate on a low swell. We have continued mapping the central Cuvier Plateau over the past 24 hours and have completed approximately half of Study Area D. We have identified one new potential dredge site on one of the new seismic lines from the Duke. After completing the next survey line we will have a better picture of the outcrop and it's potential.

**Thursday 01 January 2009.** Cuvier Plateau. Position at 1330 UTC 24 22.018S 107 48.893E. Winds: 10.0 m/s from south-southeast. Seas: Slight on a low swell. We completed another half a survey line before proceeding to Stn 055 (24 21.746S 107 48.418E), which we identified as a new site using the seismic recently acquired by the Duke and our multi-beam bathymetry. We arrived on station at approximately 0300 hrs 01/01/2009 UTC and successfully completed a video transect and a grab at the conclusion of the transect using BODO. The seabed was observed to be generally flat and featureless, except for a narrow rock wall approximately 10 m wide and <5 m high (unknown strike length), which was our dredge target. Unfortunately, the dredge was of limited success, with nothing in the chain bag, and only a small piece of poorly-moderately sorted quartz sandstone with darker accessory minerals and a small piece of manganese-oxide crust in the pipe dredge. Most of the material in the pipe dredge was unlithified muddy sand (carbonate). A benthic sled at Stn 055 is currently in progress. After completing the benthic sled we will resume mapping the central Cuvier Plateau.

To date, Legs 1-3 have mapped a total of 157,169 sq km of the Western Australian margin.

**Friday 02 January 2009.** Cuvier Plateau. Position 1145 UTC 24 21.647S 108 12.164E. Winds: 8.5 m/s from south-southeast. Seas: Slight on a low swell. The benthic sled at Stn 055 returned no biological samples, but it did return a few kilograms of rock (mainly pebble size). Most, if not all, were igneous. On leaving Stn 055 we resumed mapping the central Cuvier Plateau. We have one more WNW-ESE line to complete in order to finish the central part of the plateau. The EM120 had a couple of hiccups today, losing the realtime processing/display update (but no lost data), as well as the re-appearance of a noise problem that has cropped up intermittently over the past few days. Several possible solutions are being sequentially implemented over the next 12 hours to attempt to solve the problems. The gravity, mag and sub-bottom profiler acquisition is continuing smoothly.

Over the next 24 hours we will continue mapping the central plateau before moving on to map and sample the northern part of the Cuvier Plateau.

**Saturday 03 January 2009.** Cuvier Plateau. Position 1200 UTC 23 52.467S 109 17.281E. Winds: 11.0 m/s from south-southeast. Seas: Moderate on a moderate swell. We completed mapping the WSW-ESE oriented part of the polygon on the Cuvier Plateau (with the exception of some short exit lines) and began the first line in the NNE-SSW oriented part of the polygon at approximately 0630 hrs 03/01/2009 UTC. This morning the ship speed had to be slowed to about 7-8 kn, due to deteriorating sea conditions, but the ship motion improved considerably with the change in orientation of the survey lines mid afternoon and we are mapping again at over 10 kn. The multi-beam system seems to be over its hiccups from yesterday and performing normally.

In the next 24 hours we will continue mapping the northern part of the polygon over the Cuvier Plateau and proceed to Stn 056 (24 1.046S 109 11.648E; Site J). We should arrive on station at about 0330 04/01/2009 UTC, and will undertake a video grab transect and dredge operation.

**Sunday 04 January 2009.** Cuvier Plateau. Position at 1300 UTC 24 01.345S 109 12.133E. Winds: 8.3 m/s from south-southeast. Seas: Slight on a low-moderate swell. We continued mapping the northern part of the Cuvier Plateau polygon for the first half of the day, until we reached Stn 056 (24 01.119S 109 11.9249E, Site J), situated in approximately 3200 m water depth. A camera transect and grab were successfully completed. The camera tow was consistent with previous sites, indicating a relatively barren seafloor. The grab returned sandy carbonate ooze with forams and other nanofossils, plus about half a kilogram of mafic volcanic pebbles. The camera showed considerable (low relief) rock outcrop along the entire transect, but the first dredge attempt yielded nothing in the chain bag and less than 5kg of pebbles and gravel in the pipe dredges. The relatively low seabed gradient and low relief outcrop, characteristic of the potential dredge sites on the Cuvier Plateau, appears to be limiting our success. We are attempting a second dredge at this sight in the hope of recovering enough material for dating. This dredge operation is currently in progress.

Over the next 24 hours we intend to complete another one and a half survey lines in the northern part of the polygon and begin sampling Stn 057 (Site K).

**Monday 05 January 2009:** Cuvier Plateau: Position at 1200 UTC 23 40.908S 109 42.056E. Winds: 8.7 m/s from south. Seas: Slight on a low swell. The second dredge attempt at Stn 056 yielded no more than the first – largely mafic volcanic pebbles and one gravel sized zeolite. Most of today we have continued mapping the northern part of the polygon over the Cuvier Plateau. The plateau appears to be a terrain of volcanic flows, with several geomorphic features that appear to be shield volcanos. The best example is centred at 24 12.2S 109 12.8E.

Given recent experience, we have dismissed Site K as a poor dredge prospect and are currently approaching Stn 057 (Site F) located at approximately 24 00.983S 109 30.536E in approximately 4050 m water depth, where we intend to do a camera transect (OFOS) and dredge. After a short transit we will repeat the same at Stn 058 (identified from seismic lines recently acquired on the Duke), located at approximately 23 40.432S 109 40.872E in 4500 m water depth. At both stations the target is basement or pre-break basin fill.

**Tuesday 06 January 2009:** Cuvier Plateau. Position 1039 UTC 24 01.147S 109 30.416E. Winds: 10.7 m/s from south. Seas: Moderate on a low-moderate swell. We arrived at Stn 057 (Site F) 23 40.323S 109 41.227E at approximately 12:45 05/01/2009 UTC. We completed a camera (OFOS) transect and a dredge at this station. The sea floor was observed to be a mixture of flat to sloping muddy substrate and low-relief rocky substrate, largely barren of benthic organisms. The dredge returned approximately 3kg of conglomerate consisting of pebble-sized basaltic clasts, as well as some basalt and unconsolidated carbonate ooze in the pipe dredges. After completing a 30 nm transit we arrived at Stn 058 (24 01.268S 109 30.974E) at approximately 0100 hrs 06/01/2009 UTC. The camera transect indicated that this site is very similar to the previous sampling station. A dredge is currently in progress.

Over the next 24 hours we will continue mapping the Cuvier Plateau polygon. We will also select 1 or 2 sites suitable for sediment sampling with the box corer.

**Wednesday 07 January 2009:** Cuvier Plateau (Study Area D). Position at 1330 UTC: 24 34.091S 108 41.669E. Winds: 11 m/s from south-southeast. Seas: Moderate on a moderate swell. The dredge at Stn 058 (24 01.268S 109 30.974E) was completed at approximately 1000 hrs 06/01/2009 UTC. Sandy ooze (carbonate) was recovered in the pipe dredge. Approximately 2 kg of mafic volcanics and manganese crust were also recovered. After completing Stn 058 we completed a tie-lie in the northern part of the polygon over the Cuvier Plateau and continued south back to the main polygon to continue mapping an area in the northeast corner. We arrived at Stn 059, which is located at 24 34.400S 108 41.736E, at 1330 hrs 07/01/2009 UTC. The camera tow (OFOS) indicated a flat, muddy seabed (as expected) with some tracks and burrows, but very little marine life. We intend to also complete a CTD and box core at this station. The intention of the CTD is to measure the benthic DO level to see if it is potentially limiting the marine life in the region. Over the next 24 hours we will complete Stn 059, complete the mapping of the northeast part of the main polygon over the Cuvier Plateau (the only piece remaining), and begin a roughly north-south tie-line on our way to another camera/CTD/box core station on the plateau.

**Thursday 08 January 2009:** Cuvier Plateau (Study Area D). Position at 11:30 UTC 24 37.232S 109 00.525E. Winds: 10.9 m/s from southeast. Seas: Slight-moderate on a moderate swell. We completed Stn 059 early in the day. We lost communication with the CTD in the last 200 m coming up to the surface, so were unable to obtain water samples in the surface mixed layer of the water column. The Sonne technicians have addressed the issue and hopefully the CTD will perform flawlessly at the next station. The box core was successful and returned 30 cm penetration of sandy-mud (carbonate ooze). For most of today we have continued mapping the northeast corner of the main part of the polygon over the Cuvier Plateau. We have now mapped what appear to be 3 shield volcanos approximately 20 nm in diameter and two that are approximately 70 nm in diameter. Their relief is approximately 1000-1500 m. We expect to finish mapping the Cuvier Plateau polygon at around 1500 hrs 08/01/2008 UTC, at which time we will commence a tie line that will take us south to Stn 060, located at approximately 25 31.221S 109 10.873E, in approximately 3800 m water depth. We intend to complete a camera tow (OFOS), CTD and box core at this station. At the completion of Stn 060 we will complete the tie line and transit to Stn 061, where we have attempted a dredge previously. This will be our last roll of the dice (or dredge in this case) in an attempt to recover pre-rift basin fill sediments from the Cuvier Plateau.

**Friday 09 January 2009 :** Cuvier Plateau (Study Area D). Position at 1330 UTC 25 32.569S 108 31.997E. Winds: 8.5 m/s from south-southeast. Seas: Slight on a low-moderate swell. We arrived at Stn 060 (25 31.186S 109 10.892E) at approximately 2200 hr. 08/01/2009 UTC. The camera tow (OFOS) indicated a flat, low relief, muddy seabed. A couple of orange prawns were observed in the video and one came on deck; caught up in OFOS. It is now in a sample jar, as you might expect. The box core returned over 30 cm (80% full) of undisturbed seabed, consisting of sandy mud (carbonate ooze). Biota recovered from the box core included 2 Tanaids, a Mason worm, and various other worms. A limited mix, but without doubt the most biota we have extracted from a site to date. The box core was also sampled for geochem analysis, as have all the box cores and BODO grabs collected to date. With the completion of a proposed Stn 062 (see below), we will have geochem analyses for a depth range covering 2600-4700 m. The CTD showed a seasonal thermocline sitting above the permanent thermocline, which is typical in these latitudes for summer.

**Saturday 10 January 2009:** Wallaby Saddle (Study Area D)Position At 15:30 UTC 26 36.511S 110 02.929E. Winds: 9.9 m/s from south-southeast. Seas: Slight on a low-moderate swell. We arrived at Stn 061 (25 32.4655S 108 32.1128E), where we have had a previous dredge attempt, at approximately 1230 hr 09/01/2009. This time round was much more successful and we recovered about 100 kg of material including (a) 30 kg of massive, very-well-sorted clay/siltstone containing molluscs, (b) 20 kg of massive, well-sorted claystone with no apparent fossils, and (c) 15 kg of andesitic-dacitic, coarsely crystalline volcanic material. After completing Stn 061 we began our transit to the inboard section of the Houtman Sub-basin (Study Area B) to obtain mag/grav data over the gravity anomaly on the eastern side of the polygon. At approximately 0830 10/01/2009 we arrived at Stn 062, on our transit line across the saddle between the Cuvier Plateau and the continental shelf. We completed a camera (OFOS) tow, and a box core is currently underway. The seabed here is 4,600 m deep, flat, muddy and relatively barren.

**Sunday 11 January 2009:** Houtman Sub-basin (Study Area B). Position at 1200 hrs UTC 26 40.010S 112 05.843E**.** Winds: 9.5 m/s from south-southwest. Seas: Slight on a low-moderate swell**.** The box core at Stn 062 was unsuccessful. The tension record on the winch clearly indicated good penetration of the seabed, but it is most likely that a wire tangle prevented the bottom of the corer from closing immediately and the material was lost shortly after extraction. Due to the large water depth it was decided that there was insufficient time to repeat the attempt and we resumed our transit to the Houtman Sub-basin (Study Area B). We arrived at the inboard margin of the Houtman polygon at about 0700 11/01/2009 UTC and began acquiring multi-beam bathymetry, magnetic and gravity data at a line spacing that will give us good coverage of the gravity anomaly in the area in the time available. The line spacing will not deliver 100% swath coverage however. We will continue mapping in the Houtman Sub-basin for the next 48 hours.

**Monday 12 January 2009:** Houtman Sub-basin (Study Area B). Position at 1330 hrs UTC 25 07.110S 111 32.226E. Winds: 11.0 m/s from south-southeast. Seas: Slight-moderate on a low swell. Today we continued acquiring multi-beam bathymetry, magnetic and gravity data on the inboard side of the Houtman Sub-basin. We completed all of the planned lines and are currently on our last line heading north to the Carnarvon Basin and on to Port Hedland. Our transit will add to the previous legs coverage of the inboard side of the Carnarvon Basin. Gear is slowly being packed up, data backups are under way etc. etc.

## 13.2. APPENDIX B – SURVEY STAFFING

### Scientific Personnel

The multi-disciplinary nature of the survey required the efforts of a group of scientists with a wide variety of complementary skills to make it successful. The survey personnel, representing organisation, and their substantive roles are listed in Table 13.1-3.

**Table 13.1.** Scientific survey personnel for survey GA2476 Leg 1, representing organisation, and their substantive roles.

| NAME | ORGANISATION | ROLE |
|---|---|---|
| *Leg 1 (20 October – 20 November)* | | |
| Kriton Glenn | Geoscience Australia | Chief Scientist |
| Chris Nicholson | Geoscience Australia | Co-chief Scientist |
| Lynda Radke | Geoscience Australia | Geochemist |
| Justy Siwabessy | Geoscience Australia | Swath Processor |
| Cameron Buchanan | Geoscience Australia | Swath Processor |
| Tanya Whiteway | Geoscience Australia | GIS Technician |
| Diane Jorgensen | Geoscience Australia | Petroleum Geoscientist |
| Daniel Mantle | Geoscience Australia | Petroleum Geoscientist |
| Arthur Mory | Geological Survey of Western Australia | Petroleum Geoscientist |
| Danielle Payne | Geoscience Australia | Petroleum Geoscientist |
| Andrew Hislop | Geoscience Australia | Mechanical Technician |
| Craig Wintle | Geoscience Australia | Mechanical Technician |
| John Jaycock | Geoscience Australia | Geological Technician |
| Stephen Hodgkin | Geoscience Australia | Electronic Technician |
| Tara Anderson | Geoscience Australia | Marine Biologist |
| | | |
| Kelsie Dadd | University of the Sea | Teaching Scientist |
| Cody Miller | University of the Sea | Scientist |
| Ben Harris | University of the Sea | Scientist |
| Bryna Flaim | University of the Sea | Scientist |
| Rebecca Norman | University of the Sea | Scientist |
| Wentao Ma | University of the Sea | Scientist |
| Yadi Aryadi | University of the Sea | Scientist |

**Table 13.2.** Scientific survey personnel for survey GA2476 Leg 2, representing organisation, and their substantive roles.

| *Leg 2 (21 November – 18 December)* | | |
|---|---|---|
| Andrew Heap | Geoscience Australia | Chief Scientist |
| James Daniell | Geoscience Australia | Co-chief Scientist |
| Craig Smith | Geoscience Australia | Geochemist |
| Shoaib Burq | Geoscience Australia | Swath Processor |
| Michele Spinoccia | Geoscience Australia | Swath Processor |
| Tom Mueller (GEMD) | Geoscience Australia | GIS Technician |
| Irina Borissova | Geoscience Australia | Petroleum Geoscientist |
| Peter Haines | Geological Survey of Western Australia | Petroleum Geoscientist |
| Gary Williams | Geological Survey of Western Australia | Geological Technician |
| Vanessa Coisne | Geoscience Australia | Petroleum Geoscientist |
| Ray DeGraaf | Geoscience Australia | Mechanical Technician |
| John Jaycock | Geoscience Australia | Geological Technician |
| Gareth Crook | Geoscience Australia | Mechanical Technician |
| Stan Hancock | Geoscience Australia | Electronics Technician |
| Steve Whalan | Australian Institute of Marine Science | Marine Biologist |
| | | |
| Inke Falkner | University of the Sea | Teaching Scientist |
| Haowen Dang | University of the Sea | Scientist |
| Laurent Devriendt | University of the Sea | Scientist |
| Cuifen Pui | University of the Sea | Scientist |
| Merinda Nash | University of the Sea | Scientist |
| Liesbeth Van Kerckhoven | University of the Sea | Scientist |
| Jeffery Graham | University of the Sea | Scientist |

**Table 13.3.** Scientific survey personnel for survey GA2476 Leg 3, representing organisation, and their substantive roles.

| *Leg 3 (19 December – 19 January)* | | |
|---|---|---|
| Michael Hughes | Geoscience Australia | Chief Scientist |
| Cameron Mitchell | Geoscience Australia | Co-chief Scientist |
| Michelle Ayling | Geoscience Australia | Swath Processor |
| Cameron Buchanan | Geoscience Australia | Swath Processor |
| Oi Li (GEMD) | Geoscience Australia | GIS Technician |
| Scott Nichol | Geoscience Australia | Marine Geologist |
| Gabriel Nelson | Geoscience Australia | Petroleum Geoscientist |
| Kane Rawsthorn | Geoscience Australia | Petroleum Geoscientist |
| Bridgette Lewis | Geoscience Australia | Petroleum Geoscientist |
| Norman Alavi | Geological Survey of Western Australia | Petroleum Geoscientist |
| Andrew Hislop | Geoscience Australia | Mechanical Technician |
| Craig Wintle | Geoscience Australia | Mechanical Technician |
| Matt Carey | Geoscience Australia | Geological Technician |
| Stephen Hodgkin | Geoscience Australia | Electronics Technician |
| Rachel Przeslawski | Geoscience Australia | Benthic Marine Ecologist |
| | | |
| Stephen Barry | University of the Sea | Teaching Scientist |
| Made Andi Arsana | University of the Sea | Scientist |
| Neda Darbeheshti | University of the Sea | Scientist |
| Lavenia Ratnarajah | University of the Sea | Scientist |
| Peter Harley | University of the Sea | Scientist |
| Januar Harianto | University of the Sea | Scientist |
| Daniel Ward | University of the Sea | Scientist |

## 13.3. APPENDIX C – MULTIBEAM SONAR STATISTICS

A report detailing the summary statistics for the multi‐beam sonar data collected during the survey is provided as an excel spreadsheet on the data DVD. The report contains details about data acquisition and statistics on the quality of the data collected for each of the raw multi‐beam file.

## 13.4. APPENDIX D – REPORT FROM GRAVIONICS DETAILING ACQUISITION AND PROCESSING OF MAGNETICS AND GRAVITY DATSETS ACQUIRED DURING SURVEY GA2476

A report detailing the acquisition and processing of the magnetics and gravity data acquired during survey GA2476 is provided as a pdf on the data DVD.

## 13.5. APPENDIX E – ROCK-SAMPLE SITES IN RELATION TO TARGET AND SEISMIC LINES

This appendix contains a table that outlines the geological targets for the equipment used on survey GA2476 – including visual equipment (e.g. camera tracks on OFOS and BODO). All sample types are recorded here, even if no rocks were physically recovered. This table does not record if these targets were acquired, as this is subsequent and ongoing work. For descriptions of the rocks recovered, see Appendix P. For preliminary palynology and palaeontology results, see Appendix Q.

**Table 13.4.** Summary of geological targets for physical and visual equipment used on survey GA2476.

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| 005CAM001 | Pre-rift, Zeewyck Sub-basin, Houtman Canyon | Petrel n309<br>AGSO Survey 057/08 | 0 m; crosses over<br>0 m; crosses over |
| 006BC001 | Pre-rift, Houtman Sub-basin,<br>Houtman Canyon | Moon 2D am02-113 | 55 m |
| 006BC002 | Post-rift, Houtman Sub-basin, Houtman Canyon | Moon 2D am02-113 | 5 m |
| 006BT001 | Post-rift, Houtman Sub-basin, Houtman Canyon | Moon 2D am02-113<br>Moon 2D am02-192<br>Moon 2D am02-194 | 0 m; crosses over<br>0 m; crosses over<br>0 m; crosses over |
| 006CAM002 | Pre-rift, Houtman Sub-basin,<br>Houtman Canyon | Moon 2D am02-113<br>Abrolhos West wa91-16 | 95 m; roughly parallel<br>0 m; crosses over |
| 006DR001 | Pre-rift, Houtman Sub-basin,<br>Houtman Canyon | Abrolhos West wa91-16<br>Moon 2D am02-113 | 0 m; crosses over<br>100 m |
| 006DR002 | Pre-rift, Houtman Sub-basin,<br>Houtman Canyon | Abrolhos West wa91-16<br>Moon 2D am02-113 | 0 m; crosses over<br>50 m |
| 007DR003 | Pre-rift, Houtman Sub-basin | Moon 2D am02-104<br>Moon 2D am02-101 | 0 m; crosses over<br>3.2 km; roughly parallel |
| 007DR004 | Pre-rift, Houtman Sub-basin | Moon 2D am02-104<br>Moon 2D am02-101 | 290 m<br>3.0 km; roughly parallel |
| 007DR005 | Pre-rift, Houtman Sub-basin | Moon 2D am02-104<br>Moon 2D am02-101 | 480 m<br>1.1 km; roughly parallel |
| 007DR006 | Pre-rift, Houtman Sub-basin | Moon 2D am02-104<br>Moon 2D am02-101 | 905 m<br>170 m; roughly parallel |
| 008DR007 | Post-rift, Houtman Sub-basin | Ramsgate 2D sr03-01<br>Ramsgate 2D sr03-28 | 0 m; crosses over<br>0 m; crosses over |
| 008DR008 | Post-rift, Houtman Sub-basin | Ramsgate 2D sr03-01<br>Ramsgate 2D sr03-28 | 0 m; crosses over<br>0 m; crosses over |
| 009CAM003 | Peak feature, Houtman Sub-basin | Abrolhos West wa91-01 | 330 m |
| 009DR009 | Peak feature, Houtman Sub-basin | Abrolhos West wa91-01 | 25 m |
| 009GR001 | Peak feature, Houtman Sub-basin | Abrolhos West wa91-01 | 580 m |
| 010GR002 | Peak feature, Houtman Sub-basin | Abrolhos West wa91-01 | 730 m |
| 011GR003 | Peak feature, Houtman Sub-basin | Abrolhos West wa91-01 | 91 m |
| 012DR010 | Peak feature, Houtman Sub- | Abrolhos West wa91-01 | 0 m; crosses over |

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| | basin | | |
| 014DR011 | Pre-rift, Zeewyck Sub-basin, Houtman Canyon | AGSO Survey 057/08 | 460 m |
| 014DR012 | Pre-rift, Zeewyck Sub-basin, Houtman Canyon | AGSO Survey 057/08 | 0 m; crosses over |
| 015DR013 | Pre-rift, Zeewyck Sub-basin, Geraldton Canyon | Petrol Roving 1971 n311<br>GA Survey s310-23 | 5 km<br>8.7 km; roughly parallel |
| 015DR014 | Pre-rift, Zeewyck Sub-basin, Geraldton Canyon | Petrol Roving 1971 n311<br>GA Survey s310-23 | 2.5 km<br>6.1 km; roughly parallel |
| 015DR015 | Pre-rift, Zeewyck Sub-basin, Geraldton Canyon | Petrol Roving 1971 n311<br>GA Survey s310-23 | 3.6 km<br>7.5 km; roughly parallel |
| 016DR016 | Unresolved Seismic (basement?), Zeewyck Sub-basin | AGSO Survey 081/15<br>AGSO Survey 57/04<br>GA Survey s310-32 | 12.5 km; roughly parallel<br>8.7 km; roughly parallel<br>8.7 km; roughly parallel |
| 016DR017 | Unresolved Seismic (basement?), Zeewyck Sub-basin | AGSO Survey 081/15<br>AGSO Survey 57/04<br>GA Survey s310-32 | 16.5 km; roughly parallel<br>5.2 km; roughly parallel<br>12.5 km; roughly parallel |
| 016DR018 | Unresolved Seismic (basement?), Zeewyck Sub-basin | AGSO Survey 081/15<br>AGSO Survey 57/04<br>GA Survey s310-32 | 9.8 km; roughly parallel<br>11.4 km; roughly parallel<br>5.3 km; roughly parallel |
| 017GR004 | Abyssal Plain, outer Zeewyck Sub-basin | AGSO Survey 081/13 | Start of camera: 14 km |
| 018DR019 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n312<br>Petrel Roving 1971 n312a<br>GA Survey s310-71 | 0 m; crosses over<br>65 m; roughly parallel<br>6.5 km |
| 018GR005 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n312<br>Petrel Roving 1971 n312a<br>GA Survey s310-71 | 110 m<br>135 m; roughly parallel<br>6.5 km |
| 018GR006 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n312<br>Petrel Roving 1971 n312a<br>GA Survey s310-71 | 45 m<br>300 m; roughly parallel<br>6.7 km |
| 020DR020 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n313 | 2.6 km; roughly parallel |
| 020GR007 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n313 | 2.6 km; roughly parallel |
| 020GR008 | Unresolved Seismic (basement?), Zeewyck Sub-basin | Petrel Roving 1971 n313 | 2.6 km; roughly parallel |
| 021DR021 | Post-rift, Zeewyck Sub-basin | Petrel Roving 1971 n314 | 1.6 km |
| 021GR009 | Post-rift, Zeewyck Sub-basin | Petrel Roving 1971 n314 | Start of camera: 3.2 km; Physical sample: 1.5 km |
| 022BC003 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | 165 m |

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| 022DR022 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | 125 m; roughly parallel |
| 022DR023 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | 0 m; crosses over |
| 022DR024 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | 300 m; roughly parallel |
| 022GR010 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | Start of camera: 80 m; Physical sample: 725 m |
| 023BC004 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | 4 km |
| 023GR011 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/09 | Start of camera: 3.9 km; Physical sample: 3.7 km |
| 024DR025 | Unresolved Seismic (basement?),<br>Zeewyck Sub-basin | AGSO Survey 081/15<br>GA Survey s310-32 | 990 m; roughly parallel<br>4 km; roughly parallel |
| 025DR026 | Pre-rift, Houtman Sub-basin,<br>Houtman Canyon | Moon 2D am02-111<br>Abrolhos West wa91-16 | 3 m; roughly parallel<br>0 m; crosses over |
| 026DR027 | Pre-rift, Zeewyck Sub-basin, Houtman Canyon | Petrel n309<br>AGSO Survey 057/08 | 900 m; roughly parallel<br>400 m |
| 027BS001 | Pre-rift, Houtman Canyon | GA Survey s310-52<br>AGSO Survey 135/08 | 14.9 km; roughly parallel<br>13.1 km |
| 027GR012 | Pre-rift, Houtman Canyon | GA Survey s310-52<br>AGSO Survey 135/08 | Start of camera: 15.4 km; Physical sample: 15.3 km<br>Start of camera: 11.7 km; Physical sample: 12.7 km |
| 028BS002 | Pre-rift, Houtman Canyon | GA Survey s310-55<br>Petrel Roving 1971 n304 | 5.8 km; roughly parallel<br>7.2 km |
| 028GR013 | Pre-rift, Houtman Canyon | GA Survey s310-55<br>Petrel Roving 1971 n304 | Start of Camera: 4.6 km; Physical sample: 5.5 km<br>Start of Camera: 6.2 km; Physical sample: 6.9 km |
| 029BS003 | Pre-rift, Houtman Canyon | Petrel Roving 1971 n304<br>GA Survey s310-41<br>AGSO Survey 135/05 | 10.5 km<br>13.1 km<br>17.6 km |
| 029GR014 | Pre-rift, Houtman Canyon | Petrel Roving 1971 n304<br>GA Survey s310-41<br>AGSO Survey 135/05 | Start of Camera: 12.1 km; Physical sample: 11.2 km<br>Start of Camera: 11.7 km; Physical sample: 12.7 km<br>Start of Camera: 15.8 km; Physical sample: 16.9 km |
| 031DR028 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | 1.1 km; roughly parallel |
| 031GR015 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | Start of Camera: 1.4 km; Physical sample: 1.2 km |
| 032DR029 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | 4.1 km; roughly parallel |
| 032GR016 | Pre-rift, Carnarvon Basin, | Petrel Roving 1971 n300 | Start of Camera: 4.1 km; |

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| | Cape Range Canyon | | Physical sample: 4.3 km |
| 033DR030 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | 6.7 km; roughly parallel |
| 033GR017 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | Start of Camera: 6.9 km; Physical sample: 7.2 km |
| 034DR031 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | 11.5 km; roughly parallel |
| 034GR018 | Pre-rift, Carnarvon Basin, Cape Range Canyon | Petrel Roving 1971 n300 | Start of Camera: 11.8 km; Physical sample: 11.3 km |
| 036DR032 | Pre-rift, Carnarvon Basin, Cloates Canyon | Petrel Roving 1971 n300 | 10.3 km; roughly parallel |
| 036GR019 | Pre-rift, Carnarvon Basin, Cloates Canyon | Petrel Roving 1971 n300 | Start of Camera: 10.0 km; Physical sample: 10.5 km |
| 037DR033 | Pre-rift, Carnarvon Basin, Cloates Canyon | Carnarvon Terrace 2D Speculative wg98ct-026 | 13.3 km; roughly parallel |
| 037GR020 | Pre-rift, Carnarvon Basin, Cloates Canyon | Carnarvon Terrace 2D Speculative wg98ct-026 | Start of Camera: 13.3 km; Physical sample: 13.6 km |
| 038DR034 | Pre-rift, Carnarvon Basin | Petrel Roving 1971 n302 | 17.6 km; roughly parallel |
| 038GR021 | Pre-rift, Carnarvon Basin | Petrel Roving 1971 n302 | Start of Camera: 17.7 km; Physical sample: 17.9 km |
| 039DR035 | Pre-rift, Carnarvon Basin | Petrel Roving 1971 n302 | 11.2 km; roughly parallel |
| 039GR022 | Pre-rift, Carnarvon Basin | Petrel Roving 1971 n302 | Start of Camera: 10.8 km; Physical sample: 10.7 km |
| 040GR023 | Pre-rift, Carnarvon Basin | Petrel Roving 1971 n302 | Start of Camera: 12.2 km; Physical sample: 13.0 km |
| 041GR024 | Pre-rift, Carnarvon Basin | GA Survey s310-57 | Start of Camera: 6.9 km; Physical sample: 5.9 km |
| 042CAM004 | Pre-rift, Carnarvon Basin, Carnarvon Canyon | GA Survey s310-57 | 2.7 km; roughly parallel |
| 042DR036 | Pre-rift, Carnarvon Basin, Carnarvon Canyon | GA Survey s310-57 | 2.5 km; roughly parallel |
| 043CAM005 | Pre-rift, Carnarvon Basin, Carnarvon Canyon | GA Survey s310-57 | 2.1 km; roughly parallel |
| 043DR037 | Pre-rift, Carnarvon Basin, Carnarvon Canyon | GA Survey s310-57 | 2.0 km; roughly parallel |
| 044CAM006 | Peak feature, Houtman Sub-basin | GA Survey s310-39 | 1.1 km; roughly parallel |
| 044DR038 | Peak feature, Houtman Sub-basin | GA Survey s310-39 | 1.0 km; roughly parallel |
| 045CAM007 | Pre-rift, Houtman Canyon | GA Survey s310-59 | 13.9 km; roughly parallel |
| 045DR039 | Pre-rift, Houtman Canyon | GA Survey s310-59 | 13.9 km; roughly |

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| | | | parallel |
| 046DR040 | Pre-rift, Houtman Canyon | GA Survey s310-59<br>GA Survey s310-48<br>Petrel Roving 1971 n306 | 10.8 km<br>8.2 km<br>14.3 km; roughly parallel |
| 046GR025 | Pre-rift, Houtman Canyon | GA Survey s310-59<br>GA Survey s310-48<br>Petrel Roving 1971 n306 | Start of Camera: 10.2 km; Physical sample: 10.9 km<br>Start of Camera: 7.8 km; Physical sample: 8.3 km<br>Start of Camera: 14.0 km; Physical sample: 14.0 km |
| 047CAM008 | Pre-rift, Houtman Canyon | GA Survey s310-59<br>GA Survey s310-48<br>Petrel Roving 1971 n306 | 6.8 km<br>5.3 km<br>5.8 km; roughly parallel |
| 047DR041 | Pre-rift, Houtman Canyon | GA Survey s310-59<br>GA Survey s310-48<br>Petrel Roving 1971 n306 | 7.2 km; roughly parallel<br>5.8 km; roughly parallel<br>6.7 km |
| 048BC005 | Post-rift, Houtman Canyon | Houtman Basin 2001 Non Exclusive 2D hb01-200<br>GA Survey s310-50 | 2.6 km<br>6.1 km |
| 048CAM009 | Post-rift, Houtman Canyon | Houtman Basin 2001 Non Exclusive 2D hb01-200<br>GA Survey s310-50 | 2.2 km<br>6.0 km |
| 049DR042 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/07<br>GA Survey s310-22 | 1.2 km; roughly parallel<br>5.5 km |
| 049GR026 | Pre-rift, Zeewyck Sub-basin | AGSO Survey 081/07<br>GA Survey s310-22 | Start of Camera: 900 m; Physical sample: 800 m<br>Start of Camera: 5.3 km; Physical sample: 5.7 km |
| 050CAM010 | Pre-breakup basin fill or basement?, Cuvier Plateau | GA Survey s310-62<br>GA Survey s310-65 | 680 m; roughly parallel<br>5.9 km |
| 050DR043 | Pre-breakup basin fill or basement?, Cuvier Plateau | GA Survey s310-62<br>GA Survey s310-65 | 680 m; roughly parallel<br>5.9 km |
| 051CAM011 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/09 | 50 m; roughly parallel |
| 051DR044 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/09 | 0 m; crosses over and roughly parallel |
| 051DR045 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/09 | 0 m; crosses over and roughly parallel |
| 052DR046 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/09 | 6 m; roughly parallel |
| 053DR047 | Pre-breakup basin fill or basement?, Cuvier Plateau | Petrel Roving 1971 n302a | 0 m; crosses over |
| 054BC006 | plateau, Cuvier Plateau | GA Survey s310-65<br>GA Survey s310-62 | 18.5 km<br>27.0 km |
| 054CAM012 | plateau, Cuvier Plateau | GA Survey s310-65<br>GA Survey s310-62 | 18.5 km<br>27.0 km |
| 055BS004 | Pre-breakup basin fill, | GA Survey s310-59 | 850 m; roughly parallel |

| STATION, SAMPLE TYPE AND NUMBER | GEOLOGICAL TARGET | NEARBY SEISMIC LINE | APPROXIMATE DISTANCE TO SEISMIC LINE |
|---|---|---|---|
| | Cuvier Plateau | | |
| 055DR048 | Pre-breakup basin fill, Cuvier Plateau | GA Survey s310-59 | 700 m; roughly parallel |
| 055GR027 | Pre-breakup basin fill, Cuvier Plateau | GA Survey s310-59 | Start of Camera: 1.1 km; Physical sample: 600 m |
| 056DR049 | Seamount, Cuvier Plateau | AGSO Survey 135/11 | 650 m; roughly parallel |
| 056DR050 | Seamount, Cuvier Plateau | AGSO Survey 135/11 | 600 m; roughly parallel |
| 056GR028 | Seamount, Cuvier Plateau | AGSO Survey 135/11 | Start of Camera: 920 m; Physical sample: 360 m |
| 057CAM013 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/05 | 300 m |
| 057DR051 | Pre-breakup basin fill or basement?, Cuvier Plateau | AGSO Survey 135/05 | 350 m |
| 058CAM014 | Pre-breakup basin fill or basement?, Cuvier Plateau | GA Survey s310-61 | 2.1 km; roughly parallel |
| 058DR052 | Pre-breakup basin fill or basement?, Cuvier Plateau | GA Survey s310-61 | 2.2 km; roughly parallel |
| 059BC007 | plateau, Cuvier Plateau | AGSO Survey 135/08 | 2.9 km |
| 059CAM015 | plateau, Cuvier Plateau | AGSO Survey 135/08 | 2.9 km |
| 060BC008 | plateau, Cuvier Plateau | GA Survey s310-59 | 22.5 km |
| 060CAM016 | plateau, Cuvier Plateau | GA Survey s310-59 | 22.5 km |
| 061DR053 | Pre-breakup basin fill or basement?, Cuvier Plateau | Petrel Roving 1971 n302a | 0 m; crosses over |
| 062CAM017 | saddle, Wallaby Saddle | AGSO Survey 135/10<br>GA Survey s310-59 | 47.5 km<br>71.8 km |

## 13.6. APPENDIX F – SEABED SEDIMENT TEXTURE AND COMPOSITION

Data in this appendix are based on sieve analysis and carbonate composition analysis, and are thus expressed as weight percents (Tables 13.4). Grainsize distributions for all of the surface samples are expressed as volume percentages measured from the Malvern™ Mastersizer 2000 laser particle size analyser and can be found on the accompanying data DVD. Grainsize distribution graphs and associated data are contained on the data DVD in pdf format. The filenames follow the convention: 7 - digit Lab Number, GA Survey Number, Station Number, Operation Type, and Operation Number.

**Table 13.5.** Results of sediment laboratory analysis from west Australian margin survey GA2476. "-" = no gravel "+" = insufficient sample for analysis.

| SAMPLEID | Region | Lat | Lon | Depth | %Gravel >2mm | %Sand 63-2000 µm | %Mud <63 µm | Folk class | Mean Grainsize µm | Bulk CaCO3% |
|---|---|---|---|---|---|---|---|---|---|---|
| GA2476/006BC002A1.1 | Houtman | -28.3641 | 112.8805 | -1200 | 0.1 | 11.3 | 88.5 | sM | 20.072 | 74.9 |
| GA2476/006BC01A1.1 | Houtman | -28.3503 | 112.8701 | -1982 | 0.0 | 32.0 | 68.0 | sM | 9.382 | 1.5 |
| GA2476/006DR002SSA1.1 | Houtman | -28.3543 | 112.8721 | -1847 | 0.2 | 22.4 | 77.4 | sM | 19.451 | 61.6 |
| GA2476/007DR003SSA1.1 | Houtman | -28.1100 | 112.3870 | -2488 | 0.0 | 16.8 | 83.2 | sM | 8.291 | 79.0 |
| GA2476/007DR004SSA1.1 | Houtman | -28.1150 | 112.3992 | -2588 | 0.0 | 17.2 | 82.8 | sM | 16.025 | 78.8 |
| GA2476/007DR005SSA1.1 | Houtman | -28.1063 | 112.4164 | -2526 | 0.0 | 17.0 | 83.0 | sM | 11.484 | 78.3 |
| GA2476/007DR006SSA1.1 | Houtman | -28.1010 | 112.4324 | -2409 | 0.0 | 16.0 | 84.0 | sM | 8.842 | 76.7 |
| GA2476/008DR007SSA1.1 | Houtman | -27.8356 | 112.2146 | -2600 | 0.1 | 37.8 | 62.1 | sM | 21.146 | 70.7 |
| GA2476/009GR001A1.1 | Houtman | -28.4968 | 112.8009 | -910 | 14.1 | 38.1 | 47.8 | gM | 56.503 | 86.6 |
| GA2476/011GR003A1.1A | Houtman | -28.5538 | 112.8381 | -906 | 2.6 | 24.9 | 72.6 | (g)M | 8.006 | 85.8 |
| GA2476/014DR011SSA1.1 | Zeewyck | -28.7403 | 112.4529 | -4103 | 0.0 | 10.2 | 89.8 | sM | 7.125 | 68.0 |
| GA2476/014DR012SSA1.1 | Zeewyck | -28.7273 | 112.4540 | -4007 | 0.3 | 7.9 | 91.8 | M | 8.173 | 62.5 |
| GA2476/015DR013SSA1.1 | Zeewyck | -29.2918 | 112.8350 | -4587 | 0.0 | 5.5 | 94.5 | M | 7.899 | 61.5 |
| GA2476/015DR014SSA1.1 | Zeewyck | -29.2891 | 112.8627 | -4574 | 0.0 | 6.4 | 93.6 | M | 6.134 | 61.5 |
| GA2476/015DR015SSA1.1 | Zeewyck | -29.2910 | 112.8515 | -4577 | 0.5 | 7.2 | 92.3 | M | 4.749 | 55.4 |
| GA2476/016DR016SSA1.1 | Zeewyck | -29.5835 | 112.9633 | -4770 | 0.2 | 7.1 | 92.6 | M | 5.651 | 54.3 |
| GA2476/016DR017SSA1.1 | Zeewyck | -29.5644 | 112.9306 | -4600 | 0.0 | 10.0 | 89.9 | sM | 6.382 | 62.2 |
| GA2476/016DR018SSA1.1 | Zeewyck | -29.5958 | 112.9982 | -4250 | 0.0 | 7.9 | 92.1 | M | 5.433 | 65.5 |
| GA2476/017GR004A1.1 | Zeewyck | -29.9951 | 113.3266 | -4799 | 0.0 | 8.4 | 91.6 | M | 11.461 | 45.2 |
| GA2476/018DR019SSA1.1 | Zeewyck | -30.0147 | 113.7147 | -3512 | 0.9 | 16.9 | 82.2 | sM | 9.758 | 71.9 |
| GA2476/018GR005A1.1 | Zeewyck | -30.0186 | 113.7180 | -3261 | 0.0 | 25.5 | 74.5 | sM | 14.429 | 72.9 |
| GA2476/018GR006A1.1 | Zeewyck | -30.0114 | 113.7111 | -3595 | 0.0 | 31.8 | 68.2 | sM | 12.086 | 72.4 |
| GA2476/020DR020SSA1.1 | Zeewyck | -30.4548 | 114.1771 | -3685 | 0.2 | 23.7 | 76.1 | sM | 12.367 | 59.4 |
| GA2476/020GR008A1.1A | Zeewyck | -30.4543 | 114.1770 | -3680 | 0.0 | 16.5 | 83.5 | sM | 8.724 | 70.9 |
| GA2476/021DR021SSA1.1 | Zeewyck | -30.8099 | 114.4410 | -2248 | 0.0 | 36.0 | 64.0 | sM | 28.197 | 80.1 |
| GA2476/021GR009A1.1A | Zeewyck | -30.8088 | 114.4400 | -2380 | 0.0 | 12.1 | 87.9 | sM | 9.386 | 74.6 |
| GA2476/022BC003A1.1 | Zeewyck | -30.9442 | 114.4501 | -2355 | 0.0 | 17.4 | 82.6 | sM | 11.811 | 75.4 |
| GA2476/022DR022SSA1.1 | Zeewyck | -30.9350 | 114.4350 | -2808 | 0.1 | 11.8 | 88.2 | sM | 9.125 | 69.2 |
| GA2476/022DR023SSA1.1 | Zeewyck | -30.9361 | 114.4365 | -2686 | 0.0 | 15.9 | 84.1 | sM | 7.421 | 75.5 |
| GA2476/022DR024SSA1.1 | Zeewyck | -30.9360 | 114.4296 | -2822 | 0.0 | 22.4 | 77.6 | sM | 13.242 | 76.5 |
| GA2476/023BC004A1.1 | Zeewyck | -30.9613 | 114.2605 | -3794 | 0.0 | 12.0 | 88.0 | sM | 8.056 | 69.2 |
| GA2476/023GR011A1.1 | Zeewyck | -30.9580 | 114.2564 | -4209 | 0.0 | 8.2 | 91.8 | M | 4.808 | 62.6 |
| GA2476/024DR025SSA1.1 | Zeewyck | -29.6430 | 113.0861 | -4000 | 0.0 | 11.8 | 88.2 | sM | 6.28 | 76.2 |
| GA2476/025DR026SSA1.1 | Zeewyck | -28.3685 | 112.8540 | -2057 | 0.0 | 8.1 | 91.9 | M | 16.262 | 73.9 |

**Table 13.5 (continued).** Results of sediment laboratory analysis from west Australian margin survey GA2476. "-" = no gravel "+" = insufficient sample for analysis.

| SAMPLEID | Region | Lat | Lon | Depth | %Gravel >2mm | %Sand 63-2000 μm | %Mud <63 μm | Folk class | Mean Grainsize μm | Bulk CaCO3 % |
|---|---|---|---|---|---|---|---|---|---|---|
| GA2476/026DR027SSA1.1 | Zeewyck | -28.6963 | 112.4950 | -3933 | 0.0 | 10.8 | 89.2 | sM | 7.116 | 68.1 |
| GA2476/027GR012A1.1 | Houtman | -25.7922 | 110.9237 | -2975 | 0.0 | 31.9 | 68.1 | sM | 19.062 | 80.1 |
| GA2476/028GR013A1.1 | Houtman | -24.7916 | 110.9072 | -2197 | 0.0 | 28.9 | 71.1 | sM | 13.023 | 79.9 |
| GA2476/029GR014A1.1 | Houtman | -24.5240 | 110.9751 | -1966 | 0.0 | 23.0 | 77.0 | sM | 4.193 | 85.2 |
| GA2476/031DR028SSA1.1 | Cuvier | -21.9076 | 112.7626 | -3710 | 0.0 | 57.5 | 42.5 | mS | 28.234 | 22.9 |
| GA2476/032GR016A1.1 | Cuvier | -21.8590 | 112.7480 | -4222 | 0.3 | 18.6 | 81.1 | sM | 6.81 | 45.8 |
| GA2476/033DR030SSA1.1 | Cuvier | -21.8624 | 112.6876 | -4291 | 0.0 | 43.5 | 56.5 | sM | 15.635 | 29.5 |
| GA2476/033GR017A1.1 | Cuvier | -21.8610 | 112.6870 | -4271 | 0.0 | 29.0 | 71.0 | sM | 7.543 | 34.4 |
| GA2476/034DR031SSA1.1 | Cuvier | -21.8168 | 112.6907 | -4029 | 0.0 | 15.0 | 85.0 | sM | 4.809 | 55.7 |
| GA2476/034GR018A1.1 | Cuvier | -21.8160 | 112.6910 | -4032 | 0.1 | 12.7 | 87.3 | sM | 3.987 | 50.2 |
| GA2476/036DR032SSA1.1 | Cuvier | -22.1751 | 112.4428 | -4660 | 0.0 | 13.7 | 86.3 | sM | 4.632 | 37.9 |
| GA2476/036GR019A1.1 | Cuvier | -22.1750 | 112.4420 | -4678 | 0.0 | 18.7 | 81.3 | sM | 5.512 | 35.9 |
| GA2476/037DR033SSA1.1 | Cuvier | -22.2465 | 112.8713 | -2732 | 0.0 | 27.6 | 72.4 | sM | 11.911 | 65.5 |
| GA2476/037GR020A1.1 | Cuvier | -22.2463 | 112.8721 | -2708 | 0.0 | 20.8 | 79.2 | sM | 9.695 | 61.4 |
| GA2476/038DR034SSA1.1 | Cuvier | -22.7765 | 112.1732 | -3955 | 0.0 | 8.5 | 91.5 | M | 7.451 | 58.9 |
| GA2476/038GR021A1.1 | Cuvier | -22.7738 | 112.1747 | -3993 | 0.0 | 27.4 | 72.6 | sM | 10.389 | 55.7 |
| GA2476/039DR035SSA1.1 | Cuvier | -22.8126 | 112.2229 | -3520 | 0.0 | 20.4 | 79.6 | sM | 10.268 | 66.3 |
| GA2476/039GR022A1.1 | Cuvier | -22.8161 | 112.2268 | -3564 | 0.0 | 24.4 | 75.6 | sM | 9.841 | 64.1 |
| GA2476/040GR023A1.1 | Cuvier | -23.5026 | 111.0835 | -4862 | 0.0 | 0.9 | 99.1 | M | 4.607 | 65.5 |
| GA2476/041GR024A1.1 | Cuvier | -23.6511 | 111.2322 | -4103 | 0.0 | 15.1 | 84.9 | sM | 5.003 | 70.6 |
| GA2476/042DR036SSA1.1 | Cuvier | -23.7335 | 111.3036 | -4036 | 0.0 | 21.5 | 78.5 | sM | 7.829 | 73.4 |
| GA2476/043DR037SSA1.1 | Cuvier | -23.8303 | 111.3548 | -3199 | 0.0 | 35.4 | 64.6 | sM | 14.291 | 79.2 |
| GA2476/044DR038SSA1.1 | Houtman | -25.2353 | 111.4175 | -1145 | 3.5 | 94.3 | 2.2 | (g)S | 505.437 | 89.7 |
| GA2476/045DR039SSA1.1 | Houtman | -26.2360 | 110.8460 | -3285 | 0.0 | 67.7 | 32.3 | mS | 63.454 | 87.1 |
| GA2476/046DR040SSA1.1 | Houtman | -26.8380 | 111.3290 | -3262 | 0.6 | 29.7 | 69.7 | sM | 10.216 | 73.9 |
| GA2476/047DR041SSA1.2A | Houtman | -26.8502 | 111.4186 | -2936 | 0.0 | 26.7 | 73.3 | sM | 9.551 | 78.3 |
| GA2476/048BC005A1.1 | Houtman | -26.5439 | 111.5026 | -1523 | 0.0 | 45.9 | 54.1 | sM | 31.878 | 81.9 |
| GA2476/050DR043A1.1 | Wallaby | -25.0411 | 107.7565 | -4162 | 0.0 | 35.4 | 64.6 | sM | 8.831 | 81.1 |
| GA2476/051DR045SSA1.1 | Wallaby | -24.4861 | 106.8936 | -3778 | 0.0 | 50.2 | 49.8 | mS | 28.102 | 87.4 |
| GA2476/052DR046SSA1.1 | Wallaby | -25.1638 | 107.9689 | -4264 | 61.6 | 20.6 | 17.8 | msG | 11.772 | 42.9 |
| GA2476/053DR047SSA1.1 | Wallaby | -25.5328 | 108.5391 | -4438 | 24.9 | 28.8 | 46.3 | gM | 7.255 | 35.5 |
| GA2476/054BC006A1.1 | Wallaby | -24.6359 | 107.7553 | -3467 | 0.0 | 35.5 | 64.5 | sM | 13.436 | 85.9 |
| GA2476/055GR027SSA1.1 | Wallaby | -24.3659 | 107.8203 | -3163 | 0.0 | 67.8 | 32.2 | mS | 58.383 | 88.5 |
| GA2476/056GR028AA1.1 | Wallaby | -24.0187 | 109.1987 | -3484 | 0.0 | 40.7 | 59.2 | sM | 19.548 | 83.3 |
| GA2476/057DR051SSA1.1 | Wallaby | -23.6721 | 109.6871 | -4304 | 1.9 | 27.0 | 71.1 | (g)M | 3.587 | 79.6 |
| GA2476/058DR052SSA1.1 | Wallaby | -24.0211 | 109.5162 | -4650 | 0.1 | 30.1 | 69.8 | sM | 6.893 | 74.5 |
| GA2476/059BC007A1.1 | Wallaby | -24.5733 | 108.6956 | -2608 | 0.0 | 49.6 | 50.4 | sM | 39.179 | 84.1 |
| GA2476/060BC008A1.1 | Wallaby | -25.5198 | 109.1815 | -3828 | 0.0 | 29.5 | 70.5 | sM | 8.237 | 80.4 |
| GA2476/061DR053SSA1.1 | Wallaby | -25.5415 | 108.5341 | -5159 | 8.8 | 39.7 | 51.5 | gM | 10.031 | 7.8 |

## 13.7. APPENDIX G – LOCATIONS OF SEEP WORMS COLLECTED IN AUSTRALIAN WATERS

This appendix contains known locations of seep worms (Polychaeta: Siboglinidae)collected in Australian waters, including identification of siboglinids from three stations during survey GA2476. Information was collated from the Museum of Victoria specimen database and Dr Robin Wilson. 'MOV Number' represents the unique registration number assigned to samples lodged at the Museum of Victoria. An asterisk represents specimens from Western Australia.

**Table 13.6.** Locations of seep worms collected in Australian waters.

| SURVEY | MOV NUMBER | GENUS | LAT | LONG | DEPTH (M) |
|---|---|---|---|---|---|
| FR05/86 | F 102009 | *Diplobrachia* | -38.4167 | 149.0000 | 1500 |
| FR05/86 | F 101995 | *Oligobrachia* | -38.4317 | 148.9767 | 1850 |
| FR05/86 | F 101994 | *Polybrachia* | -38.4317 | 148.9767 | 1850 |
| FR05/86 | F 102008 | *Siboglinoides* | -34.7183 | 151.3833 | 2250 |
| FR05/86 | F 75304 | *Siboglinum* | -38.4317 | 148.9767 | 1850 |
| FR05/86 | F 102000 | *Siboglinum* | -38.4317 | 148.9767 | 1850 |
| FR05/86 | F 102001 | *Siboglinum* | -38.4317 | 148.9767 | 1850 |
| FR05/86 | F 102012 | *Siboglinum* | -38.4167 | 149.0000 | 1500 |
| FR05/86 | F 102011 | *Siboglinum* | -38.4167 | 149.0000 | 1500 |
| FR05/86 | F 102010 | *Siboglinum* | -38.4167 | 149.0000 | 1500 |
| FR05/86 | F 75303 | *Siboglinum* | -38.3183 | 149.2383 | 600 |
| FR05/86 | F 75309 | *Siboglinum* | -38.3183 | 149.2383 | 600 |
| FR05/86 | F 75317 | *Siboglinum* | -38.2950 | 149.1883 | 400 |
| FR05/86 | F 75311 | *Siboglinum* | -37.1217 | 150.3367 | 520 |
| FR05/86 | F 75316 | *Siboglinum* | -34.9650 | 151.1333 | 503 |
| FR05/86 | F 75306 | *Siboglinum* | -34.8650 | 151.2100 | 770 |
| FR05/86 | F 75307 | *Siboglinum* | -34.7183 | 151.3833 | 2250 |
| FR05/86 | F 102007 | *Siboglinum* | -34.7183 | 151.3833 | 2250 |
| FR05/86 | F 75308 | unknown siboglinid | -38.4167 | 149.0000 | 1500 |
| FR05/86 | F 75305 | unknown siboglinid | -34.9733 | 151.3867 | 1700 |
| FR09/88 | F 75319 | *Siboglinoides* | -38.4888 | 149.3330 | 1795 |
| FR09/88 | F 102002 | *Siboglinoides* | -34.8910 | 151.3132 | 1564 |
| FR09/88 | F 75310 | *Siboglinum* | -38.3992 | 149.2837 | 2900 |
| FR09/88 | F 75313 | *Siboglinum* | -38.3992 | 149.2837 | 2900 |
| FR09/88 | F 75314 | *Siboglinum* | -34.8910 | 151.3132 | 1564 |
| FR09/88 | F 102003 | *Siboglinum* | -34.8910 | 151.3132 | 1564 |
| FR09/88 | F 102004 | *Siboglinum* | -34.8910 | 151.3132 | 1564 |
| FR09/88 | F 75318 | *Siboglinum* | -34.8787 | 151.2507 | 993 |
| FR09/88 | F 75315 | *Siboglinum* | -34.8787 | 151.2507 | 993 |
| FR09/88 | F 102006 | *Siboglinum* | -34.8787 | 151.2507 | 993 |
| FR09/88 | F 102005 | *Siboglinum* | -34.8787 | 151.2507 | 993 |
| FR09/88 | F 75312 | unknown siboglinid | -38.6715 | 149.3010 | 2900 |
| SS08/05 | F 150351 * | unknown siboglinid | -32.8546 | 114.2569 | 1440 |
| SS08/05 | F 150301 * | unknown siboglinid | -32.5814 | 114.3545 | 1660 |
| SS08/05 | F 150313* | unknown siboglinid | -32.0230 | 114.6893 | 1510 |
| SS10/05 | F 151648 | unknown siboglinid | -35.2140 | 118.651 | 420 |
| GA2476 | pending* | unknown siboglinid | -30.9350 | 114.4350 | 2808 |
| GA2476 | pending* | unknown siboglinid | -24.5240 | 110.9751 | 1966 |
| GA2476 | pending* | unknown siboglinid | -21.8667 | 112.6851 | 3820 |
| GA2476 | pending* | unknown siboglinid | -31 0.959 | 114 14.615 | 1939 |
| GA2476 | Empty tubes only* | unknown siboglinid | -28 21.847 | 112 52.829 | 1200 |

### 13.8. APPENDIX H – BENTHIC BIOTA

This appendix contains summary details of the seabed video characterisation scheme used to classify video data acquired during survey GA2476.

**Table 13.7.** Seabed video characterisation scheme: substratum, bedform-relief, and biota types and definition used to characterise the seabed.

| TYPE | TYPE | DEFINITION |
|---|---|---|
| Substratum | Rock | Exposed Bedrock |
| | Boulders | Boulders (> 25.5 cm loose material) |
| | Cobble | Cobbles (> 6.5 cm and < 25.5 cm) |
| | Sand | Sand (lighter colour, grains visible to naked eye) |
| | Mud | Mud (darker colour than sand, grains not visible) |
| | Pebbles | Pebbles (< 6.5 cm) |
| Relief | Rock Wall | Vertical wall with a slope angle > 80° (visual line-chain method) |
| | High relief | >3 m substratum relief |
| | Moderate relief | 1-3 m substratum relief |
| | Low relief | <1 m substratum relief |
| | Slope | 0 m relief and a slope angle of 50-80° |
| | Flat relief | 0 m substratum relief |
| Bedforms | Hummocky | Irregular bedform, >50% of surface-area |
| | Sediment waves | **Wave-like bedform in sediment** |
| | Sediment ripples | Ripple-like bedform in sediment |
| Biota | Cnidaria | Cnidaria |
| | Anemones a,b | Cnidaria: Anthozoa: Actiniaria (sp 1, sp 2) |
| | Soft coral | Cnidaria: Anthozoa: Alcyonacea |
| | Christmas tree coral | Cnidaria: Anthozoa: Antipathria (*e.g. black corals*) |
| | Gorgonian - fan | Cnidaria: Anthozoa: Gorgonacea – fan shaped |
| | Gorgonian - sea whip | Cnidaria: Anthozoa: Gorgonacea – whip shaped |
| | Gorgonian - other | Cnidaria: Anthozoa: Gorgonacea |
| | Sea pens | Cnidaria: Anthozoa: Pennatulacea |
| | Hard coral | Cnidaria: Anthozoa: Scleractinia – live hard corals |
| | Hard coral fragment | Cnidaria: Anthozoa: Scleractinia – dead coral fragments |
| | Hydroids other | Cnidaria: Hydrozoa |
| | Hydroids a, b | Cnidaria: Hydrozoa (sp 1, sp 2) |
| | Jellyfish | Cnidaria: Scyphozoa |
| | Sponges - 3d | Porifera: 3-dimensional forms (*e.g. vase sponges*) |
| | Lumpy sponge | Porifera: unknown small latticed sponge found on sediment |
| | Glass sponge | Porifera: Hexactinellida |
| | Echinoderm | Echinodermata |
| | Starfish (seastar) | Echinodermata: Asteroidea |
| | Brittlestars | Echinodermata: Ophiuroidea |
| | Crinoid (featherstar) | Echinodermata: Crinoidea |
| | Sea urchin | Echinodermata: Echinoidea |
| | Sea cucumber | Echinodermata: Holothuroidea |
| | Piglet | Echinodermata: Holothuroidea: Elasipodida |
| | Crustacea | Arthropoda: Crustacea |
| | Crab | Arthropoda: Crustacea: Decapoda: Malacostraca – all crabs |
| | Shrimp/prawn | Arthropoda: Crustacea: Decapoda: Malacostraca – shrimp/prawns |
| | Tubeworms | Annelida: Polychaeta |
| | Acorn worm | Hemicordata: Enteropneusta |
| | Acorn worm trail | Spiral, meandering and switchback tracks left by acorn worms |
| | Mollusc | Mollusca |
| | Gastropod | Mollusca: Gastropoda (marine snails and slugs) |
| | Octopus | Mollusca: Cephalopoda: Octopoda |
| | Fish | Chordata: Osteichthyes |
| | Shark | Chordata: Chondrichthyes |
| | Ray | Chordata: Chondrichthyes |
| | Motile invertebrate | Unknown motile invertebrates, such as fishes, jellyfish, etc. |
| | Sessile invertebrate | Unknown invertebrates attached the seabed |
| Lebensspuren | Tracks | Tracks visible on the surface of the sediments |
| | Burrows | Holes that penetrate into the seabed |
| | Mounds | Mounds of sediment |
| | Pits | A depression in the seabed ≤ 10 wide |
| | Craters | A depression in the seabed > 10 wide |
| Other | Trash | any form of human waste (*e.g. beer cans, paint can*) |
| | Unknown | substratum visible, but not enough to discern benthic organism |
| | Undefined | seabed not visible |

### 13.9. APPENDIX I – BENTHIC BIOTA PRESERVATION

This appendix contains summary details of the methods used to preserve different taxa during survey GA2476.

**Table 13.8.** Fixation and preservation methods used for marine taxa collected during the survey. A = absolute ethanol; F = 4% Formalin; C = Freezer.

| TAXA CLASS | PRESERVATION |
|---|---|
| ANNELIDA: Polychaeta (segmented worms) | F |
| ASCIDIA: TUNICATA (sea squirts) | F |
| BIOLOGICAL CONGLOMERATES (+sponges) | C |
| BIOLOGICAL CONGLOMERATES (no sponges) | A |
| BRACHIOPODA: (brachiopods) | A |
| BRYOZOA: (bryozoans) | C |
| CNIDARIA: (anemones) | F |
| CNIDARIA: (gorgonians) | A |
| CNIDARIA: (hydroids) | A |
| CNIDARIA: (jellyfish) | F |
| CNIDARIA: (sea pens) | A |
| CNIDARIA: (soft corals) | A |
| CNIDARIA: (unknown) | A |
| CNIDARIA: coral fragments | A |
| CNIDARIA: Scleractinia (live stony corals) | A |
| CRUSTACEA (unknown) | A |
| CRUSTACEA: (non-decapods) | A |
| CRUSTACEA: Cirripedia (barnacles) | A |
| CRUSTACEA: Decapoda (lobsters shrimp) | A |
| CRUSTACEA: Galathaid (squat lobsters) | A |
| ECHINODERMATA (unknown) | A |
| ECHINODERMATA: Asteroidea (starfish) | A |
| ECHINODERMATA: Crinoidea (featherstars) | A |
| ECHINODERMATA: Crinoidea entwined on cnidarian | A |
| ECHINODERMATA: Echinoidea (urchins) | A |
| ECHINODERMATA: Holothuroidea (sea cucumbers) | A |
| ECHINODERMATA: Ophiuroidea (brittle+basket stars) | A |
| ECHINODERMATA: Ophiuroidea entwined on cnidarian | A |
| FISH | F |
| FORAMINIFERA | A |
| MISCELLANEOUS - ETHANOL | A |
| MISCELLANEOUS - FORMALIN | F |
| MISCELLANEOUS - FREEZER | C |
| MOLLUSCA (unknown) | A |
| MOLLUSCA: Bivalve | A |
| MOLLUSCA: Cephalopoda (octopus squid) | A |
| MOLLUSCA: Gastropoda | A |
| MOLLUSCA: Opisthobranchia Nudibranchia (slugs) | A |
| MOLLUSCA: Polyplacophora (chitons) | A |
| MOLLUSCA: Pteropods (sea butterflies) | A |
| MOLLUSCA: Scaphopoda (tusk shells) | A |
| NEMERTEANS (ribbon worms) | F |
| PLANTS (marine) | C |
| PORIFERA: (glass sponges) | C |
| PORIFERA: (sponges) | C |
| PYCNOGONIDA (sea spiders) | A |
| RUBBLE - SUBSTRATA | S |
| SEDIMENT ANIMALS 1MM SIEVED | A |
| SEDIMENT ANIMALS 500um SIEVED | A |
| SEDIMENT ANIMALS 500um SIEVED - Boxcore btm > 5cm | A |
| SEDIMENT ANIMALS 500um SIEVED - Boxcore top 5cm | A |
| SEDIMENT ANIMALS 500um SIEVED - Pipe-Dredge Sample | A |
| SIPUNCULA: | F |
| SUPERNATANT ANIMALS 500um SIEVED | A |
| WORM unknown | F |

## 13.10. APPENDIX J – WORMS COLLECTED ON GA2476

This appendix contains details of worms collected during GA2476. Taxa were identified by Dr Robin Wilson, Museum of Victoria. Asterisks indicate tentative identifications.

**Table 13.9.** Worm collected on survey GA2476.

| STATION | DEPTH (M) | PHYLA | FAMILY | NUMBER |
|---|---|---|---|---|
| 6 | 1200 | Polychaeta | Ampharetidae | 2 |
| 6 | 1200 | Polychaeta | Chaetopteridae | 1 |
| 6 | 1200 | Polychaeta | Lumbrineridae | 1 |
| 6 | 1910 | Polychaeta | Sabellidae | 1 |
| 17 | 4799 | Polychaeta | Amphinomidae | 1 |
| 18 | 3261 | Polychaeta | Dorvilleidae | 1 |
| 18 | 3261 | Polychaeta | Lumbrineridae | 1 |
| 18 | 3261 | Polychaeta | Maldanidae | fragment |
| 18 | 3261 | Polychaeta | Poecilochaetidae | 1 |
| 18 | 3261 | Polychaeta | Spionidae | 2 |
| 18 | 3261 | Polychaeta | unknown | fragment |
| 18 | 3261 | Sipuncula | | 1 |
| 21 | 2380 | Polychaeta | Ampharetidae | 1 |
| 21 | 2380 | Polychaeta | Cirratulidae | 1 |
| 21 | 2380 | Polychaeta | Onuphidae | 1 |
| 22 | 2355 | Polychaeta | Siboglinidae | 1 |
| 22 | 2355 | Polychaeta | Spionidae | 1 |
| 22 | 2355 | Polychaeta | unknown | fragment |
| 23 | 3829 | Polychaeta | Capitellidae | 1 |
| 23 | 3829 | Polychaeta | Spionidae | 1 |
| 24 | 3780 | Polychaeta | Cirratulidae | fragment |
| 24 | 3780 | Sipuncula | | 1 |
| 24 | 3780 | Sipuncula | | 1 |
| 25 | 1700 | Polychaeta | Lumbrineridae | 1 |
| 25 | 1700 | Polychaeta | Opheliidae | 1 |
| 29 | 1966 | Polychaeta | Maldanidae | 1 |
| 29 | 1966 | Polychaeta | Siboglinidae* | 2 |
| 29 | 1966 | Sipuncula | | 1 |
| 31 | 3315 | Polychaeta | Cirratulidae* | 1 |
| 32 | 3818 | Polychaeta | Ampharetidae | 1 |
| 33 | 3820 | Polychaeta | Ampharetidae | 1 |
| 33 | 3820 | Polychaeta | Ampharetidae | 1 |
| 33 | 3820 | Polychaeta | Ampharetidae | 1 |
| 33 | 3820 | Polychaeta | Cirratulidae* | fragment |
| 33 | 3820 | Polychaeta | Goniadidae | 1 |
| 33 | 3820 | Polychaeta | Serpulidae | 4 |
| 33 | 3820 | Polychaeta | Siboglinidae* | 1 |
| 36 | 4323 | Polychaeta | Cirratulidae | 1 |
| 37 | 2732 | Polychaeta | Maldanidae | fragment |
| 37 | 2732 | Polychaeta | Spionidae Paraprionospio sp. | 1 |
| 39 | 3546 | Polychaeta | Scalibregmatidae* | 1 |
| 45 | 3150 | Sipuncula | | 1 |
| 48 | 1626 | Polychaeta | Maldanidae | fragment |
| 48 | 1626 | Polychaeta | Onuphidae | 1 |
| 48 | 1626 | Sipuncula | | 1 |
| 49 | 2235 | Polychaeta | Opheliidae | 1 |
| 49 | 1939 | Polychaeta | Siboglinidae* | fragment |
| 54 | 3467 | Polychaeta | Cirratulidae | fragment |
| 55 | 3163 | Polychaeta | Cirratulidae | 1 |
| 55 | 3163 | Polychaeta | Poecilochaetidae | 1 |
| 55 | 3113 | Polychaeta | Serpulidae | 2 |
| 56 | 3484 | Polychaeta | Cirratulidae | 1 |
| 56 | 3484 | Polychaeta | Spionidae | 1 |
| 60 | 3828 | Polychaeta | Amphinomidae | fragment |

## 13.11. APPENDIX K – BIOLOGICAL DATA FROM INFAUNAL BOXCORES

This appendix contains details of biological data recovered from infaunal boxcore samples during survey GA2476. 'Abundance of target groups' and 'Species richness' data are presented (Tables 13.9 and 13.10 respectively).

**Table 13.10.** Abundance of four target groups (worms, crustaceans, molluscs and sponges) within boxcore samples. § indicates supernatant was not collected from a station. * represents samples in which masses of worm tubes were excluded from abundance counts.

| BOXCORE | SAMPLE LAYER | WORMS | CRUSTACEANS | MOLLUSCS | SPONGES |
|---|---|---|---|---|---|
| 06BC01 | Total | 6 | 1 | 1 | 0 |
| | Supernatant§ | na | na | na | na |
| | Top | 1 | 0 | 0 | 0 |
| | Bottom | 5 | 1 | 1 | 0 |
| 06BC02 | Total | 14 | 5 | 15 | 25 |
| | Supernatant | 0 | 0 | 0 | 5 |
| | Top | 13* | 5 | 15 | 20 |
| | Bottom | 1 | 0 | 0 | 0 |
| 22BC03 | Total | 15 | 4 | 5 | 0 |
| | Supernatant | 4 | 1 | 0 | 0 |
| | Top | 8 | 3 | 5 | 0 |
| | Bottom | 3 | 0 | 0 | 0 |
| 23BC04 | Total | | | | |
| | Supernatant | 2* | 0 | 0 | 0 |
| | Top | 18* | 1 | 0 | 39 |
| | Bottom | 0 | 0 | 0 | 0 |
| 48BC05 | Total | 24 | 9 | 4 | 17 |
| | Supernatant | 1 | 0 | 0 | 3 |
| | Top | 22 | 9 | 1 | 14 |
| | Bottom | 1 | 0 | 3 | 0 |
| 54BC06 | Total | 5 | 1 | 0 | 5 |
| | Supernatant | 2 | 1 | 0 | 1 |
| | Top | 0* | 0 | 0 | 2 |
| | Bottom | 0 | 0 | 0 | 0 |
| | Supernatant (100µm) | 2 | 0 | 0 | 0 |
| | Top (300 µm) | 1 | 0 | 0 | 2 |
| 59BC07 | Total | 10 | 3 | 0 | 0 |
| | Supernatant | 5 | 0 | 0 | 0 |
| | Top | 3 | 2 | 0 | 0 |
| | Bottom | 0 | 0 | 0 | 0 |
| | Supernatant (100µm) | 0 | 0 | 0 | 0 |
| | Top (300 µm) | 2 | 1 | 0 | 0 |
| 60BC08 | Total | 20 | 7 | 0 | 1 |
| | Supernatant | 4 | 0 | 0 | 0 |
| | Top | 11 | 3 | 0 | 0 |
| | Bottom | 0 | 1 | 0 | 0 |
| | Supernatant (100µm) | 1 | 0 | 0 | 0 |
| | Top (300 µm) | 4 | 3 | 0 | 1 |

**Table 13.11.** Species richness overall, and within four target groups (worms, crustaceans, molluscs and sponges) from boxcore samples. For total species richness, any species that occurred in multiple layers was counted only once, according to the layer in which they appeared first with preference as follows: top, bottom, supernatant, top 300, supernatant 100. § indicates supernatant was not collected from a station. * represents samples in which masses of worm tubes were excluded from abundance counts.

| BOXCORE | SAMPLE LAYER | TOTAL | WORMS | CRUSTACEANS | MOLLUSCS | SPONGES |
|---|---|---|---|---|---|---|
| 06BC01 | Total | 3 | 2 | 1 | 1 | 0 |
| | Supernatant[1] | na | na | na | na | na |
| | Top | 1 | 1 | 0 | 0 | 0 |
| | Bottom | 2 | 1 | 1 | 1 | 0 |
| 06BC02 | Total | 32 | 12 | 4 | 12 | 2 |
| | Supernatant | 0 | 0 | 0 | 0 | 1 |
| | Top | 30 | 11 | 4 | 12 | 1 |
| | Bottom | 2 | 1 | 0 | 0 | 0 |
| 22BC03 | Total | 22 | 12 | 3 | 5 | 0 |
| | Supernatant | 2 | 2 | 1 | 0 | 0 |
| | Top | 18 | 9 | 2 | 5 | 0 |
| | Bottom | 2 | 1 | 0 | 0 | 0 |
| 23BC04 | Total | 15 | 8 | 1 | 0 | 3 |
| | Supernatant | 2 | 2 | 0 | 0 | 0 |
| | Top | 12 | 6 | 1 | 0 | 3 |
| | Bottom | 1 | 0 | 0 | 0 | |
| 48BC05 | Total | 25 | 13 | 6 | 3 | 2 |
| | Supernatant | 0 | 0 | 0 | | 0 |
| | Top | 23 | 13 | 6 | 1 | 2 |
| | Bottom | 2 | 0 | 0 | 2 | 0 |
| 54BC06 | Total | 6 | 2 | 1 | 0 | 2 |
| | Supernatant | 3 | 1 | 1 | 0 | 1 |
| | Top | 3 | 1 | 0 | 0 | 1 |
| | Bottom | 0 | 0 | 0 | 0 | 0 |
| | Supernatant (100µm) | 0 | 0 | 0 | 0 | 0 |
| | Top (300 µm) | 3 | 1 | 0 | 0 | 1 |
| 59BC07 | Total | 7 | 2 | 2 | 0 | 0 |
| | Supernatant | 1 | 0 | 0 | 0 | 0 |
| | Top | 6 | 2 | 2 | 0 | 0 |
| | Bottom | 0 | 0 | 0 | 0 | 0 |
| | Supernatant (100µm) | 1 | 0 | 0 | 0 | 0 |
| | Top (300 µm) | 4 | 1 | 1 | 0 | 0 |
| 60BC08 | Total | 10 | 6 | 1 | 0 | 0 |
| | Supernatant | 0 | 0 | 0 | 0 | 0 |
| | Top | 10 | 6 | 1 | 0 | 0 |
| | Bottom | 0 | 0 | 0 | 0 | 0 |
| | Supernatant (100µm) | 1 | 0 | 0 | 0 | 0 |
| | Top (300 µm) | 5 | 1 | 3 | 0 | 1 |

## 13.12. APPENDIX L - OCCURRENCE OF COMMON BIOTA TYPES IN VIDEO-TRANSECTS

This appendix contains a summary of biological and geomorphic observations made from video classifications during survey GA2476.

**Table 13.12.** Percent occurrence of common biota types recorded in video-transects within the Zeewyck and Houtman Sub-basin, Cuvier margin and Cuvier Plateau study areas of survey GA2476. Taxa are included where percent occurrence was > 10% for one or more video-transects. % mud and % rock values were calculated from mean values of combined primary (50% cover) and secondary cover (20% cover) per transect (ie total reflects 70% cover); underlined taxa denotes a combined taxa group; lebensspurren = all bioturbation marks; tan-shading denotes video-transect undertaken in rocky-dominated areas, such as volcanic cones; [x] denote video-transects that were post-processed; * denote video-transects in Area B collected during Leg 2, while ** denotes Area A collected during Leg 3 of the survey. Locations: C = canyon, P = Peak, s/c = slope/canyon, P=Plateau, S=Seamount, WS=Wallaby Saddle.

| survey area | Video-transect No. | % mud | % rock | Location | % lebensspurren | % tracks | % burrows | % mounds | % Holothurians | % Acorn worm | % Acorn worm trails-only | % Fairy-ring marks | % Suspension-feeders | % Cnidaria | % Softcoral | % Coral fragments | % live coral | % Gorgonian | % Sea-whip | % Sponges | % brittlestars | % crinoids | % echinoids | % fish | % shrimp/prawn | % jellyfish |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perth margin - Zeewyck and Houtman sub-basins | stn05cam01 | 60 | 40 | C | 64 | 64 | 22 | 7 | 3 | - | - | - | 11 | 11 | - | - | - | - | - | - | 3 | - | 3 | 15 | 13 | 1 |
| | Stn06cam02 | 81 | 19 | C | 36 | 22 | 13 | 11 | 11 | 3 | 6 | 4 | 21 | 21 | - | - | - | 11 | 7 | - | 18 | 4 | 26 | 52 | 15 | 11 |
| | Stn09cam03 | 29 | 71 | P | 24 | 24 | 5 | - | 2 | - | - | - | 36 | 31 | 2 | 19 | - | 2 | - | 10 | 2 | 14 | 17 | 21 | 7 | - |
| | Stn09gr01 | 9 | 88 | P | - | - | - | - | - | - | - | - | 100 | 100 | - | 100 | - | - | - | - | - | - | - | 9 | - | - |
| | Stn09gr02 | 46 | 47 | P | - | - | - | - | - | - | - | - | 64 | 57 | - | 50 | - | 7 | - | 7 | - | 21 | 29 | - | - | - |
| | Stn11gr03 | 61 | 35 | P | - | - | - | - | - | - | - | - | 100 | 100 | - | 100 | - | - | - | - | - | - | - | - | - | - |
| | Stn17gr04 | 100 | 0 | C | 76 | 68 | 28 | - | 4 | - | 4 | - | 20 | 12 | - | - | - | 12 | 12 | 8 | - | 12 | 12 | - | - | - |
| | Stn18gr05 | 83 | 17 | C | 17 | 8 | 8 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 17 | - |
| | Stn18gr06 | 87 | 13 | C | 55 | 54 | 10 | - | 21 | - | - | - | 1 | 1 | - | - | - | 1 | 1 | - | - | 1 | 3 | 1 | 7 | 3 |
| | Stn20gr0708 | 76 | 19 | C | 40 | 30 | 30 | - | 7 | - | - | - | 5 | 5 | - | - | 2 | 2 | 2 | - | - | - | 2 | 7 | 9 | - |
| | Stn21gr09 | 58 | 42 | C | 60 | 58 | 15 | 5 | 4 | 2 | 9 | 2 | 29 | 20 | - | - | - | 10 | 3 | 12 | - | 4 | 7 | 16 | 5 | 3 |
| | Stn22gr10 | 72 | 28 | C | 68 | 57 | 21 | 5 | 19 | 7 | 14 | 3 | 23 | 23 | - | - | - | 15 | 10 | 1 | 4 | 1 | 7 | 14 | 19 | 3 |
| | Stn23gr11 | 70 | 30 | C | 59 | 38 | 33 | - | 26 | - | - | - | 8 | 8 | - | - | - | 7 | 1 | - | - | - | 1 | 1 | 8 | - |
| | Stn27gr12[x] | 99 | 1 | S/C | 35 | 11 | 22 | 6 | 44 | -0 | - | - | 4 | 4 | - | - | - | - | - | - | - | - | 1 | 7 | 18 | - |
| | Stn28gr13[x] | 100 | - | S/C | 34 | 11 | 1 | 1 | 9 | 11 | 37 | - | 4 | 4 | - | - | - | - | - | - | 1 | - | 3 | 6 | 3 | - |
| | Stn29gr14 | 94 | 6 | S/C | 70 | 65 | 3 | - | 9 | - | 46 | - | 15 | 15 | - | - | - | 12 | 12 | - | 1 | - | 7 | 17 | 1 | - |
| | *stn44cam06 | 3 | 81 | P | 1 | 1 | - | - | 8 | - | - | - | 38 | 38 | 18 | - | - | 33 | - | 4 | 1 | 33 | 34 | 11 | 8 | - |
| | *stn45cam07 | 53 | 47 | S/C | 29 | 29 | 2 | - | 24 | - | - | - | 1 | 1 | - | - | - | - | - | - | 1 | - | 1 | 2 | 4 | 1 |
| | *stn47cam08 | 78 | 21 | S/C | 20 | 18 | 3 | - | 38 | 3 | 26 | - | 5 | 5 | - | - | - | 3 | 3 | - | - | - | 1 | 13 | 13 | 14 |
| | *stn48cam09 | 89 | 11 | S | 67 | 24 | - | 20 | 2 | - | 1 | 45 | 6 | 5 | - | 1 | - | 4 | 2 | 1 | - | - | 8 | 8 | 14 | 1 |
| | **stn49gr26 | 95 | 5 | C | 69 | 33 | 35 | 11 | 2 | 10 | 46 | - | - | - | - | - | - | - | - | - | 1 | - | 1 | 4 | 1 | - |

| survey area | Video-transect No. | % mud | % rock | Location | % lebensspurren | % tracks | % burrows | % mounds | % Holothurians | % Acorn worm | % Acorn worm trails-only | % Fairy-ring marks | % Suspension-feeders | % Cnidaria | % Softcoral | % Coral fragments | % live coral | % Gorgonians | % Sea-whip | % Sponges | % brittlestars | % crinoids | % echinoids | % fish | % shrimp/prawn | % jellyfish |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cuvier margin | stn31gr15 | 42 | 58 | C | 19 | 10 | 10 | - | 8 | 1 | - | - | 4 | 3 | - | - | - | 3 | 3 | 1 | - | - | - | 3 | 3 | - |
| | stn32gr16 | 74 | 26 | C | 6 | 4 | - | - | 2 | - | - | - | 17 | 17 | - | - | - | 17 | 17 | - | 2 | - | 2 | 2 | 2 | - |
| | stn33gr17 | 49 | 51 | C | 6 | 5 | - | - | - | - | - | 1 | 15 | 15 | - | - | - | 15 | 15 | - | 4 | - | 4 | 8 | - | - |
| | stn34gr18 | 37 | 63 | C | 11 | 4 | 7 | - | 2 | - | - | - | 9 | 9 | - | - | - | 8 | 8 | - | - | - | 4 | 1 | 1 | 1 |
| | Stn36gr19 | 79 | 21 | C | 14 | 10 | 4 | - | 1 | - | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | 3 | - |
| | stn37gr20 | 52 | 48 | C | 11 | 2 | 9 | - | 2 | - | - | - | 59 | 59 | - | - | - | 59 | 2 | - | 4 | - | 15 | 15 | 22 | - |
| | stn38gr21 | 82 | 18 | C | 6 | 6 | 1 | - | 30 | 1 | - | - | 13 | 13 | - | - | 1 | 11 | 11 | - | - | - | - | 6 | 1 | - |
| | stn39gr22 | 100 | 0 | C | 11 | 7 | 4 | - | 42 | - | - | - | 2 | 2 | - | - | - | 2 | 2 | - | - | - | 1 | 2 | 14 | - |
| | stn40gr23 | 99 | 1 | C | 26 | 23 | 3 | - | 15 | - | - | - | 3 | 3 | - | - | - | 3 | 3 | - | - | - | 1 | - | 11 | - |
| | stn41gr24 | 100 | 0 | C | 10 | 8 | - | - | 21 | 2 | - | 1 | - | - | - | - | - | - | - | - | - | - | - | 2 | 16 | 1 |
| | stn42cam04 | 63 | 36 | C | 17 | 8 | 8 | 1 | 9 | - | 1 | - | 4 | 4 | - | - | - | 4 | 3 | - | - | 1 | 1 | 4 | 8 | 1 |
| | stn43cam05 | 56 | 44 | C | 7 | 2 | 4 | 1 | 76 | - | - | 1 | - | - | - | - | - | - | - | - | 1 | - | 2 | 9 | 11 | 1 |
| | stn46gr25 | 82 | 18 | C | 17 | 9 | 1 | - | 14 | - | 3 | - | 2 | 2 | - | - | - | - | - | - | - | - | - | 4 | 7 | - |
| Cuvier Plateau | stn50cam10 | 47 | 49 | P | 36 | 25 | 21 | - | 1 | - | - | - | 2 | - | - | - | - | - | - | 2 | - | 2 | 2 | - | 1 | 1 |
| | stn51cam11 | 58 | 41 | P | 50 | 49 | 5 | 1 | 5 | - | - | - | 3 | 2 | - | - | - | 2 | - | 1 | - | 6 | 6 | 1 | 5 | 1 |
| | stn54cam12 | 99 | 0 | P | 93 | 30 | 90 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3 | 3 | - |
| | stn55gr27 | 97 | 2 | P | 41 | 11 | 29 | 1 | 6 | - | - | - | 1 | 1 | - | - | - | - | - | 1 | - | - | - | 2 | 8 | 1 |
| | stn56gr28 | 81 | 19 | S | 40 | 27 | 9 | - | 5 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 3 | 1 | 8 | - |
| | stn57cam13 | 49 | 51 | S | 24 | 19 | 9 | - | 13 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | - |
| | stn58cam14 | 48 | 51 | S | 7 | 2 | 6 | - | 13 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 2 | 7 |
| | stn59cam15 | 100 | 0 | S | 82 | 50 | 58 | 5 | 6 | - | - | - | - | - | - | - | - | - | - | - | 1 | - | 1 | - | 14 | 2 |
| | stn60cam16 | 100 | 0 | WS | 88 | 82 | 69 | 11 | 6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | - |
| | stn62cam17 | 100 | 0 | WS | 52 | 3 | 48 | 3 | 8 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 5 | 3 |

## 13.13. APPENDIX M – ZOOPLANKTON SAMPLES

This appendix contains metadata for zooplankton samples taken during survey GA2476. TR = tradtional (surface tow), O = opportunisitic (deckwater).

**Table 13.13.** Metadata for zooplankton sampling.

| | | | | start of sampling | | | | end of sampling | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **Location** | **UTC Date** | **s_lat** | **s_long** | **s_depth** | **s_time** | **e_lat** | **e_long** | **e_depth** | **e_time** |
| Zp_N1 | Wallaby | 26/12/2008 | -25.0322 | 107.7802 | 4185 | 14:32 | -25.0955 | 107.8702 | 3841 | 15:32 |
| Zp_D1 | Wallaby | 27/12/2008 | -25.3137 | 108.354 | 3665 | 2:28 | -25.3673 | 108.4294 | 3631 | 3:28 |
| Zp_N2 | Wallaby | 28/12/2008 | -24.1245 | 107.0673 | 3714 | 14:28 | -24.1858 | 107.1533 | 3293 | 15:28 |
| Zp_D2 | Wallaby | 29/12/2008 | -25.0591 | 108.3884 | 2952 | 2:30 | -25.1377 | 108.5004 | 3168 | 3:30 |
| Zp_N3 | Wallaby | 30/12/2008 | -24.2346 | 107.5122 | 2725 | 14:26 | -24.3375 | 107.6575 | 2928 | 15:26 |
| Zp_D3 | Wallaby | 31/12/2008 | -25.4471 | 109.3843 | 3919 | 3:02 | -25.3408 | 109.2315 | 3805 | 4:02 |
| Zp_N4 | Wallaby | 1/01/2009 | -24.373 | 107.8185 | 3176 | 14:59 | -24.2769 | 107.898 | 2970 | 15:59 |
| Zp_D4 | Wallaby | 2/01/2009 | -25.3496 | 109.4253 | 3887 | 2:25 | -25.2593 | 109.4811 | 3883 | 3:25 |
| Zp_N5 | Wallaby | 2/01/2009 | -24.0739 | 107.7976 | 2508 | 14:30 | -23.9655 | 107.6445 | 2654 | 15:30 |
| Zp_D5 | Wallaby | 3/01/2009 | -24.2629 | 108.2544 | 2761 | 2:34 | -24.3557 | 108.386 | 2833 | 3:34 |
| Zp_N6 | Wallaby | 3/01/2009 | -23.4461 | 109.526 | 3982 | 14:51 | -23.2974 | 109.6072 | 4359 | 15:51 |
| Zp_D6 | Wallaby | 5/01/2009 | -24.0134 | 109.4398 | 3759 | 2:32 | -23.8583 | 109.5297 | 3325 | 3:32 |
| Zp_N7 | Wallaby | 4/01/2009 | -24.022 | 109.1967 | - | 11:58 | -24.0189 | 109.1987 | - | 12:58 |
| Zp_D7 | Wallaby | 7/01/2009 | -24.3001 | 108.9354 | 3072 | 2:59 | -24.4222 | 108.872 | 2907 | 3:59 |
| Zp_N8 | Wallaby | 8/01/2009 | -24.8334 | 109.4181 | 3472 | 14:32 | -24.9084 | 109.529 | 4003 | 15:34 |
| Zp_D8 | Wallaby | 8/01/2009 | -24.9535 | 109.2291 | 3405 | 2:32 | -25.0279 | 109.336 | 3730 | 3:30 |
| Zp_N9 | Houtman | 11/01/2009 | -26.2779 | 111.9732 | 771 | 14:30 | -26.2037 | 111.8688 | 877 | 15:30 |
| Zp_D9 | Houtman | 11/01/2009 | -26.7426 | 111.3518 | 2789 | 2:31 | -26.6827 | 111.522 | 1621 | 3:31 |
| Zp_N10 | Houtman | 12/01/2009 | -24.9252 | 111.4985 | 1074 | 14:30 | -24.7471 | 111.4633 | 1155 | 15:30 |
| Zp_D10 | Houtman | 12/01/2009 | -26.7894 | 111.9127 | 971 | 2:31 | -26.7997 | 111.9423 | 954 | 3:31 |
| Zp_56TR1 | Station 56 (Wallaby) | 4/01/2009 | -24.0263 | 109.1991 | - | 13:30 | | | - | 13:31 |
| Zp_56O1 | Station 56 (Wallaby) | 4/01/2009 | -24.0263 | 109.1991 | - | 13:30 | -24.0242 | 109.1988 | - | 14:30 |
| Zp_56TR2 | Station 56 (Wallaby) | 4/01/2009 | -24.0211 | 109.2003 | - | 15:40 | | | - | 15:41 |
| Zp_56O2 | Station 56 (Wallaby) | 4/01/2009 | -24.0162 | 109.1999 | - | 15:40 | -24.0226 | 109.2025 | - | 16:40 |
| Zp_56TR3 | Station 56 (Wallaby) | 4/01/2009 | -24.0186 | 109.199 | - | 17:30 | | | - | 17:32 |
| Zp_56O3 | Station 56 (Wallaby) | 4/01/2009 | -24.0186 | 109.199 | - | 17:30 | -24.02 | 109.1983 | - | 18:30 |
| Zp_56TR4 | Station 56 (Wallaby) | 4/01/2009 | -24.0253 | 109.1993 | - | 19:26 | | | - | 19:27 |
| Zp_56O4 | Station 56 (Wallaby) | 4/01/2009 | -24.0254 | 109.1988 | - | 19:26 | -24.0256 | 109.1998 | - | 20:26 |
| Zp_56TR5 | Station 56 (Wallaby) | 4/01/2009 | -24.0223 | 109.2028 | - | 21:50 | | | - | 21:51 |
| Zp_56O5 | Station 56 (Wallaby) | 4/01/2009 | -24.0223 | 109.2028 | - | 21:50 | -24.0219 | 109.1985 | - | 22:50 |
| Zp_56TR6 | Station 56 (Wallaby) | 4/01/2009 | -24.022 | 109.1967 | - | 11:58 | | | - | 11:59 |
| Zp_56O6 | Station 56 (Wallaby) | 4/01/2009 | -24.022 | 109.1967 | - | 11:58 | -24.0189 | 109.1987 | - | 0:58 |

### 13.14. APPENDIX N – UNDERWATER STILLS IMAGES

This appendix contains select digital still photographs taken during the survey. All still images in this appendix were selected to give representative assessments of the seabed environments and biota. The images are catalogued by station, faunal type, and substrate type for quick reference.

Filenames follow the following convention: Station number_operation number_ photograph number (e.g., stnXX_camXX_XXXX).

### 13.15. APPENDIX O – UNDERWATER VIDEO FOOTAGE

The files in Appendix O represent video snippets from the main video footage. The video snippets have been made from select stations that highlight representative habitat and biota from the study areas. The transects were chosen to represent a range of depths and locations. Each video snippet is approximately one to two minutes duration and show representative seabed habitat and biota. The red lasers are 20 cm apart. These excerpts were compiled by the University of the Sea students during spare time onboard. As such, not all stations are represented.

All video is in .wmv or .avi format. Windows Media Player or appropriate software that uses the Cinepak codec is required for viewing. This codec comes with all Windows platforms above Windows 95. The appropriate version of the code can be downloaded from www.probo.com/cinepak.htm. The filenames follow the format: *Survey number, Video-Transect, Station Number, Gear Type, Operation Number*.

### 13.16. APPENDIX P – SUMMARY OF ACQUIRED LITHILOGY SAMPLES

This appendix contains a summary of all the rock samples acquired from dredges, BODOs, boxcores, and epibenthic sleds and their subsequent laboratory analysis.

**Table 13.14.** Summary of acquired lithology samples and subsequent laboratory analysis. At the time of publication, some palynological and palaeontological analyses has been completed and can be found in Appendix Q. The type of sample analysis is located under the Sample ID number in brackets and uses the following abbreviations: TS = Thin sectioned; P = Palynological sampling done; G = Geochemical sampling done; N = Nannofossil sampling done; F = Foraminifera sampling done; and M = Macrofossil sampling done. Note that subsequent sampling and analysis may still be carried out.

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/006BC001E_A (P,G) | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz grains, carbonaceous grains | Strong brown (7.5YR 4/6) | Moderately lithified, friable | Massive | Well sorted, subrounded to rounded grains | Fine grained sand, granular to small pebble sized carbonaceous grains | None |
| GA2476/006BC001E_B (P,G) | Houtman Sub-basin, Houtman Canyon | Stratified claystone and sandstone | Clay, quartz grains, carbonaceous laminae | Dark greenish grey (5G4/1) | Moderately lithified, friable | Laminae (0.5 to 1 cm) to beds (1 to 3 cm) | Moderately well sorted | Clay sized, very fine grained sand, silt sized | None |
| GA2476/006BC001E_C | Houtman Sub-basin, Houtman Canyon | Siltstone | Quartz grains | Dark red (10R 3/6) | Moderately lithified, friable | Laminae (0.1 cm) | Poorly sorted, subangular to subrounded grains | Silt sized, very fine grained sand | None |
| GA2476/006BC001E_D (P,G) | Houtman Sub-basin, Houtman Canyon | Mudstone (destroyed for analysis) | Quartz grains, clay | Greenish brown (2.5Y 5/2), light yellowish brown (2.5Y 6/3) | Moderately lithified | Massive | Well sorted | Silt sized, clay sized | None |
| GA2476/006BC001E_E (P,G) | Houtman Sub-basin, Houtman Canyon | Mudstone (destroyed for analysis) | Quartz grains, clay, carbonaceous material | Black (N/2.5) | Moderately lithified | Massive | Well sorted | Silt sized, clay sized | Coaly wood fragments |
| GA2476/006DR001A (P,G) | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz, clay, mica grains, carbonaceous grains | Light olive grey (5Y 6/2) | Lithified | Laminae (0.7 to 1 cm) to beds (2 to 3 cm), cross- | Moderately well sorted, subangular to subrounded | Very fine to medium grained sand, clay sized, medium to coarse grained carbonaceous | None |

| **Sample ID** | **Locality** | **Rock Type** | **Mineralogy** | **Colour** | **Lithification** | **Sedimentary Structures** bedding | **Fabric** grains | **Particle Size** grains | **Fossil Content** |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/006DR001B (F,N) | Houtman Sub-basin, Houtman Canyon | Limestone (micrite: silty clastic) | Carbonate grains, quartz grains | Light grey (2.5Y 7/2) | Moderately lithified, friable | Massive | Well sorted | Silt sized, very fine grained sand | None |
| GA2476/006DR001C | Houtman Sub-basin, Houtman Canyon | Limestone (micrite: silty clastic) | Carbonate grains | Light greenish grey (10GY7/1) | Moderately lithified, friable | Beds poorly defined, bioturbation | Well sorted | Silt sized | None |
| GA2476/006DR001D (P,G) | Houtman Sub-basin, Houtman Canyon | Claystone | Clay, mica grains | Very dark grey (2.5Y 3/1) | Weakly lithified, friable | Massive | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/006DR002A | Houtman Sub-basin, Houtman Canyon | Pebbly sandstone | Quartz grains, clay, mica grains, carbonaceous grains, unidentified grains | Olive brown (2.5Y 4/4) | Moderately lithified, friable | Massive | Very poorly sorted, subangular to subrounded grains | Fine to medium grained sand, granule to pebble sized grains, clay sized, elongate mudstone intraclast (<3 cm) | None |
| GA2476/006DR002B (P,G) | Houtman Sub-basin, Houtman Canyon | Claystone | Quartz grains, mica grains, carbonate crystals | Greenish black (10G2.5/1) | Moderately lithified, friable | Massive | Moderately well sorted | Clay sized, silt sized, medium sized carbonate crystals | None |
| GA2476/006DR002C (P,G) | Houtman Sub-basin, Houtman Canyon | Limestone (micrite: silty clastic) | Carbonate grains | Light greenish grey (10Y8/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/006DR002D (P,G) | Houtman Sub-basin, Houtman Canyon | Limestone (micrite: silty clastic) | Carbonate grains | Light yellowish brown (2.5Y 6/3) | Moderately lithified, friable | Laminae poorly defined | Moderately well sorted | Clay sized, silt sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/006DR002E (P,G) | Houtman Sub-basin, Houtman Canyon | Claystone | Clay, quartz grains, mica grains, carbonaceous grains | Dark olive grey (5Y 3/2) | Moderately lithified, friable | Laminae poorly defined, bioturbation possible | Moderately well sorted | Clay sized, silt sized to medium grained sand | None |
| GA2476/006DR002F (P,G) | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz grains | Dark greenish grey (5GY3/1) | Weakly lithified, friable | Massive | Well sorted, subangular to subrounded grains | Fine to medium grained sand | None |
| GA2476/006DR002G | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz grains, unidentified grains | Dark greenish grey (10Y4/1) | Moderately lithified, friable | Massive | Poorly sorted, subangular to subrounded grains | Fine to very coarse grained sand | None |
| GA2476/006DR002H | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz grains | Dark yellowish brown (10YR 3/6), dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Lens of very coarse grains | Moderately well sorted, angular to subrounded grains | Medium to very coarse grained sand | None |
| GA2476/007DR004A | Houtman Sub-basin | Chert | Silica, carbonate grains | Yellowish brown (10YR 5/4), white (10YR 8/1) | Lithified | Massive | None | N/A | None |
| GA2476/007DR004B (P,G) | Houtman Sub-basin | Claystone | Clay, quartz grains | Grey (N6) | Moderately lithified, friable | Laminae poorly defined | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/007DR004C (F,N) | Houtman Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains | White (N8) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/007DR004D | Houtman Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains | White (10YR 8/1) | Lithified | Massive | Well sorted | Silt sized, clay sized | None |
| GA2476/007DR004E | Houtman Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains | White (5Y 8/1) | Lithified | Massive | Well sorted | Silt sized, clay sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/007DR004F | Houtman Sub-basin | Sandstone | Quartz grains | Pale olive (5Y 6/3) | Lithified | Massive | Poorly sorted, subrounded to well rounded grains | Medium to very coarse grained sand, pebble sized grains | None |
| GA2476/007DR004G | Houtman Sub-basin | Limestone (micrite: silty clastic) and chert | Carbonate grains, silica | White (N8); dark grey (2.5Y 4/1) | Moderately lithified, friable; lithified | Massive | Well sorted; none | Silt sized, clay sized; N/A | None |
| GA2476/007DR005A (P,N) | Houtman Sub-basin | Limestone (micrite: silty clastic, destroyed for analysis) | Carbonate grains | Dark greenish grey (5GY4/1) | Moderately lithified, friable | Massive | Poorly sorted | Silt sized, fine to medium grained sand, granule to medium pebble sized grains | None |
| GA2476/007DR005B | Houtman Sub-basin | Limestone (micrite) | Carbonate clay | White (N8) | Moderately lithified, friable | Massive | Well sorted | Clay sized | None |
| GA2476/007DR005C (P,G) | Houtman Sub-basin | Claystone | Clay, carbonaceous laminae, carbonate grains | Olive (5Y 5/4) | Moderately lithified, friable | Laminae (<0.1 to 0.2 cm), discontinuous lenses (0.5 to 2 cm) | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/007DR005D (P) | Houtman Sub-basin | Mudstone (destroyed for analysis) | Quartz grains, clay, carbonaceous material | Black (N2.5) | Moderately lithified, friable | Laminae (<0.1 cm) | Well sorted, fissile | Silt sized, clay sized | None |
| GA2476/007DR006A (P,G) | Houtman Sub-basin | Limestone (micrite), (destroyed for analysis) | Carbonate clay | Very dark grey (5Y 3/1) | Weakly lithified, friable | Massive | Well sorted | Clay sized | None |
| GA2476/007DR006B | Houtman Sub-basin | Chert | Silica | Black (N2.5) | Lithified | Massive | None | N/A | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/007DR006C | Houtman Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains | White (N8) | Lithified | Laminae poorly defined | Well sorted | Silt sized, clay sized | None |
| GA2476/007DR006D | Houtman Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | Pale olive (5Y 6/3) | Moderately lithified, friable | Massive | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/007DR006E (F,N) | Houtman Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | White (10YR 8/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/007DR006F | Houtman Sub-basin | Sandstone | Quartz grains | Olive (5Y 5/3) | Moderately lithified | Beds (1 to 2 cm) | Well sorted | Very fine grained sand, silt sized | None |
| GA2476/007DR006G | Houtman Sub-basin | Chert and limestone (silty clastic) | Silica, carbonate grains | Dark grey (2.5Y 4/1); white (N8) | Lithified | Massive | None; well sorted | N/A; silt sized | None |
| GA2476/008DR007A (F,N) | Houtman Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | White (5Y 8/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/008DR008A | Houtman Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | White (5Y 8/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/009DR009A (TS) | Houtman Sub-basin, Peak feature | Volcaniclastic breccia | Basaltic intraclasts, glass, carbonate clay | Strong brown (7.5YR 5/6), black (2.5Y 2.5/1); white (7.5YR 8/1) | Lithified | N/A | Very poorly sorted, very angular to subangular intraclasts | Ash sized, lapilli sized, micritic sized cement | N/A |
| GA2476/011GR003E_A | Houtman Sub-basin, Peak feature | Limestone (sparse biomicrite) | Carbonate grains, carbonate clay, carbonate biogenic grains | Light grey (10YR 7/1) | Moderately lithified, friable | Massive | Very poorly sorted, very angular to subangular grains | Silt sized, clay sized, granule to very large pebble sized grains | Corals, spicules or spines, braciopods, serpulid worm tubes |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/012DR010A (TS) | Houtman Sub-basin, Peak feature | Basalt | Too fine to determine, glass, carbonate clay | Black (7.5YR 2.5/1) | Lithified | N/A | Vesicular | Aphanitic | N/A |
| GA2476/012DR010B | Houtman Sub-basin, Peak feature | Basalt | Too fine to determine, carbonate clay | Dark reddish brown (5YR 2.5/2) | Moderately lithified, friable | N/A | Vesicular | Aphanitic | N/A |
| GA2476/014DR011A (P,G) | Zeewyck Sub-basin, Houtman Canyon | Stratified claystone and sandstone | Quartz grains, clay, mica grains | Grey (5Y 5/1); light grey (10YR 7/1) | Lithified | Laminae (<0.1 to 0.2 cm), planar beds (1 to >3 cm), trough and planar cross-bedding, normal grading, bioturbation | Well sorted; moderately to well sorted, rounded to well rounded grains | Clay sized, silt sized, very fine to medium grained sand | None |
| GA2476/014DR011B (P,G) | Zeewyck Sub-basin, Houtman Canyon | Sandstone | Quartz grains, mica grains, carbonceous grains | Grey (5Y 6/1) | Moderately lithified, friable | Massive | Well sorted, rounded to well rounded grains | Very fine grained sand, medium to coarse grained carbonaceous grains | None |
| GA2476/014DR012A | Zeewyck Sub-basin, Houtman Canyon | Sandstone | Quartz grains, carbonacous grains | Yellowish brown (10YR 5/8) | Lithified | Beds (1 to 4 cm), cross-bedding | Well sorted, subrounded to well rounded grains | Fine grained sand, fine to medium grained carbonaceous grains | None |
| GA2476/014DR012B (P,G) | Zeewyck Sub-basin, Houtman Canyon | Claystone | Clay, quartz grains, mica grains, carbonaceous grains | Dark grey (10YR 4/1) | Moderately lithified, friable | Massive | Moderately well sorted, well rounded grains | Clay sized, silt sized, fine grained sand | None |
| GA2476/014DR012C | Zeewyck Sub-basin, Houtman Canyon | Sandstone | Quartz grains, opaque grains | Yellowish brown (10YR 5/4) | Weakly lithified, friable | Massive | Well sorted, subrounded to rounded grains | Medium to coarse grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/014DR012D | Zeewyck Sub-basin, Houtman Canyon | Sandstone | Quartz grains, opaque grains | Light grey (10YR 7/1) | Weakly lithified, friable | Massive | Very well sorted, rounded to well rounded grains | Fine grained sand | None |
| GA2476/014DR012E | Zeewyck Sub-basin, Houtman Canyon | Sandstone | Quartz grains, carbonaceous laminae, carbonaceous grains | Light grey (10YR 7/1), grey (10YR 6/1) | Moderately lithified, friable | Laminae (<0.1 to 0.2 cm), cross-lamination | Well sorted, subrounded to rounded grains | Very fine grained sand, fine grained carbonaceous grains | None |
| GA2476/015DR013A | Zeewyck Sub-basin, Geraldton Canyon | Sandstone | Quartz grains, carbonaceous grains | Yellowish brown (10YR 5/6), light grey (2.5Y 7/2) | Moderately lithified, friable | Beds poorly defined | Well sorted, subangular to rounded grains | Fine to very coarse grained sand | None |
| GA2476/015DR013B (P,G) | Zeewyck Sub-basin, Geraldton Canyon | Siltstone | Quartz grains, carbonaceous laminae, carbonaceous grains, clay | Light grey (N7) | Moderately lithified, friable | Beds (3 to >8 cm) | Moderately well sorted, subangular to subrounded grains | Silt sized, fine grained sand, clay, medium to coarse grained carbonaceous grains | None |
| GA2476/015DR013C (P,G) | Zeewyck Sub-basin, Geraldton Canyon | Stratified claystone and siltstone | Clay, quartz grains, mica grains, carbonaceous grains | Light olive brown (2.5Y 5/4) | Moderately lithified, friable | Beds (1 cm), laminae (0.5 cm) | Well sorted | Clay sized, silt sized, fine grained carbonaceous grains | None |
| GA2476/015DR013D (P,G) | Zeewyck Sub-basin, Geraldton Canyon | Siltstone (destroyed for analysis) | Quartz grains, carbonaceous material | Very dark greyish brown (2.5Y 3/2) | Moderately lithified, friable | Laminae poorly defined | Well sorted | Silt sized, very fine grained sand | None |
| GA2476/015DR014A | Zeewyck Sub-basin, Geraldton Canyon | Sandstone | Quartz grains, opaque grains | Olive brown (2.5Y 4/4) | Moderately lithified, friable | Massive | Well sorted, subrounded to rounded grains | Fine to medium grained sand | None |
| GA2476/015DR015A | Zeewyck Sub-basin, Geraldton Canyon | Claystone | Clay, quartz grains | Dark greenish grey (10Y4/1) | Moderately lithified, friable | Massive | Very well sorted | Clay sized, silt sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/015DR015B | Zeewyck Sub-basin, Geraldton Canyon | Sandstone | Quartz grains, mica grains | Very dark greenish grey (10Y3/1) | Moderately lithified, friable | Massive | Well sorted | Very fine grained sand | None |
| GA2476/016DR016A (P,G) | Zeewyck Sub-basin | Siltstone | Carbonaceous material, quartz grains, mica grains | Greenish black (10Y2.5/1) | Lithified | Massive | Well sorted, fissile | Silt sized, clay sized | None |
| GA2476/016DR017A | Zeewyck Sub-basin | Granite | Quartz crystals, biotite crystals | Yellowish brown (10YR 5/8) | Lithified | N/A | Subhedral, porphyritic | Fine grained crystals | None |
| GA2476/018DR019A | Zeewyck Sub-basin | Sandstone | Quartz grains, opaque grains | Light greenish grey (10Y7/1), strong brown (7.5YR 5/6) | Lithified | Massive | Well sorted, subangular to rounded grains | Very fine to medium grained sand | None |
| GA2476/018DR019B (P) | Zeewyck Sub-basin | Sandstone | Quartz grains, mica grains, carbonaceous grains | Light yellowish brown (10YR 6/4) | Moderately lithified, friable | Laminae (<0.1 cm) | Moderately well sorted, subangular to subrounded grains | Very fine grained sand, silt sized, medium grained carbonaceous grains | None |
| GA2476/018DR019C (P,G) | Zeewyck Sub-basin | Claystone | Clay, mica grains, carbonaceous grains, quartz grains | Dark grey (5Y 4/1) | Moderately lithified, friable | Massive | Moderately well sorted, fissile | Clay sized, silt sized, fine grained mica grains, medium grained carbonaceous grains | None |
| GA2476/018DR019D (P,G) | Zeewyck Sub-basin | Stratified claystone and sandstone | Clay, quartz grains, mica grains, carbonaceous grains | Brown (10YR 4/3); light yellowish brown (10YR 6/4) | Moderately lithified, friable | Beds (>1.5 cm), bioturbation | Moderately sorted; moderately well sorted, subangular to rounded grains | Clay sized, silt sized, fine to medium grained carbonaceous grains; very fine to fine grained sand, fine to medium grained carbonaceous grains | None |
| GA2476/018GR005E_A | Zeewyck Sub-basin | Sandstone | Quartz grains, opaque grains | Brownish yellow (10YR 6/6) | Moderately lithified, friable | Massive | Very well sorted, subrounded to well rounded grains | Fine to medium grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/018GR005E_B (P,G) | Zeewyck Sub-basin | Stratified claystone, siltstone and sandstone | Clay, quartz grains, mica grains, carbonaceous grains, carbonaceous laminae | Dark greenish grey (10GY4/1) | Moderately lithified, friable | Laminae (0.2 to 0.9 cm) | Very well sorted; well sorted; very well sorted, subrounded to well rounded grains | Clay sized, silt sized, fine to medium grained sand | None |
| GA2476/018GR006E_A | Zeewyck Sub-basin | Sandstone | Quartz grains, opaque grains | Light grey (2.5Y 7/2) | Moderately lithified, friable | Massive | Moderately well sorted, subangular to rounded grains | Very fine to coarse grained sand | None |
| GA2476/020DR020A (P,G) | Zeewyck Sub-basin | Stratified claystone and sandstone | Clay, quartz grains, mica grains, carbonaceous material | Black (N2.5) | Lithified | Laminae (<0.1 to 0.5 cm) | Very well sorted; well sorted, subrounded to rounded grains | Clay sized; very fine to fine grained sand | None |
| GA2476/020DR020B | Zeewyck Sub-basin | Sandstone | Quartz grains, carbonaceous grains | Greenish grey (10Y5/1) | Moderately lithified, friable | Massive | Well sorted, subangular to rounded grains | Fine to coarse grained sand | None |
| GA2476/020DR020C (P,G) | Zeewyck Sub-basin | Stratified siltstone and sandstone | Quartz grains, mica grains | Greenish grey (10BG5/1) | Moderately lithified, friable | Laminae (<0.1 to >0.7cm) | Well sorted; well sorted, subangular to subrounded grains | Silt sized; very fine grained sand | None |
| GA2476/020DR020D (P,G) | Zeewyck Sub-basin | Claystone | Clay, quartz grains | Black (N2.5) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/020DR020E | Zeewyck Sub-basin | Sandstone | Quartz grains, carbonaceous grains, mica grains | Reddish yellow (7.5YR 6/8) | Moderately lithified, friable | Massive | Well sorted, subrounded to well rounded grains | Fine to medium grained sand, coarse grained carbonaceous grains | None |
| GA2476/020DR020F | Zeewyck Sub-basin | Sandstone | Quartz grains, mica grains | Reddish yellow (7.5YR 6/8) | Moderately lithified, friable | Massive | Moderately well sorted, subangular to subrounded grains | Fine to coarse grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/020DR020G (P) | Zeewyck Sub-basin | Sandstone | Quartz grains, clay | Yellowish brown (10YR 5/8) | Moderately lithified, friable | Beds (>1 cm), cross-lamination | Poorly sorted, angular to subrounded grains; well sorted, subangular to rounded grains | Fine to very coarse grained sand, siltstone and claystone intraclasts (<5 cm) | None |
| GA2476/020DR020H | Zeewyck Sub-basin | Sandstone | Quartz grains, clay | Light blueish grey (5B7/1) | Weakly lithified, friable | Massive | Poorly to moderately sorted, angular to rounded grains | Medium grained sand to granule sized grains, claystone intraclasts (<2 cm) | None |
| GA2476/021DR021A | Zeewyck Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains, opaque grains | Light grey (2.5Y 7/2) | Lithified | Bioturbation | Very well sorted | Silt sized | Shells |
| GA2476/021DR021B (F,N) | Zeewyck Sub-basin | Limestone (fossiliferous micrite) | Carbonate clay, carbonate grains, carbonate shells | Greyish brown (2.5Y 5/2) | Moderately lithified, friable | Beds poorly defined, laminae (<0.9 cm) | Very well sorted | Clay sized, silt sized, coarse grained sand to granule sized shells | Gastropod and unidentified shell fragments |
| GA2476/021DR021C | Zeewyck Sub-basin | Limestone (micrite) and chert | Carbonate clay, carbonate grains, silica | Light grey (2.5Y 7/2); greyish brown (2.5Y 5/2) | Moderately lithified, friable; lithified | Beds (1 to 4 cm), laminae (<0.1 to 1 cm) | Very well sorted; none | Clay sized, silt sized | None |
| GA2476/021GR009E_A (F,N) | Zeewyck Sub-basin | Limestone (fossiliferous micrite) | Carbonate clay, carbonate grains, carbonaceous grains | White (N8) | Moderately lithified, friable | Laminae (<0.4 cm), bioturbation | Well sorted | Clay sized, silt sized | None |
| GA2476/021GR009E_B | Zeewyck Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains, opaque grains | White (N8) | Lithified | Laminae (<0.7 cm) | Very well sorted | Silt sized | Possible shell fragments |
| GA2476/021GR009E_C | Zeewyck Sub-basin | Limestone (micrite: silty clastic) and chert | Carbonate grains, silica, opaque grains | White (N8); dark grey (2.5Y 4/1) | Moderately lithified, friable; lithified | Discontinuous laminae of opaque grains | Very well sorted; none | Silt sized; N/A | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/022DR022A (F,N) | Zeewyck Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | Pale yellow (5Y 8/2) | Weakly lithified, friable | Massive | Very well sorted | Clay sized, silt sized | None |
| GA2476/022DR023A | Zeewyck Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | Light greenish grey (10Y8/1) | Lithified | Beds (1 cm), laminae (<0.1 cm) | Very well sorted | Clay sized, silt sized | None |
| GA2476/022DR024A (F,N) | Zeewyck Sub-basin | Limestone (fossiliferous micrite) | Carbonate clay, carbonate grains | Light greenish grey (10Y8/1) | Moderately lithified, friable | Laminae (<0.1 to 0.5 cm) | Very well sorted | Clay sized, silt sized | Shell fragments |
| GA2476/024DR025A (P,G) | Zeewyck Sub-basin | Claystone | Clay, carbonaceous material | Very dark grey (N3) | Moderately lithified, friable | Laminae (<0.1 cm) | Well sorted, fissile | Clay sized, silt sized | None |
| GA2476/024DR025B (P,G) | Zeewyck Sub-basin | Stratified sandstone and siltstone | Quartz grains, mica grains, carbonaceous grains | Dark grey (2.5Y 4/1) | Lithified | Laminae (<0.1 to 0.4 cm), cross-lamination, grading | Well sorted, subrounded to rounded grains | Very fine grained sand, silt sized, medium to coarse grained carbonaceous grains | None |
| GA2476/024DR025C (P,G) | Zeewyck Sub-basin | Sandstone | Quartz grains, mica grains, carbonaceous clay intraclast | Dark olive brown (2.5Y 3/3) | Lithified | Massive | Moderately sorted, subangular to subrounded grains, very angular to subangular intraclasts | Fine to medium grained sand, coarse grained to pebble sized intraclasts | None |
| GA2476/025DR026A (P,G,N) | Houtman Sub-basin, Houtman Canyon | Stratified siltstone and sandstone | Quartz grains, clay, mica grains | Dark yellowish brown (10YR 4/6); dark reddish brown (2.5YR 3/3) | Moderately lithified, friable | Wavy laminae (0.1 to 0.6 cm), cross-lamination | Well sorted; well sorted, subangular to rounded grains | Silt sized, clay sized; very fine to fine grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/025DR026B (P,G) | Houtman Sub-basin, Houtman Canyon | Sandstone | Quartz grains, carbonaceous laminae, mica grains | Greyish brown (2.5Y 5/2), light grey (2.5Y 7/1) | Moderately lithified, friable | Beds (1 to 1.3 cm), laminae (<0.1 to 0.2 cm), ripple cross-lamination, soft sediment deformation | Moderately well sorted, angular to subrounded grains | Very fine to medium grained sand | None |
| GA2476/025DR026C (P,G,N) | Houtman Sub-basin, Houtman Canyon | Stratified sandstone and siltstone | Quartz grains, mica grains, clay, carbonaceous grains | Dark greenish grey (10GY4/1); yellowish brown (10YR 5/6) | Moderately lithified, friable | Laminae (<0.1 to 0.4 cm), bioturbation | Well sorted, subangular to subrounded grains | Very fine to fine grained sand, silt sized, clay sized | None |
| GA2476/025DR026D (P,G,N) | Houtman Sub-basin, Houtman Canyon | Claystone | Clay, quartz grains, carbonaceous grains, mica grains | Very dark greyish brown (10YR 3/2), dark brown (10YR 3/3) | Moderately lithified, friable | Laminae (<0.1 cm) | Well sorted | Clay sized, silt sized, very fine to fine grained carbonaceous and mica grains | None |
| GA2476/025DR026E (P,G,N) | Houtman Sub-basin, Houtman Canyon | Stratified claystone and sandstone | Clay, quartz grains, mica grains, carbonaceous grains | Dark grey (5Y 4/1) | Weakly lithified, friable | Laminae (<0.1 to 0.4 cm) and beds (1.5 cm) | Well sorted; well sorted, subrounded to rounded grains | Clay sized, silt sized; very fine to fine grained sand | None |
| GA2476/025DR026F (F,N) | Houtman Sub-basin, Houtman Canyon | Claystone | Clay, quartz grains, carbonaceous grains, mica grains | Grey (10YR 6/1) | Lithified | Massive | Moderately well sorted, subangular to rounded carbonaceous grains | Clay sized, silt sized, very fine to fine grained carbonaceous grains | None |
| GA2476/025DR026G (P,G) | Houtman Sub-basin, Houtman Canyon | Stratified siltstone and sandstone | Quartz grains, mica grains | Dark brown (10YR 3/2) | Moderately lithified, friable | Laminae (<0.1 to 0.4 cm), wavy laminae | Well sorted | Silt sized, clay sized; very fine to fine grained sand | None |
| GA2476/026DR027A (TS) | Zeewyck Sub-basin | Basalt | Too fine to determine, chlorite crystals, calcite crystals | Black (N2.5) | Lithified | N/A | Vesicular, porphyritic | Aphanitic groundmass, fine to medium grained phenocrysts | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/026DR027B (F,N) | Zeewyck Sub-basin | Limestone (micrite: silty clastic) and chert | Carbonate grains, carbonate clay, silica, opaque grains | Light grey (N7) | Lithified | Laminae (<0.1 to 0.5 cm) | Well sorted; none | Silt sized, clay sized; N/A | None |
| GA2476/026DR027C (P,G,N) | Zeewyck Sub-basin | Claystone | Clay, quartz grains, mica grains, carbonate material, carbonaceous grains | Grey (N5) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized, medium to coarse grained carbonaceous grains | None |
| GA2476/026DR027D (P,G) | Zeewyck Sub-basin | Stratified micritic limestone (stratified sandy clastic and silty clastic) | Carbonate grains, opaque grains, clay | Light grey (2.5Y 7/2) | Moderately lithified, friable | Laminae (<0.1 cm), beds (>6 cm), extensive bioturbation | Moderately well sorted | Very fine grained sand, silt sized, clay sized | None |
| GA2476/026DR027E | Zeewyck Sub-basin | Sandstone | Quartz grains, carbonaceous grains, mica grains | Grey (2.5Y 6/1) | Moderately lithified, friable | Laminae (0.2 to 0.6 cm) | Moderately well sorted, subrounded to well rounded grains, very angular to rounded carbonaceous grains | Fine to medium grained sand, fine grained sand to granule sized carbonaceous grains | Coaly wood fragments |
| GA2476/026DR027F (P,G) | Zeewyck Sub-basin | Sandstone | Quartz grains, mica grains, carbonaceous grains | Grey (2.5Y 5/1) | Lithified | Laminae (0.1 to 0.3 cm) | Well sorted, subangular to subrounded grains | Very fine grained sand, fine grained sand to granule sized carbonaceous grains | None |
| GA2476/026DR027G (P,G) | Zeewyck Sub-basin | Stratified sandstone and siltstone | Quartz grains, carbonaceous grains, carbonaceous laminae, mica grains | Light brownish grey (10YR 6/2) | Moderately lithified, friable | Wavy laminae (<0.1 to 0.9 cm) | Moderately well sorted, subrounded to rounded grains | Very fine grained sand, fine to medium grained carbonaceous grains; silt sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/026DR027H | Zeewyck Sub-basin | Chert | Silica | Light grey (2.5Y 7/1) | Lithified | N/A | None | N/A | None |
| GA2476/026DR027I (P,G) | Zeewyck Sub-basin | Claystone | Clay, quartz grains, carbonaceous grains | Dark grey (2.5Y 4/1) | Weakly lithified, friable | Massive | Very poorly sorted, subrounded to rounded grains | Clay sized, fine to coarse grained sand | None |
| GA2476/026DR027K | Zeewyck Sub-basin | Limestone (micrite: silty clastic) | Carbonate grains, carbonate clay | White (2.5Y 8/1) | Moderately lithified, friable | Massive | Well sorted, rounded grains | Silt sized, clay sized, very fine grained | None |
| GA2476/026DR027L (TS) | Zeewyck Sub-basin | Basalt | Too fine to determine, silica | Dark bluish grey (5PB4/1) | Lithified | N/A | None | Aphanitic | None |
| GA2476/028BS002A | Houtman Sub-basin | Basalt | Too fine to determine, glass | Black (N2.5) | Lithified | N/A | Vesicular | Aphanitic | None |
| GA2476/029BS003A | Houtman Sub-basin | Mineral precipitate | Iron oxide, sulfidic compounds, unidentified minerals | Very dark grey (10YR 3/1), dark reddish brown (5YR 3/4) | Moderately lithified, friable | N/A | None | N/A | None |
| GA2476/029GR014E_B | Houtman Sub-basin | Manganese oxide | Manganese oxide, iron oxide | Dark reddish brown (5YR 2.5/2) | Lithified | N/A | None | N/A | None |
| GA2476/031DR028A (P,G) | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, carbonaceous laminae, mica grains, clay | Dark yellowish brown (10YR 3/4), reddish brown (5YR 4/4) | Moderately lithified, friable | Laminae (<0.1 to 0.5 cm), sandstone lenses (1.5 to 2 cm long) | Moderately well sorted, subrounded to rounded grains | Fine to medium grained sand, clay sized | None |
| GA2476/031DR028B | Cuvier margin, Cape Range Canyon | Siltstone (sample missing) | Quartz grains, mica grains, clay | Dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Massive | Poorly sorted | Silt sized, clay sized, fine grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/032DR029A (P,G) | Cuvier margin, Cape Range Canyon | Claystone | Clay, carbonaceous material, quartz grains, mica grains | Black (N2.5) | Lithified | Laminae (<0.1 cm) | Well sorted, fissile | Clay sized, silt sized | None |
| GA2476/032DR029B (TS) | Cuvier margin, Cape Range Canyon | Rhyolite | Too fine to determine, feldspar crystals, unidentified crystals | Grey (N6) | Lithified | N/A | Porphyritic | Groundmass aphanitic, fine to medium grained phenocrysts | None |
| GA2476/032DR029C | Cuvier margin, Cape Range Canyon | Limestone (micrite) | Carbonate clay, carbonate grains | Light yellowish brown (2.5Y 6/3) | Lithified | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/032DR029D (TS) | Cuvier margin, Cape Range Canyon | Dacite | Too fine to determine, mica crystals, unidentified crystals | Greenish grey (5G6/1) | Lithified | N/A | Equigranular | Aphantic to fine grained crystals | None |
| GA2476/032DR029E | Cuvier margin, Cape Range Canyon | Limestone (micrite) | Carbonate clay, carbonate grains | Light bluish grey (10B7/1) | Moderately lithified, friable | Massive | Well sorted, 5-15% porosity (<0.05 cm pores) | Clay sized, silt sized | None |
| GA2476/032DR029F | Cuvier margin, Cape Range Canyon | Chert | Silica | Weak red (10R 4/3), pink (7.5YR 7/3) | Lithified | N/A | None | N/A | None |
| GA2476/032DR029G | Cuvier margin, Cape Range Canyon | Mineral precipitate | Too fine to determine | Pale yellow (2.5Y 7/3) | Moderately lithified, friable | N/A | None | N/A | None |
| GA2476/032DR029H | Cuvier margin, Cape Range Canyon | Siltstone | Quartz grains, opaque grains | Light greenish grey (10Y7/1) | Lithified | Massive | Very well sorted | Silt sized, clay sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/032DR029I | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains | Light brown (7.5YR 6/3) | Lithified | Massive | Very well sorted | Very fine grained sand | None |
| GA2476/032GR016E_A (P,G) | Cuvier margin, Cape Range Canyon | Claystone | Carbonaceous material, quartz grains | Black (N2.5) | Weakly lithified, friable | Massive | Very well sorted, fissile | Clay sized, silt sized | None |
| GA2476/033DR030A (P,G) | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, mica grains, carbonate cement, opaque grains, carbonaceous grains, glauconite grains | Olive grey (5Y 4/2) | Lithified | Massive | Poorly to moderately sorted, angular to rounded grains | Very fine to medium grained sand, silt sized | None |
| GA2476/033DR030B (P,G) | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, opaque grains, mica grains | Very dark grey (N3) | Moderately lithified, friable | Massive | Moderately to well sorted, subangular to well rounded grains | Very fine to fine grained sand | None |
| GA2476/033DR030D | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, mica grains, opaque grains, carbonaceous grains | Olive (5Y 5/3) | Moderately lithified, friable | Massive | Well sorted, subangular to subrounded grains | Very fine to medium grained sand | None |
| GA2476/033GR017E_A (P,G) | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, carbonaceous grains, mica grains | Light olive brown (2.5Y 5/4) | Moderately lithified, friable | Massive | Moderately to well sorted, subrounded to rounded grains | Very fine to medium grained sand | None |
| GA2476/033GR017E_B | Cuvier margin, Cape Range Canyon | Claystone | Clay, mica grains, carbonaceous grains, quartz grains | Light grey (2.5Y 7/2) | Moderately lithified, friable | Massive | Moderately sorted, subangular to rounded grains | Clay sized, silt sized, very fine to fine grained carbonaceous grains | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/034DR031B | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, carbonaceous grains, mica grains | Dark olive-brown (2.5Y 3/3) | Moderately lithified, friable | Massive | Moderately to well sorted, subangular to rounded grains | Very fine to fine grained sand, fine to medium grained carbonaceous grains | None |
| GA2476/034DR031C | Cuvier margin, Cape Range Canyon | Mineral precipitate | Silica | Grey (2.5Y 6/1) | Lithified | N/A | None | N/A | Possible gastropod shell |
| GA2476/034DR031D | Cuvier margin, Cape Range Canyon | Claystone | Clay, pyrite crystals | Black (N2.5) | Lithified | Massive | Very well sorted, <0.1 cm pyrite veins | Clay sized, fine grained crystals | None |
| GA2476/034GR018E_B | Cuvier margin, Cape Range Canyon | Sandstone | Quartz grains, mica grains, carbonate grains | Dark olive grey (5Y 3/2) | Weakly lithified, friable | Massive | Moderately well sorted, subangular to subrounded grains | Very fine to fine grained sand | None |
| GA2476/036DR032B (P,G) | Cuvier margin, Cloates Canyon | Stratified sandstone and siltstone | Quartz grains, mica grains, opaque grains | Dark olive brown (2.5Y 3/3); very dark greenish grey (10Y 3/1) | Moderately lithified, friable | Beds (1 to 4 cm), laminae (0.5 cm) | Moderately sorted, subangular to subrounded grains | Very fine grained sand, silt sized, fine grained mica grains | None |
| GA2476/036DR032C (P,G,N) | Cuvier margin, Cloates Canyon | Siltstone | Quartz grains, clay, mica grains | Olive brown (2.5Y 3/4) | Moderately lithified, friable | Lenticular bedding, bioturbation possible | Moderately sorted, subangular to subrounded grains | Silt sized, very fine grained sand, clay sized | None |
| GA2476/036DR032D | Cuvier margin, Cloates Canyon | Siltstone | Quartz grains, mica grains, carbonaceous grains | Brown (10YR 5/3) | Moderately lithified, friable | Massive | Moderately well sorted, subangular to rounded grains | Silt sized, clay sized, very fine grained sand, very fine to fine grained mica grains | Bivalve fragments |
| GA2476/036DR032E (P,G,N) | Cuvier margin, Cloates Canyon | Siltstone | Quartz grains, mica grains, opaque grains, carbonate cement | Grey (5Y 5/1) | Lithified | Massive | Well sorted, subangular to rounded grains | Silt sized, very fine to fine grained sand | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/036GR019E_B (P,G) | Cuvier margin, Cloates Canyon | Siltstone | Quartz grains, clay, mica grains | Very dark grey (N3) | Moderately lithified, friable | Massive | Well to very well sorted | Silt sized, clay sized, very fine to fine grained mica grains | None |
| GA2476/036GR019E_C (P,G,N) | Cuvier margin, Cloates Canyon | Siltstone | Quartz grains, clay, mica grains, carbonaceous grains | Dark brown (7.5 YR 3/2) | Moderately lithified, friable | Lenticular bedding | Moderately well sorted, subangular to subrounded grains | Silt sized, very fine grained sand, clay sized, very fine to fine grained mica grains | None |
| GA2476/037DR033A (F,N) | Cuvier margin, Cloates Canyon | Limestone (micrite) | Carbonate clay, carbonaceous material | Greyish brown (10 YR 5/2) | Moderately lithified, friable | Massive | Well sorted | Clay sized | None |
| GA2476/037GR020E_B | Cuvier margin, Cloates Canyon | Limestone (micrite) | Carbonate clay, carbonate grains | Grey (5Y 6/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/037GR020E_C | Cuvier margin, Cloates Canyon | Limestone (micrite) | Carbonate clay | Light grey (5Y 7/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized | None |
| GA2476/038DR034B (P,G) | Cuvier margin | Siltstone | Quartz grains, clay, mica grains | Dark greyish brown (10YR 4/2) | Moderately lithified, friable | Lenses of claystone (0.1 to 0.6 cm) | Well sorted | Silt sized, clay sized | None |
| GA2476/038DR034C | Cuvier margin | Siltstone | Quartz grains, carbonate crystals, clay, mica grains, opaque grains | Dark greyish brown (2.5Y 3/2) | Lithified | Massive | Well sorted, radial brecciation filled with carbonate crystals | Silt sized, clay sized, very fine to fine grained mica grains, fine to medium grained carbonate crystals | None |
| GA2476/038DR034D | Cuvier margin | Limestone (micrite) | Carbonate clay | White (5Y 8/1) | Moderately lithified, friable | Massive | Very well sorted | Clay sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/038GR021E_B (F,N) | Cuvier margin | Limestone (micrite) | Carbonate clay | White (5Y 8/1) | Moderately lithified, friable | Massive | Very well sorted | Clay sized | None |
| GA2476/038GR021E_C | Cuvier margin | Limestone (micrite) | Carbonate clay | Pale yellow (5Y 8/2) | Moderately lithified, friable | Massive | Very well sorted | Clay sized | None |
| GA2476/038GR021E_D | Cuvier margin | Limestone (micrite) | Carbonate clay, quartz grains, silica | Light grey (5Y 7/2) | Lithified | Massive | Well sorted, rounded grains | Clay sized, fine grained sand | None |
| GA2476/038GR021E_E (P,G,N) | Cuvier margin | Siltstone | Quartz grains, clay, mica grains, glauconite grains | Very dark greyish brown (10YR 4/2) | Moderately lithified, friable | Beds (1.2 cm) | Moderately well sorted, subangular to subrounded grains, subrounded to rounded glauconite grains | Silt sized, clay sized, very fine to fine grained sand grains | None |
| GA2476/038GR021E_F (P,G) | Cuvier margin | Siltstone | Quartz grains, clay, mica grains | Greenish grey (10Y5/1) | Moderately lithified, friable | Massive | Well sorted, subrounded to rounded grains | Silt sized, clay sized, very fine grained sand | None |
| GA2476/038GR021E_G (P,G) | Cuvier margin | Claystone | Clay, quartz grains, mica grains | Greyish brown (2.5Y 5/2) | Moderately lithified, friable | Massive | Well sorted, subrounded to rounded grains | Clay sized, silt sized, very fine grained mica grains | None |
| GA2476/038GR021E_H (P,G,N) | Cuvier margin | Limestone (micrite) | Carbonate clay, carbonate grains, mica grains | Light grey (2.5Y 7/1) | Moderately lithified, friable | Laminae (0.1 to 0.8 cm) | Well sorted | Clay sized, silt sized, very fine grained mica grains | None |
| GA2476/038GR021E_I | Cuvier margin | Limestone (micrite) | Carbonate clay, silica | Grey (5Y 5/1) | Lithified | Massive | Very well sorted | Clay sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/038GR021E_J (P,G) | Cuvier margin | Limestone (micrite) | Carbonate clay, clay, carbonate grains, mica grains | Very dark grey (5Y 3/1) | Moderately lithified, friable | Massive | Well sorted, fissile | Clay sized, silt sized | None |
| GA2476/038GR021E_K | Cuvier margin | Limestone (micrite) | Carbonate clay, clay, carbonate grains, mica grains | Grey (5Y 6/1) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/038GR021E_L | Cuvier margin | Limestone (micrite) | Carbonate clay, carbonate silt | Olive (5Y 5/3) | Moderately lithified, friable | Massive | Very well sorted | Clay sized, silt sized | None |
| GA2476/038GR021E_M | Cuvier margin | Sandstone | Quartz grains, mica grains, opaque grains | Pale brown (10YR 6/3) | Moderately lithified, friable | Massive | Moderately well sorted, subangular to subrounded grains | Very fine to fine grained sand | None |
| GA2476/039DR035B | Cuvier margin | Limestone (micrite) | Carbonate clay, carbonate silt | Pale yellow (2.5Y 7/3) | Moderately lithified, friable | Massive | Well sorted | Clay sized, silt sized | None |
| GA2476/039GR022E_B (F,N) | Cuvier margin | Limestone (fossiliferous micrite) | Carbonate clay | Pale Yellow (2.5Y 7/3) | Moderately lithified, friable | Massive | Very well sorted | Clay sized | Bivalve fragments |
| GA2476/042DR036B (P,G) | Cuvier margin, Carnarvon Canyon | Sandstone | Quartz grains, clay, opaque grains, carbonaceous intraclasts, lithic intraclasts, biogenic intraclasts | Dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Massive | Very poorly sorted, subangular to well rounded grains, highly angular carbonaceous intraclasts, rounded lithic intraclasts | Very fine to fine grained sand, clay sized, coarse grained sand to large cobble sized carbonaceous intraclasts, medium grained sand to large pebble sized lithic intraclasts | Coaly wood fragments, bivalve mould (1 to 1.5 cm diameter) |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/042DR036C (P,G) | Cuvier margin, Carnarvon Canyon | Claystone | Clay, quartz grains, opaque grains | Black (5Y 2.5/1) | Lithified | Sandy beds (3 cm), laminae (0.5 cm), extensive bioturbation | Moderately sorted, subangular to well rounded grains | Clay sized, very fine to fine grained sand | None |
| GA2476/042DR036D | Cuvier margin, Carnarvon Canyon | Limestone (micrite) | Carbonate clay, carbonate silt | Light grey (5Y 7/2) | Moderately lithified, friable | Massive | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/043DR037B (P,G) | Cuvier margin, Carnarvon Canyon | Siltstone | Quartz grains, clay, mica grains | Dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Parallel layering of extensive bioturbation burrows/tracks | Moderately well sorted | Silt sized, clay sized, very fine to fine grained sand | None |
| GA2476/043DR037C (P,G) | Cuvier margin, Carnarvon Canyon | Claystone | Clay, quartz grains, carbonaceous material | Dark olive brown (2.5Y 3/3) | Weakly lithified, friable | Massive | Well sorted, fissile | Clay sized, silt sized | None |
| GA2476/044DR038A (TS) | Houtman Sub-basin, Peak feature | Volcaniclastic conglomerate | Weathered intraclasts, glassy vesicular intraclasts, carbonate cement | Dark brown (10YR 3/3) | Moderately lithified, friable | Massive | Poorly sorted, subrounded to well rounded intraclasts | Ash to lapilli sized intraclasts, glassy vesicular lapilli, micritic sized cement | None |
| GA2476/044DR038C (TS) | Houtman Sub-basin, Peak feature | Basalt | Hornblende crystals, green crystals, calcite crystals, glass, weathered phenocrysts, pumice phenocrysts | Brown (10YR 4/3) | Lithified | N/A | Porphyritic, angular to rounded phenocrysts | Aphanitic groundmass, fine to coarse grained phenocrysts | None |
| GA2476/045DR039B (F,N) | Houtman Sub-basin | Limestone (micrite) | Carbonate clay | White (7.5YR 8/1) | Moderately lithified, friable | Massive | Very well sorted | Clay sized | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/045DR039C | Houtman Sub-basin | Mineral precipitate | Manganese oxide, iron oxide | Black (N2.5) | Moderately lithified, friable | N/A | None | N/A | None |
| GA2476/045DR039D | Houtman Sub-basin | Basalt | Too fine to determine, glass | Black (N2.5) | Lithified | N/A | Vesicular | Aphanitic | None |
| GA2476/045DR039E | Houtman Sub-basin | Basalt | Too fine to determine, glass, zeolite | Light yellowish brown (10YR 6/4) | Lithified | N/A | None | Aphanitic | None |
| GA2476/046DR040B (P,G,N) | Houtman Sub-basin | Sandstone | Quartz grains, mica grains, clay, opaque grains, carbonaceous grains | Brown (10YR 4/3) | Moderately lithified, friable | Beds (>1.3 cm), laminae (0.5 cm) | Moderately well sorted, subangular to rounded grains | Very fine grained sand, silt sized, clay sized | None |
| GA2476/047DR041B (P,G) | Houtman Sub-basin | Limestone (fossiliferous micrite) | Carbonate clay, carbonate silt, quartz grains, opaque grains, carbonaceous laminae | Olive (5Y 4/3) | Moderately lithified, friable | Laminae (<0.1 to 0.5 cm) | Moderately well sorted | Clay sized, silt sized, very fine to fine grained sand | Bivalve fragments and mould |
| GA2476/047DR041C (P,G,N) | Houtman Sub-basin | Claystone | Clay, quartz grains, mica grains | Dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Massive | Moderately well sorted | Clay sized, silt sized | None |
| GA2476/047DR041D (P,G) | Houtman Sub-basin | Siltstone | Quartz grains, glauconite grains, clay | Dark olive brown (2.5Y 3/3) | Moderately lithified, friable | Massive | Moderately well sorted | Silt sized, very fine to fine grained sand, clay sized | None |
| GA2476/049DR042B (F,N) | Zeewyck Sub-basin | Limestone (micrite) | Carbonate clay, carbonate grains | White (7.5YR 8/1) | Moderately lithified, friable | Bioturbation | Very well sorted | Clay sized, silt sized | None |
| GA2476/050DR043A (P,G) | Cuvier Plateau | Claystone | Clay, quartz grains, carbonaceous | Dark greenish grey (10Y4/1) | Moderately lithified, friable | Bioturbation | Well sorted | Clay sized, silt sized, very fine grained | Shell fragments |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| | | | grains, mica grains | | | | | carbonaceous grains | |
| GA2476/051DR044A | Cuvier Plateau | Alteration lithology | Too fine to determine, clay, unidentified grains | Olive grey (5Y 5/2) | Weakly lithified, friable | N/A | None | Aphanitic, clay sized, coarse grained unknowns | None |
| GA2476/051DR045B | Cuvier Plateau | Basalt | Too fine to determine, carbonate clay | Olive Grey (5Y 4/2) | Lithified | N/A | Vesicular | Aphanitic, micritic carbonate cement | None |
| GA2476/051DR045C | Cuvier Plateau | Basalt | Too fine to determine | Yellowish brown (10YR 5/6) | Lithified | N/A | None | Aphanitic | None |
| GA2476/052DR046A (P,G) | Cuvier Plateau | Siltstone | Quartz grains, clay, opaque grains, carbonaceous grains | Light olive brown (2.5Y 5/6) | Moderately lithified, friable | Massive | Well sorted | Silt sized, clay sized, very fine grained sand | None |
| GA2476/052DR046B (TS) | Cuvier Plateau | Andesite | Too fine to determine, quartz cyrstals, glass | Light brownish grey (2.5Y 6/2) | Lithified | N/A | None | Aphanitic | None |
| GA2476/053DR047B | Cuvier Plateau | Volcaniclastic breccia | Too fine to determine | Dark greyish brown (2.5Y 4/2) | Moderately lithified, friable | N/A | Very poorly sorted, angular to subrounded intraclasts | Aphanitic matrix, ash to lapilli sized intraclasts | None |
| GA2476/053DR047C (TS) | Cuvier Plateau | Basalt | Too fine to determine, white crystals, massive green mineral in vesicles | Olive (5Y 4/3) | Lithified | N/A | Vesicular | Aphanitic | None |
| GA2476/053DR047D (P,G,N) | Cuvier Plateau | Sandstone | Quartz grains, carbonate cement | Olive brown (2.5Y 4/4) | Moderately lithified, friable | Massive | Very poorly sorted, subangular to subrounded grains | Very fine grained sand, medium grained sand to medium pebble sized bioclasts | Bivalve fragments, echinoderm spines, bryozoan fragment |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/053DR047E | Cuvier Plateau | Basalt | Too fine to determine, glass | Grey (2.5Y 6/1) | Lithified | N/A | Vesicular | Aphanitic | None |
| GA2476/055BS004A | Cuvier Plateau | Basalt | Too fine and altered to determine | Yellowish brown (10YR 5/4) | Lithified | N/A | None | Aphanitic | None |
| GA2476/055BS004B | Cuvier Plateau | Volcaniclastic sandstone | Quartz grains, clay, carbonate cement, unidentified grains | Olive brown (2.5Y 4/4) | Moderately lithified, friable | Massive | Very poorly sorted, subrounded to well rounded grains | Clay sized, medium grained sand to very large pebble sized grains | None |
| GA2476/055BS004C | Cuvier Plateau | Basalt | Too fine to determine, carbonate clay | Reddish brown (5YR 4/3) | Lithified | N/A | Vesicular | Aphanitic | None |
| GA2476/055BS004D | Cuvier Plateau | Limestone (micrite) | Carbonate clay, mafic lithic intraclasts | Very pale brown (10YR 8/3) | Lithified | Massive | Poorly sorted, subangular to subrounded lithic intraclasts | Clay sized, medium grained sand to granule sized lithic intraclasts | None |
| GA2476/055BS004E | Cuvier Plateau | Mineral precipitate | Manganese oxide | Black (5YR 2.5/2) | Lithified | N/A | None | N/A | None |
| GA2476/055BS004F | Cuvier Plateau | Chert | Silica, quartz crystals, unidentified crystals | Light grey (10YR 7/1) | Lithified | N/A | None | N/A | None |
| GA2476/055BS004G | Cuvier Plateau | Mineral precipitate | Iron oxide, manganese oxide | Dark red (10R 3/6) | Lithified | N/A | None | N/A | None |
| GA2476/055DR048B | Cuvier Plateau | Mineral precipitate | Manganese oxide | Black (N2.5) | Lithified | N/A | None | N/A | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/055DR048C | Cuvier Plateau | Volcaniclastic sandstone | Quartz grains, unidentified lithic grains, carbonate cement, mica grains | Olive brown (2.5Y 4/4) | Moderately lithified, friable | Massive | Moderately sorted, subangular to rounded grains | Very fine to medium grained sand | None |
| GA2476/056DR049B (TS) | Cuvier Plateau, Seamount | Andesite | Quartz crystals, opaque crystals, unidentified grains | Brown (7.5YR 4/4) | Lithified | N/A | None | Aphanitic | None |
| GA2476/056DR049C | Cuvier Plateau, Seamount | Alteration breccia | Too fine to determine, felsic volcanic intraclasts | Strong brown (7.5YR 4/6), yellow (5Y 7/6) | Moderately lithified, friable | N/A | Very poorly sorted, very angular to subrounded intraclasts | Aphanitic, medium to very large pebble sized felsic volcanic intraclasts | None |
| GA2476/056DR049D | Cuvier Plateau, Seamount | Limestone (micrite) | Carbonate clay | White (2.5Y 8/1) | Lithified | Massive | Well sorted | Clay sized | None |
| GA2476/056DR050A | Cuvier Plateau, Seamount | Alteration breccia | Too fine to determine, mafic volcanic intraclasts | Olive (5Y 5/3) | Lithified | N/A | Very poorly sorted, angular to subrounded mafic intraclasts | Aphanitic, coarse grained sand to very large pebble sized mafic intraclasts | None |
| GA2476/056GR028E_B | Cuvier Plateau, Seamount | Basalt | Too fine to determine | Yellowish red (5YR 4/6) | Lithified | N/A | None | Aphanitic | None |
| GA2476/057DR051A (TS) | Cuvier Plateau | Basalt | Too fine to determine, glass | Blueish grey (5PB5/1) | Lithified | N/A | None | Aphanitic | None |
| GA2476/058DR052B | Cuvier Plateau | Basalt | Too fine to determine | Dark olive grey (5Y 3/2) | Lithified | N/A | None | Aphanitic | None |

| Sample ID | Locality | Rock Type | Mineralogy | Colour | Lithification | Sedimentary Structures | Fabric | Particle Size | Fossil Content |
|---|---|---|---|---|---|---|---|---|---|
| GA2476/058DR052C | Cuvier Plateau | Mineral precipitate | Manganese oxide, unidentified minerals | Black (N2.5) | Lithified | N/A | None | N/A | None |
| GA2476/061DR053A (P,G,N, M) | Cuvier Plateau | Claystone | Clay, quartz grains | Pale yellow (2.5Y 7/3) | Moderately lithified, friable | Massive, extensive bioturbation | Well sorted | Clay sized, silt sized | Molluscs (fragments and whole) |
| GA2476/061DR053B (P,G,N) | Cuvier Plateau | Claystone | Clay, quartz grains | Light brownish grey (2.5Y 6/2) | Moderately lithified, friable | Massive, bioturbation | Well sorted | Clay sized, silt sized, very fine grained sand | None |
| GA2476/061DR053C (TS) | Cuvier Plateau | Andesite | Too fine to determine, unidentified crystals | Blueish grey (10B6/1) | Lithified | N/A | None | Aphanitic to medium grained crystals | None |
| GA2476/061DR053D (TS) | Cuvier Plateau | Basalt | Too fine to determine, glass | Greenish grey (5G6/1) | Lithified | N/A | None | Aphanitic | None |

### 13.17. APPENDIX Q – INITIAL PALYNOLOGICAL AND PALAEONTOLOGICAL ANALYSES

This appendix contains four parts: Q1) Summary of palynology data; Q2) Summary of nannofossil data; Q3) Summary of foraminiferal data; and Q4) Summary of macrofossil data. For full reference details, see section 11 (References), and for sample descriptions, see Appendix P.

***Q1: Summary of palynology data***

**Table 13.15.** Summary details of the palynological analyses carried out on rock samples collected during survey GA2476 by Dr Daniel Mantle (Geoscience Australia) and contained within a report submitted to Geoscience Australia by Drs Mike MacPhail and Alan D. Partridge (MacPhail and Partridge 2009).

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/042DR036C1 | 1982090 | Cuvier | Late Aptian | D. davidii DZ | Indet. | Middle to outer neritic open marine |
| GA2476/038GR021E_F1 | 1985157 | Cuvier | Hauterivian | P. burgeri DZ | B. eneabbaensis SPZ | Open marine |
| GA2476/038GR021E_H | 1983036 | Cuvier | Late Albian | E. ludbrookiae DZ | Indet. | Middle to outer neritic open marine |
| GA2476/038GR021E_J1 | 1983039 | Cuvier | Late Albian | E. ludbrookiae DZ | Indet. | Middle to outer neritic open marine |
| GA2476/036DR032E1 | 1983017 | Cuvier | Berriasian-basal Valanginian | F. cylindrica Superzone | B. eneabbaensis SPZ | Open marine |
| GA2476/032GR016E_A1 | 1982086 | Cuvier | Berriasian | F. tumida DZ | B. eneabbaensis SPZ | Marginal (Restricted) Marine |
| GA-2476/032DR029A2 | 1982087 | Cuvier | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/038DR034B1 | 1982095 | Cuvier | Hauterivian | M. testudinaria DZ | R. australiensis SPZ or younger | Shallow marine |
| GA2476/038DR034B2 | 1982096 | Cuvier | Hauterivian | M. testudinaria DZ | R. australiensis SPZ or younger | Shallow marine |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/038GR021E_E1 | 1983031 | Cuvier | Hauterivian | M. testudinaria DZ | B. limbata SPZ | Open marine |
| GA2476/038GR021E_G1 | 1983035 | Cuvier | Hauterivian | M. testudinaria DZ | B. limbata SPZ | Open marine |
| GA2476/043DR037B1 | 1983059 | Cuvier | Early Aptian | O. operculata DZ | B. limbata SPZ | Inner to outer neritic open marine |
| GA2476/043DR037C1 | 1983061 | Cuvier | Early Aptian | O. operculata DZ | B. limbata SPZ | Inner to outer neritic open marine |
| GA2476/036GR019E_B1 | 1982088 | Cuvier | Hauterivian | P. burgeri DZ | B. eneabbaenis or younger | Shallow marine |
| GA2476/036DR032B1 | 1982089 | Cuvier | Hauterivian | P. burgeri DZ | B. eneabbaenis or younger | Shallow marine |
| GA2476/031DR028A1 | 1982977 | Cuvier | Hauterivian | (upper) S. tabulata DZ | B. eneabbaenis or younger | Shelfal/Marine |
| GA2476/033GR017E_A | 1982990 | Cuvier | Hauterivian | (lower) P. burgeri DZ | B. eneabbaenis or younger | Distal delta/Shallow Shelf |
| GA2476/033DR030A1 | 1982993 | Cuvier | Valanginian-Hauterivian | S. tabulata DZ | B. eneabbaenis or younger | Distal delta/Shallow Shelf |
| GA2476/033DR030A3 | 1982995 | Cuvier | Valanginian-Hauterivian | S. areolata-S. tabulata DZ | B. eneabbaenis or younger | Distal delta/Shallow Shelf |
| GA2476/033DR030B1 | 1982997 | Cuvier | Valanginian-Hauterivian | S. tabulata DZ | B. limbata SPZ | Distal delta/Shallow Shelf |
| GA2476/036GR019E_C1 | 1983008 | Cuvier | Hauterivian | (upper) P. burgeri DZ | B. eneabbaenis or younger | Distal delta/Shallow Shelf |
| GA2476/036GR019C2 | 1983009 | Cuvier | Hauterivian | (upper) P. burgeri DZ | B. limbata SPZ | Distal delta/Shallow Shelf |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/025DR026D1 | 1982083 | Houtman | Berriasian | F. tumida DZ | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/025DR026G1 | 1982084 | Houtman | Berriasian | F. tumida DZ | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/006BC001E_D | 1978945 | Houtman | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/006BC001E_E | 1978946 | Houtman | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/007DR005A | 1978977 | Houtman | Middle Albian | C. denticulata DZ | Indeterminate | Open marine |
| GA2476/007DR005C | 1978979 | Houtman | Middle Albian | C. denticulata DZ | Indeterminate | Middle to outer neritic open marine |
| GA2476/007DR004B1 | 1978962 | Houtman | Late Aptian | D. davidii DZ | B. limbata SPZ | Middle to outer neritic open marine |
| GA2476/007DR004B4 | 1978965 | Houtman | Late Aptian | D. davidii DZ | B. limbata SPZ | Middle to outer neritic open marine |
| GA2476/007DR004B5 | 1978966 | Houtman | Late Aptian | D. davidii DZ | Microcachryidites Superzone | Middle to outer neritic open marine |
| GA2476/006BC001E_B | 1978943 | Houtman | late Middle Eocene | D. heterophylcta DZ | Indet. | Middle neritic to bathyal open marine |
| GA2476/006DR002D | 1978954 | Houtman | late Middle Eocene | D. heterophylcta DZ | Indet. | Middle neritic to bathyal open marine |
| GA2476/006BC001E_A | 1978942 | Houtman | Cretaceous | Indet. | B. eneabbensis or younger | Fluvio-deltaic/Estuarine |
| GA2476/025DR026B1 | 1982946 | Houtman | Berriasian-basal Aptian | Indet. | B. eneabbaensis SPZ | Restricted marine |
| GA2476/025DR026C1 | 1982949 | Houtman | Berriasian-basal | Indet. | B. eneabbaensis | Fluvio-deltaic/Estuarine |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| | | | Aptian | | SPZ | |
| GA2476/025DR026C3 | 1982951 | Houtman | Berriasian-Early Valanginian | Indet. | B. eneabbaensis SPZ | Fluvio-deltaic/Estuarine |
| GA2476/025DR026E1 | 1982954 | Houtman | Berriasian-Early Valanginian | Indet. | B. eneabbaensis SPZ | Fluvio-deltaic/Estuarine |
| GA2476/046DR040B1 | 1983074 | Houtman | Late Jurassic-Early Cretaceous | Indet. | Indet. | Lacustrine/restricted marine |
| GA2476/006DR002E | 1978955 | Houtman | Early Berriasian | G. mutabilis DZ | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/007DR004B2 | 1978963 | Houtman | early Late Aptian | lower D. davidii DZ (O. striatum Acme) | Indet. | Middle to outer neritic open marine |
| GA2476/047DR041C1 | 1982091 | Houtman | Hauterivian-Barremian | M. testudinaria - M. australis DZ indet | B. limbata SPZ | Shallow Marine |
| GA2476/025DR026A1 | 1982082 | Houtman | Berriasian | F. tumida DZ | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/006DR001A | 1978947 | Houtman | Berriasian | P. iehiense DZ or younger (F. tumida or younger) | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/047DR041B1 | 1983078 | Houtman | Early Albian | upper M. tetracantha DZ | Indet. | Middle neritic to bathyal |
| GA2476/053DR047D2 | 1982092 | Wallaby | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/061DR053A1 | 1982093 | Wallaby | Late Valanginian-Early Aptian | Microfasta evansii Acme Zone | Indet. | Shallow marine |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/061DR053B1 | 1982094 | Wallaby | ?Early Cretaceous | Indet. | Indet. | Marine |
| GA2476/052DR046A1 | 1983091 | Wallaby | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/050DR043A1 | 1983088 | Wallaby | Hauterivian | Microfasta evansii Acme Zone | Indet. | Lacustrine/restricted marine |
| GA2476/026DR027I | 1982085 | Zeewyck | Berriasian | F. tumida DZ | B. eneabbaensis SPZ | Marginal marine |
| GA2476/026DR027D | 1982963 | Zeewyck | Middle Eocene | E. partridgei DZ | Indet. | Outer neritic to bathyal open marine |
| GA2476/015DR013D | 1979021 | Zeewyck | Valanginian | Gagiella mutabilis DZ | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/018DR019C3 | 1979044 | Zeewyck | Berriasian-basal Aptian | Indeterminate | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/020DR020G1 | 1979093 | Zeewyck | Valanginian | G. mutabilis DZ | B. limbata SPZ | Restricted marine (estuarine to inner neritic) |
| GA2476/024DR025B1 | 1982081 | Zeewyck | Indet. (sample BARREN) | Indet. | Indet. | Terrestrial |
| GA2476/024DR025C1 | 1982943 | Zeewyck | Early Berriasian | Indet. | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/026DR027C1 | 1982962 | Zeewyck | Berriasian-basal Aptian | Indet. | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/026DR027F | 1982965 | Zeewyck | Berriasian-basal Aptian | Indet. | B. eneabbaensis SPZ | Estuarine/Restricted marine |
| GA2476/026DR027G | 1982966 | Zeewyck | Berriasian-basal Aptian | Indet. | B. eneabbaensis SPZ | Estuarine/Restricted marine |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/014DR011A3 | 1978999 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/014DR011B1 | 1979002 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/014DR012B1 | 1979007 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/015DR013C1 | 1979020 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/016DR016A1 | 1979029 | Zeewyck | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/018DR019C4 | 1979045 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/018DR019D5 | 1979050 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis or younger | Terrestrial |
| GA2476/018GR005E_B3 | 1979059 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/018GR005E_B6 | 1979062 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ or younger | Fluvio-deltaic/Estuarine |
| GA2476/020DR020A2 | 1979072 | Zeewyck | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/020DR020A7 | 1979077 | Zeewyck | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/020DR020A8 | 1979078 | Zeewyck | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/020DR020C1 | 1979082 | Zeewyck | Valanginian | G. mutabilis DZ | B. eneabbaensis SPZ | Marginal marine |

| SAMPLEID | SAMPLENO | REGION | AGE | DINOCYST ZONE | SPORE-POLLEN ZONE | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/024DR025A1 | 1982080 | Zeewyck | Berriasian-Valanginian | Indet. | B. eneabbaensis SPZ | Terrestrial |
| GA2476/020DR020D1 | 1979083 | Zeewyck | Mid-Late Valanginian | S. tabulata DZ | B. limbata SPZ | Open marine |
| Dinocyst Zones after Helby, Morgan, and Partridge (1987) and Backhouse (1987); Spore-Pollen Zones after Helby, Morgan, and Partridge (1987) and Backhouse (1988); Time Scale after Gradstein et al. (2004) including updates published in Ogg et al. (2008). | | | | | | |

***Q2: Summary of nannofossil data***

**Table 13.16.** Summary details of the nannofossil analyses carried out on rock samples collected during survey GA2476 by Dr John P. Rexilius (Rexilius, 2009).

| SAMPLEID | SAMPLENO | REGION | AGE | NANNOFOSSIL ZONE | NANNOFOSSIL DIVERSITY (NUMBER OF TAXA) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/036GR019E_C1 | 1983008 | Cuvier | indet. | indet. | 0 | indet. |
| GA2476/036GR019E_C2 | 1983009 | Cuvier | Maastrichtian - Bajocian (? in-situ) | indet. | 1 | undiff. marine |
| GA2476/036DR032C1 | 1983014 | Cuvier | indet. | indet. | 0 | indet. |
| GA2476/036DR032E1 | 1983017 | Cuvier | Maastrichtian - Bajocian (? in-situ) | indet. | 1 | undiff. marine |
| GA2476/037DR033A1 | 1983023 | Cuvier | Early Oligocene - Late Eocene | CP16b - CP16a | 30 | distal marine |
| GA2476/038GR021E_B1 | 1983027 | Cuvier | Middle Paleocene | CP4 (upper) | 21 in-situ, 3 recycled | distal marine |

| SAMPLEID | SAMPLENO | REGION | AGE | NANNOFOSSIL ZONE | NANNOFOSSIL DIVERSITY (NUMBER OF TAXA) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/038GR021E_D1 | 1983029 | Cuvier | Early Albian | KCN28 | 25 in-situ, 3 + contaminated | distal marine |
| GA2476/038GR021E_D2 | 1983030 | Cuvier | indet. | indet. | 0 | indet. |
| GA2476/038GR021E_E2 | 1983032 | Cuvier | indet. | indet. | 0 | indet. |
| GA2476/038GR021E_H | 1983036 | Cuvier | Late Albian | KCN25c | high | distal marine |
| GA2476/039GR022E_B1 | 1985412 | Cuvier | Early Albian | KCN28 | 30 | distal marine |
| GA2476/006DR001B | 1978948 | Houtman | Late Eocene | CP15bi - CP15a | 29 | distal marine |
| GA2476/007DR004C1 | 1978967 | Houtman | Early Eocene | CP10 | 27 | distal marine |
| GA2476/007DR005A | 1978977 | Houtman | Late - Early Aptian | KCN29 | 27 | distal marine |
| GA2476/007DR006E | 1978985 | Houtman | Middle Eocene | CP14a | 31 | distal marine |
| GA2476/008DR007A1 | 1978988 | Houtman | Middle Paleocene | CP4 (upper) | 21 in-situ, 2 recycled | distal marine |
| GA2476/025DR026C4 | 1982948 | Houtman | indet. | indet. | 0 | indet. |
| GA2476/025DR026C1 | 1982949 | Houtman | indet. | indet. | 0 | indet. |
| GA2476/025DR026C3 | 1982951 | Houtman | indet. | indet. | 0 | indet. |
| GA2476/025DR026E1 | 1982954 | Houtman | indet. | indet. | 0 | indet. |
| GA2476/025DR026F | 1982955 | Houtman | indet. | indet. | 0 | indet. |

| SAMPLEID | SAMPLENO | REGION | AGE | NANNOFOSSIL ZONE | NANNOFOSSIL DIVERSITY (NUMBER OF TAXA) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/045DR039B1 | 1983068 | Houtman | Late Paleocene | CP8 (lower) | 20 | distal marine |
| GA2476/046DR040B1 | 1983074 | Houtman | indet. | indet. | 0 | indeterminate |
| GA2476/047DR041B1 | 1983078 | Houtman | Early Albian | KCN28 | high | distal marine |
| GA2476/050DR043A1 | 1983088 | Wallaby | indet. | indet. | 0 | indet. |
| GA2476/052DR46A1 | 1983091 | Wallaby | indet. | indet. | 0 | indet. |
| GA2476/053DR047D2 | 1983092 | Wallaby | indet. | indet. | 0 | indet. |
| GA2476/061DR053A1 | 1983093 | Wallaby | indet. | indet. | 0 | indet. |
| GA2476/061DR053B1 | 1983094 | Wallaby | Maastrichtian - Bajocian (? in-situ) | indet. | 1 | undiff. marine |
| GA2476/022DR024A1 | 1978935 | Zeewyck | Middle Eocene | CP13b | 38 | distal marine |
| GA2476/021DR021B5 | 1979106 | Zeewyck | Middle Eocene | CP14a | 30 | distal marine |
| GA2476/021GR009E_A | 1979122 | Zeewyck | Middle Eocene | CP14a | 34 in-situ, 1 recycled | distal marine |
| GA2476/022DR022A | 1979129 | Zeewyck | Middle Eocene | CP14a | 35 | distal marine |
| GA2476/022DR023A1 | 1979130 | Zeewyck | Middle Paleocene | CP4 | 18 in-situ, 2 recycled | distal marine |
| GA2476/026DR027B1 | 1982960 | Zeewyck | Late - Early Oligocene | CP19a - CP18 | 19 | distal marine |
| GA2476/026DR027C1 | 1982962 | Zeewyck | indet. | indet. | 0 | indet. |

| SAMPLEID | SAMPLENO | REGION | AGE | NANNOFOSSIL ZONE | NANNOFOSSIL DIVERSITY (NUMBER OF TAXA) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/026DR027D | 1982963 | Zeewyck | Middle Eocene | CP14a - CP13c | 30 | distal marine |
| GA2476/049DR042B1 | 1983086 | Zeewyck | Late Paleocene | CP8 (upper) | 21 | distal marine |
| CP Zones after Okada and Bukry (1980); KCN Zones after Rexilius (in prep.); Time Scale after Gradstein et al. (2004) including updates published in Ogg et al. (2008). | | | | | | |

***Q3: Summary of foraminiferal data***

**Table 13.17.** Summary details of the foraminiferal analyses carried out on rock samples collected during survey GA2476 by Dr Patrick G. Quilty (Quilty, 2009).

| SAMPLEID | SAMPLENO | REGION | AGE | FORAM ZONE | FORAM ZONE (BLOW 1979) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/006/DR001 B | 1978948 | Houtman | Middle Eocene | E12/13 | P13-15 | Open marine on continental shelf or thinned continental crust |
| GA2476/007/DR004 C1 | 1978967 | Houtman | Early Eocene | E6/7 | P8/9 | Marine |
| GA2476/007/DR006 E | 1978985 | Houtman | Middle Eocene | E11/12 | P12/13 | Continental slope or deeper |
| GA2476/008/DR007 A1 | 1978988 | Houtman | Late Paleocene | P4a (Olsson et al., 1999) | Indet. | Open marine |
| GA2476/025/DR026 F | 1982955 | Houtman | Indet. | Indet. | Indet. | Indet. |
| GA2476/045/DR039 B1 | 1983068 | Houtman | Late Paleocene | P4a/b (Olsson et al., 1999) | Indet. | Open ocean |

| SAMPLEID | SAMPLENO | REGION | AGE | FORAM ZONE | FORAM ZONE (BLOW 1979) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA2476/0022/DR024 A1 | 1978935 | Zeewyck | Middle Eocene | E13 | P14 | Open marine on continental shelf or thinned continental crust |
| GA2476/021/DR021 B5 | 1979106 | Zeewyck | Indet. | Indet. | Indet. | Indet. |
| GA2476/021/GR009E_A | 1979122 | Zeewyck | Middle Eocene | E11 | P12 | Open ocean |
| GA2476/022/DR022 A | 1979129 | Zeewyck | Middle Eocene | E10 or older | P12 | Oceanic in an environment where burrowing organisms were common |
| GA2476/022/DR023 A1 | 1979130 | Zeewyck | Late Paleocene | P4a (Olsson et al., 1999) | Indet. | Oceanic in an environment where burrowing organisms were common |
| GA2476/026/DR027 B1 | 1982960 | Zeewyck | Late Eocene-Early Oligocene | Indet. | Indet. | Marine in an area with sponge thicket on the sea floor |
| GA2476/049/DR042 B1 | 1983086 | Zeewyck | Indet. | Indet. | Indet. | Indet. |
| GA2476/026/DR027 D | 1982963 | Zeewyck | Middle Eocene | E7-13 | P9-14 | Indet. |
| GA2476/037/DR033 A1 | 1983023 | Cuvier | Early Oligocene | O1 | P18 | Marine in an area of sponge thickets and deep enough to allow the influx of radiolarians |
| GA2476/038/ GR021E_B1 | 1983027 | Cuvier | Late Paleocene | P4c (Olsson et al., 1999) | Indet. | Marine |
| GA2476/038/GR021E_D1 | 1983029 | Cuvier | Indet. | Indet. | Indet. | Fully marine |
| GA2476/038/GR021E_D2 | 1983030 | Cuvier | Cretaceous (possibly Late Cenomanian) | Indet. | Indet. | Marine, mid continental shelf |

| SAMPLEID | SAMPLENO | REGION | AGE | FORAM ZONE | FORAM ZONE (BLOW 1979) | PALAEOENVIRONMENT |
|---|---|---|---|---|---|---|
| GA476/039/GR022E_B1 | 1985412 | Cuvier | Late Cretaceous (possibly Late Cenomanian) | Indet. | Indet. | Shallow marine on continental shelf off a coast of low relief |
| GA 2476/052/DR046 A1 | 1983091 | Wallaby | Indet. (sample BARREN) | Indet. | Indet. | Indet. |
| GA2476/053/DR047 D2 | 1983092 | Wallaby | Oxfordian | Indet. | Indet. | Very shallow marine in a dynamic environment |
| GA2476/061/DR053 A1 | 1983093 | Wallaby | Aptian/Albian | Indet. | Indet. | Marine, probably shallow sea in a muddy environment |
| GA2476/061/DR053 B1 | 1983094 | Wallaby | Aptian/Albian | Indet. | Indet. | Marine, probably shallow sea |
| Foram Zones after Blow, 1979, Berggren et al., 1995, and Berggren and Pearson, 2005; Time Scale after Gradstein et al. (2004) including updates published in Ogg et al. (2008). | | | | | | |

***Q4: Summary of macrofossil data***

**Table 13.18.** Summary details of the macrofossil analyses carried out on rock samples collected during survey GA2476 by Dr Jeffrey D. Stilwell (Stilwell, 2009).

| SAMPLEID | SAMPLENO | REGION | AGE | PALAEOENVIRONMENT |
|---|---|---|---|---|
| GA2476/061DR053A | 1982093 | Wallaby | Late Jurassic to Early Cretaceous (probably Barremian-Aptian) | The disarticulated and fragmentary appearance of the bivalves and gastropods can be explained by deposition from turbidity currents in deeper environments and/or waning phases of storm deposition, if deposition was nearby to shore. Thus, the assemblage is undoubtedly a parauthochthonous or allochthonous one with some degree of transport from their original habitats. |

# Instructions for Data DVD

**Geoscience Australia Survey GA2476, Post-survey Report:**

*Frontier basins of the west Australian continental margin: post-survey report of marine reconnaissance and geological sampling survey GA2476* by James Daniell, Diane C. Jorgensen, Tara Anderson, Irina Borissova, Shoaib Burq, Andrew D. Heap, Michael Hughes, Daniel Mantle, Gabriel Nelson, Scott Nichol, Chris Nicholson, Danielle Payne, Rachel Przeslawski, Lynda Radke, Justy Siwabessy, Craig Smith and Shipboard Party.

**The DVD contains the above-titled report as: Record2009_38.pdf.**

View this .pdf document using Adobe Acrobat Reader (click Adobe.txt for information on readers).

Double click on **Record2009_38.pdf** to launch the document.

**Directories on data DVD**
Appendices Directory:
with sub-directories of Appendix C, Appendix D, Appendix F, Appendix N, and Appendix O.